FEASIBILITY STUDY

W4 Group - Site Unit 1

Prepared for: West of 4th Group

Project No. 050067 • August 11, 2016 Final

earth + water

Aspect CONSULTING

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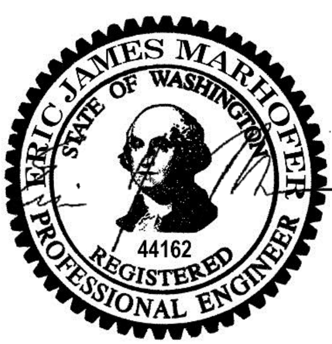

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Acronyms

AO	Agreed Order
APB	Art Brass Plating
ARAR	applicable or relevant and appropriate requirement
Aspect	Aspect Consulting, LLC
AS	air sparging
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
ERD	enhanced reductive dechlorination
FS	Feasibility Study
ISCO	*In-Situ* Chemical Oxidation
ISCR	*In-Situ* Chemical Reduction
ISS	*In-Situ* Solidification/Stabilization
M	million
MCL	Maximum Contaminant Level
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
P&T	pump-and-treat (groundwater)
PCE	tetrachloroethene
PCUL	preliminary cleanup level
PGG	Pacific Groundwater Group
PLP	potentially liable party
PRB	permeable reactive barrier
PSC	PSC Environmental Services, LLC
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
ROW	right-of-way
SCM	Site Conceptual Model
Stericycle	Stericycle Environmental Solutions, Inc.
SU1	Site Unit 1
SU2	Site Unit 2
SVE	soil vapor extraction
TCE	trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure
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	Duwamish Waterway

ZVI	zero-valent iron

Executive Summary

This West of 4th (W4) Group Site Unit 1 Feasibility Study (FS) report has been prepared on behalf of potentially liable parties (PLPs) [Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Stericycle Environmental Solutions, Inc. (Stericycle) [1]] 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 Duwamish Waterway (the Waterway). For the purposes of the FS, the Site has been divided into two site units, Site Unit 1 (SU1; ABP and Stericyle) and Site Unit 2 (SU2; BDC, CI, and Stericycle), as described in the AO and shown on Figure ES-1. This SU1 FS develops and evaluates remedial alternatives to address contaminated media at SU1 in accordance with Washington Administration Code (WAC) 173-340-350(8), to enable Ecology to select a cleanup action.

This Executive Summary provides an overview of the SU1 FS.

Background

SU1 constituents of concern (COCs) include the chlorinated solvent tricholoroethene (TCE) and associated degradation products (primarily vinyl chloride [VC]), and metals used in electroplating (primarily nickel). The primary source of COCs in SU1 is the ABP Facility at 5516 3rd Avenue South, although other suspected sources include contaminated groundwater (containing TCE, VC, and 1,4-dioxane) migrating into SU1 upgradient of the ABP Facility, and an area of tetrachloroethene (PCE) in groundwater near East Marginal Way South (EMW).

Groundwater in SU1 is relatively shallow, with the water table at depths 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. In the Remedial Investigation (RI) Report (Aspect, 2012) and in this FS, contaminated groundwater is divided into three depth-discrete zones[2]: Water Table Interval (water table to 20 feet in depth); Shallow Interval (20 to 40 feet in depth), and Intermediate Interval (greater than 40 feet). The maximum depth of contamination in SU1 is approximately 75 feet.

Site conditions are described in the RI Report (Aspect, 2012). An updated conceptual site model that includes data collected in post-RI investigations is described in the *Site Conceptual Model Technical Memorandum (Revised)* (Aspect, 2014b).

[1] Burlington Environmental, LLC, is a wholly owned subsidiary of PSC Environmental Services, LLC, which is a wholly owned subsidiary of Stericycle Environmental Solutions, Inc., hereafter referred to in this document as “Stericycle” for simplicity.
[2] The three zones are a convention established during pre-RI investigations. They are not distinct aquifers, but are hydraulically connected.

Interim remedial actions for 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. The system has operated since 2008 and has reduced TCE concentrations in groundwater by greater than 90 percent.
- Implementation of a vapor intrusion assessment, monitoring and mitigation plan (VIAMMP) for permanent structures within the footprint of contaminated shallow soil and groundwater.

Basis for Remedial Action

The W4 joint deliverable, *Revised Preliminary Site Cleanup Standards* (Farallon, 2014) outlined the preliminary cleanup standards for the Site. The preliminary cleanup levels (PCULs) for COCs are based on potential exposure pathways. PCULs are summarized in Table ES-1.

For the purposes of this FS, three generalized areas within SU1 where cleanup levels (CULs) are exceeded have been defined for consideration of remedial actions. These areas and their drivers for cleanup are as follows:

- **The Source Area** (see Figure ES-2) 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** (see Figure ES-3) includes groundwater downgradient of the Source Area where chlorinated COCs including TCE exceed CULs.
- **Vinyl Chloride Plumes Outside SU1 Source Area and Downgradient TCE Plume** (see Figure ES-4).

Remedial Action Objectives (RAOs) for soil in SU1, by pathway, are:

- Direct Contact Pathway
  - **SU1 RAO-1A:** Reduce concentrations of COCs in soil to meet Washington State Model Toxics Control Act (MTCA) Method B direct contact PCULs at the standard point of compliance (i.e., throughout SU1) within a reasonable time; or
  - **SU1 RAO-1B:** Use engineering controls to protect receptors from directly contacting soils with concentrations of COCs exceeding direct contact PCULs.
- Surface Water Pathway
  - **SU1 RAO-2A:** Reduce or immobilize concentrations of COCs in soil such that MTCA Method B groundwater CULs are achieved at the standard point of compliance within a reasonable restoration time frame; and

  - **SU1 RAO-2B:** Reduce or immobilize concentrations of COCs in soil such that MTCA Method B CULs are achieved in groundwater approaching the Waterway (to protect Waterway receptors).

- Air Pathway

  - **SU1 RAO-3A:** Reduce concentrations of COCs in soil to meet MTCA Method B CULs protective of indoor and outdoor air quality; or

  - **SU1 RAO-3B:** Use engineering controls to protect receptors.

RAOs for groundwater in SU1, by pathway, are:

- Surface Water Pathway

  - **SU1 RAO-4A:** Reduce COC concentrations in groundwater to achieve MTCA Method B groundwater CULs at the standard point of compliance within a reasonable restoration time frame; and

  - **SU1 RAO-4B:** Protect Waterway receptors by achieving MTCA Method B groundwater CULs for all COCs in groundwater approaching the Waterway.

- Air Pathway

  - **SU1 RAO-5A:** Reduce chlorinated volatile organic compound (cVOC) concentrations in groundwater in the Water Table Interval to meet MTCA Method B vapor intrusion (VI)-based groundwater PCULs at the standard point of compliance; and

  - **SU1 RAO-5B:** Apply engineered controls to protect receptors until VI-based MTCA Method B PCULs are attained.

The RAO for air in SU1 are:

- **SU1 RAO-6A:** Achieve MTCA Method B air CULs.

- **SU1 RAO-6B:** Apply engineered controls to protect receptors until MTCA Method B air CULs are attained.

RAOs for surface water/sediment in SU1 include:

- **SU1 RAO-7A:** Reduce sediment porewater COC concentrations to achieve either natural background or MTCA Method B surface water criteria; and

- **SU1 RAO-7B:** Reduce or control groundwater COC concentrations to prevent sediment contamination.

Technology Screening

Potential remedial technologies for SU1 were identified, described, and screened in the *Revised Technology Screening Memo* (PGG, 2015b). Remedial technologies retained for consideration in the FS included the following:

In-Situ Technologies

- Monitored Natural Attenuation (MNA)
- *In-Situ* Chemical Oxidation (ISCO)
- *In-Situ* Chemical Reduction (ISCR)
- Air Sparging/Soil Vapor Extraction (AS/SVE)
- Enhanced Anaerobic Bioremediation (EAnB)
- Enhanced Aerobic Bioremediation
- *In-Situ* Solidification/Stabilization (ISS)
- pH Buffering/Neutralization
- Precipitation/Immobilization

Ex-Situ Technologies

- Excavation and Off-Site Disposal
- Groundwater Pump-and-Treat (P&T)

Mitigation Technologies

- Capping
- Institutional Controls
- Impermeable Barriers
- Subslab and Submembrane Depressurization

Remedial Alternative Descriptions

In the *Remedial Alternative Technical Memorandum* (Aspect, 2015b), six alternatives were developed for consideration in the FS. Based on Ecology comments on the draft FS, those alternatives were modified and three additional alternatives have been added. The remedial alternative components are summarized in Table ES-2. These alternatives are as follows:

- **Alternative 1:** pH neutralization and MNA in the Source Area, and MNA for the downgradient TCE Plume (pH/MNA/MNA);
- **Alternative 2:** pH neutralization and MNA in the Source Area, and ISCR along South Fidalgo Street for the Downgradient TCE Plume (pH/MNA/ISCR @ Fidalgo);
- **Alternative 3:** pH neutralization and EAnB in the Source Area, and EAnB along South Fidalgo Street for the Downgradient TCE Plume (pH/EAnB/EAnB @ Fidalgo);

- **Alternative 4:** pH neutralization and ISCR in the Source Area, and ISCR along South Fidalgo Street for the Downgradient TCE Plume (pH/ISCR/ISCR @ Fidalgo);
- **Alternative 5:** pH neutralization and ISCR in the Source Area, and EAnB along South Fidalgo Street for the Downgradient TCE Plume (pH/ISCR/EAnB @ Fidalgo);
- **Alternative 6:** pH neutralization and ISCR in the Source Area, and ISCR along South Fidalgo Street and EMW for the Downgradient TCE Plume (pH/ISCR/ISCR @ Fidalgo, and EMW);
- **Alternative 7:** pH neutralization and ISCR in the Source Area, and ISCR along South Fidalgo Street, EMW, and 1st Avenue South for the Downgradient TCE Plume (pH/ISCR/ISCR @ Fidalgo, EMW, and 1st Ave);
- **Alternative 8:** ISCO and groundwater P&T in the Source Area, and ISCR along South Fidalgo Street for the Downgradient TCE Plume (ISCO/P&T/ISCR @ Fidalgo); and
- **Alternative 9:** Excavation/off-Site disposal and ISS in the Source Area, and ISCR over the areal extent of the Downgradient TCE Plume (Excavation/ISS/ISCR).

Each of these alternatives also include some degree of engineering and institutional controls, as well as MNA.

Each of the alternatives generally considers the standard point of compliance for each medium. Alternative 9 is considered the most permanent alternative because it incorporates source removal and downgradient treatment as much as is technically feasible (i.e., without removal of existing structures).

Remedial Alternative Evaluation

The nine remedial alternatives were evaluated in accordance with MTCA requirements (WAC 173-340-360). All nine 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.

A cleanup action is considered to have achieved restoration once cleanup standards have been met. The restoration time frame for SU1 is driven by the time to meet groundwater CULs based on surface water protection. Estimated restoration time frames, based on groundwater modeling, for metals range from approximately 1,000 years for Alternative 9 to 280 years for Alternative 1. Estimated restoration time frames, based on groundwater modeling, for cVOCs are listed in Table ES-3 and range from 30 years for Alternative 9 to 55 years for Alternative 1. Based on the criteria listed in WAC 173-340-360(4), all nine alternatives meet the requirement for providing for a reasonable restoration time frame.

MTCA requires that the selected cleanup action use permanent solutions to the maximum extent practicable. To determine which alternatives meet this requirement, a disproportionate cost analysis (DCA) was conducted. 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. Ratings are summarized in Table ES-4. Primary differentiating factors among the alternatives are as follows:

- **Protectiveness.** All alternatives are protective. Alternatives 2 through 9 include active treatment of groundwater near the Waterway, providing greater certainty that protectiveness will be maintained into the future without the need for contingency actions. Alternative 9 is deemed the most protective because it provides more aggressive treatment, particularly in the Source Area, that is projected to meet vapor intrusion-based CULs in a shorter time frame.

- **Permanence.** All alternatives ultimately destroy, through active treatment or natural processes, chlorinated COCs, except under Alternative 9, which involves immobilization of a portion of the Source Area via ISS. Alternatives 4 through 9 provide somewhat more permanence in addressing Source Area plating metals through treatment beyond pH neutralization (including ISCR for Alternatives 4 through 7, P&T for Alternative 8, and removal/ISS for Alternative 9). Alternative 9 provides the most permanent treatment of plating metals through removal and ISS in much of the Source Area.

- **Long-Term Effectiveness.** All alternatives have moderate to high long-term effectiveness because chlorinated COCs are destroyed and metals are immobilized. Alternative 1 has the lowest long-term effectiveness since it relies primarily on monitored natural attenuation, relies most heavily on institutional and engineering controls, and has the longest restoration time frame. Alternative 2 incorporates treatment at South Fidalgo Street, upgradient of the Waterway, but relies on natural attenuation for the Source Area, and has the next lowest long-term effectiveness. Alternatives 3 through 7 include progressively more treatment and reduced time frame to achieve CULs at the Waterway, and have a correspondingly lower potential for contingency actions and higher long-term effectiveness. Alternative 8 includes a similar level of treatment and corresponding long-term effectiveness as Alternative 3. Alternative 9, which involves removal and physical as well as chemical immobilization of metals contamination, has the highest long-term effectiveness.

- **Short-Term Risk Management.** Alternatives 1 through 7 use relatively low-toxicity materials and low-risk construction activities (e.g., drilling), and involve little short-term risk. Alternative 8 involves the handling and injection of strong oxidants, and Alternative 9 involves more challenging construction activities (excavation and ISS) with the potential for generating contaminated vapors and dust.

- **Implementability.** The primary implementability challenge for most alternatives is access restrictions in public ROWs, due to utility and traffic constraints, to conduct remedial activities involving drilling and injection. Alternatives 6 and 7 involve implementability challenges for periodic access for injections in arterial streets with significant utility corridors (EMW and 1st Avenue South). Alternative 5 also involves implementability challenges for implementing active treatment on private property and potentially maintaining for a very long time an active sparging system along the shoreline with conditions prone to fouling and high maintenance requirements. Alternative 9 has the most significant additional implementability challenges due to its extensive subsurface work within and around an active facility.

Estimated alternative costs range from $2.7M (Alternative 1) to $18M (Alternative 9). As summarized in Table ES-4, ratings were multiplied by Ecology-standard weighting factors, and then combined to develop an overall benefit score and to calculate a benefit-to-cost ratio. Based on this analysis, Alternative 1 has the highest benefit-to-cost ratio, and is deemed to satisfy the requirement of being permanent to the maximum extent practicable.

Conclusions and Recommendations

Nine remedial alternatives that provide a range of treatment options for metals and cVOC contamination in SU1 were developed and evaluated. All alternatives meet MTCA Threshold Requirements, including protection of human health and the environment. Additionally, the interim actions to date have substantially reduced cVOC concentrations in the Source Area.

Alternative 1 is the recommended cleanup action for SU1 based on the analysis and considerations presented in this Feasibility Study (Figure ES-5). Alternative 1 (pH/MNA/MNA) has the highest benefit-to-cost ratio, and is deemed to satisfy the MTCA requirement to be permanent the maximum extent practicable. This alternative is protective of human health and the environment, and is significantly less expensive than other alternatives, while achieving a restoration time frame that is marginally longer than most alternatives and only moderately longer than the most aggressive alternative (Alternative 9). Important components of this alternative include the structured implementation of a groundwater monitoring program and negotiated criteria for triggering contingency actions. Expansion of active remediation via the implementation of specific contingency actions should be based on empirical groundwater quality trends, as opposed to predictive modeling results. We recommend development of data-driven contingency action triggers and review schedule as elements of the DCAP. This approach ensures protection of human health and the environment while implementing the most practicable remedy.

Because of its reliance on MNA, Alternative 1 has the greatest chance of needing contingency actions. Possible contingency actions include active treatment along the shoreline to protect Waterway receptors, and active treatment of cVOCs in the Source Area to reduce the time to achieve cleanup levels protective of the vapor pathway. These actions are similar to active treatment measures included in other alternatives. However, even if these contingency actions are implemented, Alternative 1 would be less expensive (on a net present-value basis) than the next-most-costly alternative (Alternative 2).

The conceptual implementation of Alternative 1 is discussed in Section 7.3.1. As discussed in Section 8.5, although the information provided in this FS is adequate to evaluate alternatives on a relative basis, there are a number of uncertainties regarding implementation of this alternative that still need to be addressed. It is anticipated that a phased, adaptive design and implementation process will be appropriate. This may involve bench-, pilot-, or limited-scale application and testing of potential amendments and distribution techniques prior to full-scale construction and operation. Groundwater 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. As discussed above, there is some uncertainty in estimated restoration time frames due to modeling assumptions that simplify a complex system. Monitoring data will be used to confirm or revise model predictions of restoration time frame and determine if contingency actions are appropriate.

TABLES

Table ES-1 - Preliminary Cleanup Levels

Project No. 050067
West of 4th, 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 Direct Contact Pathway (Industrial Land Use)[2]	Soil Cleanup Level Protective of Air Quality based on Protection of Groundwater as Potable Drinking Water[3]	Soil Cleanup Level Protective of Groundwater Concentrations Protective of Surface Water Quality[4]	Groundwater Cleanup Level Protective of Air Quality Water Table Zone (Unrestricted Land Use)[5]	Groundwater Cleanup Level Protective of Air Quality Water Table Zone (Industrial Land Use)[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)[2]	Air Cleanup Level Protective of Inhalation Pathway (Industrial Land Use)[2]	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	--	476	21,000	0.08	0.44	116	482	29	36,000	9.6	40	29	--	190
Trichloroethene	Carcinogen	--	12	1,750	0.03	0.057	6.9	37	7	4,760,000	0.37	2	7	194 [12]	8,950
cis-1,2-Dichloroethene	Non-Carcinogen	--	160	7,000	--	--	--	--	--	--	--	--	--	--	--
trans-1,2-Dichloroethene	Non-Carcinogen	--	1,600	70,000	0.59	62	559	1,224	4,000	--	27.4	60	4,000	--	--
1,1-Dichloroethene	Non-Carcinogen	--	4,000	175,000	0.055	0.025	538	1,176	3.2	--	91.4	200	3.2	--	--
Vinyl chloride	Carcinogen	--	0.67	87.5	0.002	0.010	1.3	12.7	1.6	543,000	0.28	2.8	1.6	210 [13]	202
1,4-Dioxane	Carcinogen	--	10	1,310	0.004	0.32	2,551	25,510	78	--	0.5	5	78	--	--
Arsenic	Carcinogen	20	20	87.5	Not Applicable	0.082	Not Applicable	Not Applicable	0.14 / 5 [10]	241	Not Applicable	Not Applicable	0.14 / 5 [10]	36 [14]	7
Barium	Non-Carcinogen	--	16,000	700,000	Not Applicable	824	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	--	--	--
Cadmium	Non-Carcinogen	1	80	3,500	Not Applicable	1.2	Not Applicable	Not Applicable	8.8	760	Not Applicable	Not Applicable	--	8.8 [15]	5.1
Copper	Non-Carcinogen	36	3,200	140,000	Not Applicable	1.1	Not Applicable	Not Applicable	3.1 [11]	18,000	Not Applicable	Not Applicable	--	3.1 [15]	390
Iron	Non-Carcinogen	58,700	58,700	2,450,000	Not Applicable	--	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	1,000	--	--
Manganese	Non-Carcinogen	1,200	11,200	490,000	Not Applicable	--	Not Applicable	Not Applicable	100	--	Not Applicable	Not Applicable	100	--	--
Nickel	Non-Carcinogen	48	1,600	70,000	Not Applicable	11	Not Applicable	Not Applicable	8.2	2,200	Not Applicable	Not Applicable	4,600	8.2 [15]	15.9
Zinc	Non-Carcinogen	85	24,000	1,050,000	Not Applicable	101	Not Applicable	Not Applicable	81	6,600	Not Applicable	Not Applicable	26,000	81 [15]	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] Backgound metals values from Ecology Publication No. 94-115, Natural Background Soil Metals Concentrations in Washington State. Arsenic background from MTCA, Table 740-1 Method A Soil Cleanup Levels for Unrestricted Land Uses.

[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] Soil 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 for unrestricted and industrial land uses.

[4] Soil cleanup levels for protection of surface water quality are calculated using MTCA Equation 747-1 where the groundwater cleanup level protective of surface water in this table was used as Cw.

[5] Groundwater cleanup levels protective of the air pathway for unrestricted land use (residential and commercial sites) and industrial land use were derived using the following equation: Gwcul = Aircul/GIVF.

[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. Koc and Kd values are from MTCA. Fraction of carbon assumed at 0.02 based on Lower Duwamish Waterway Feasibility Study (AECOM, 2012).

[8] The most stringent exposure pathway for human health receptors are for consumption of fish. Listed values are based on ARARs listed in CLARC with one exception. 1,4-dioxane is derived from MTCA Method B default values

[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 Sediment Managment Standards (WAC 173-204)

[10] Arsenic Cleanup level of 5 ug/L based on background concentrations for state of Washington (MTCA Table 720-1).

[11] The surface water cleanup level for copper had previously been tabulated as 2.4ug/L; however this value is based on an approach using site-specific water effects ratio which has not been determined. We have replaced this with 3.1 ug/L, National Recommended Water Quality Criteria published by EPA under 304 of the Federal Clean Water Act - Aquatic Life Criteria Table.

[12] Oak Ridge Nation Laboratory (ORNL) Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota

[13] Peer Review Literature - DeRooij et al., 2004, *Euro Chlor Risk Assessment for the Marine Environment OSPARCOM Region – North Sea – Environmental Monitoring and Assessment*

[14] WAC- 173-201A-240

[15] 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 and 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).

ES-2 - Assembly of Technologies into Remedial Alternatives

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

Area of Concern[1]	General Response Actions	Remedial Technologies[2]	Contaminants Addressed	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9
				Source pH neutralization, Monitored Natural Attenuation	**Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)**	**Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)**	**Source Excavation+ISS, Downgradient ISCR (Areal Coverage)**
SU1 Source Area	Mitigation	Capping	cVOCs and Metals	X	X	X	X	X	X	X	X	X
		Institutional Controls		X	X	X	X	X	X	X	X	X
		Subslab and Submembrane Depressurization	cVOCs	X	X	X	X	X	X	X	X	X
	In- Situ Treatment	Monitored Natural Attenuation	cVOCs and Metals	X	X	X	X	X	X	X	X	X
		In-Situ Chemical Reduction		--	--	--	X	X	X	X	--	--
		Enhanced Anaerobic Biodegradation[3]	cVOCs	--	--	X	--	--	--	--	--	--
		In-Situ Chemical Oxidation		--	--	--	--	--	--	--	X	--
		Solidification/Stabilization	Metals	--	--	--	--	--	--	--	--	X
		pH Buffering/Neutralization		X	X	X	X	X	X	X	--	--
	Ex-Situ Technologies	Groundwater Pump-and-Treat[4]	cVOCs and Metals	--	--	--	--	--	--	--	X	--
		Excavation & Off-Site Disposal		--	--	--	--	--	--	--	--	X
Downgradient TCE Plumes	Mitigation	Institutional Controls	cVOCs	X	X	X	X	X	X	X	X	X
	In-Situ Treatment	Monitored Natural Attenuation	cVOCs	X	X	X	X	X	X	X	X	X
		In-Situ Chemical Reduction		--	X	--	X	--	X	X	X	X
		Enhanced Anaerobic Biodegradation[3]		--	--	X	--	X	--	--	--	--
		Sparge Curtain[5]		--	--	--	--	X	--	--	--	--
Vinyl Chloride Plumes Outside the Above Areas	Mitigation	Institutional Controls	Vinyl Chloride	X	X	X	X	X	X	X	X	X
	In-Situ Treatment	Monitored Natural Attenuation	Vinyl Chloride	X	X	X	X	X	X	X	X	X
Potential Contingency Actions	*In-Situ* Treatment	Enhanced Anaerobic Biodegradation[3]	cVOCs	--	--	--	--	--	--	--	--	--
		In-Situ Chemical Reduction		Source Area	Source Area	--	--	--	--	--	--	--
		Sparge Curtain[5]		Waterway	Waterway	Waterway	Waterway	--	Waterway	Waterway	Waterway	--
		pH Buffering/Neutralization	Metals	--	--	--	--	--	--	--	--	--
		Enhanced Aerobic Biodegradation	Vinyl Chloride	--	--	--	--	--	--	--	--	--

Notes:

1) The areas of concern called out in this column are depicted on Figures 5-1 through 5-3.
2) Precipitation/immobilization of metals is a retained remedial technology that is not called out separately in this table. However, it can be achieved through pH buffering/neutralization and/or in-situ chemical reduction.
3) Application of this technology may include bioaugmentation.
4) Application of this technology may include slurry/cutoff walls.
5) Sparge curtain is not called out in Section 6 as a retained remedial technology, but it is a specific application of air sparging (a retained technology).

Definitions:

ISCR = *In-Situ* Chemical Reduction
EAnB = Enhanced Anaerobic Biodegredation
ISCO = *In-Situ* Chemical Oxidation
PRB = Permeable Reactive Barrier
ISS = *In-Situ* Stablization

Shaded cells indicate new alternative or element

-- Dashes indicate the action is not included in the alternative except as a possible contingency action, to be evaluated in the event that additional measures are necessary to control plume migration.

Table ES-3 - Summary of Restoration Time Frames

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

	Time to Meet Cleanup Levels in Years							Time to Meet Remediation Levels in Years			
Alternative	ABP Facility	2nd Ave	1st Ave	EMW	Fidalgo	Shoreline Wells	Waterway	1st Ave	EMW	Fidalgo	Shoreline Wells
1	15	25	40	40	50	55	55	20	35	45	50
2	15	25	40	40	50	50	50	20	35	45	45
3	10	20	30	40	50	50	50	15	35	45	45
4	10	20	30	40	50	50	50	15	35	45	45
5	10	20	30	40	50	35	35	15	35	45	40
6	10	20	30	40	40	40	40	15	35	35	40
7	10	20	30	40	40	35	35	15	30	35	35
8	10	20	30	40	50	50	50	15	35	45	45
9	<5	20	20	35	40	30	30	10	25	30	30

Table ES-4 - Disproportionate Cost Analysis and Comparison to MTCA Criteria

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

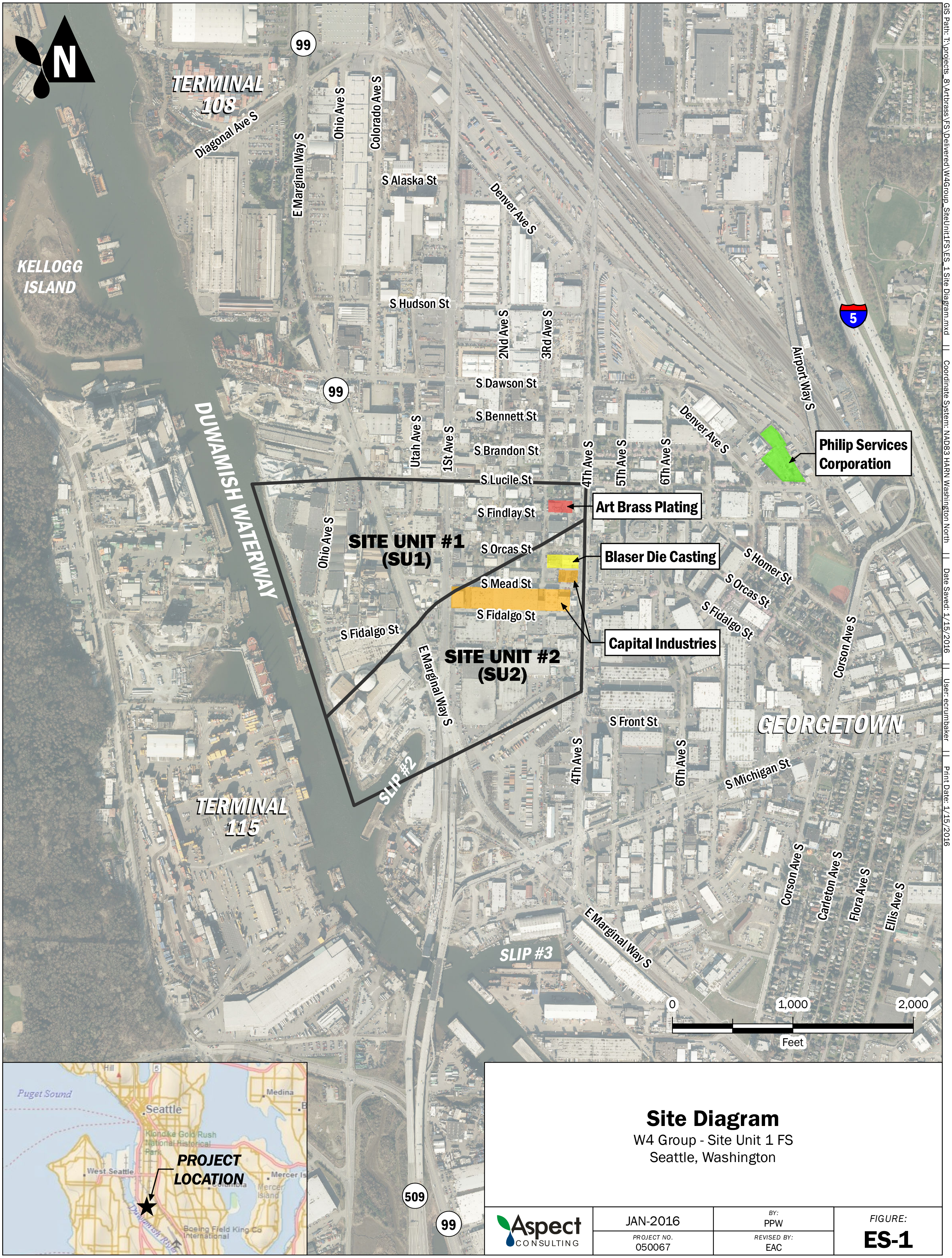
	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9
	Source pH neutralization, Monitored Natural Attenuation	**Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)**	**Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)**	**Source Excavation+ISS, Downgradient ISCR (Areal Coverage)**
Threshold Criteria									
Protection of Human Health and the Environment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compliance with Cleanup Standards	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compliance with Applicable State and Federal Laws	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Provision for Compliance Monitoring	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weighted Benefits Ranking for Disproportionate Cost Analysis (Score 1-10)									
Weighting Criteria									
30% Overall Protectiveness	4	5	6	6	8	7	7	6	9
20% Permanence	5	5	5	6	6	6	6	7	8
20% Long Term Effectiveness	3	4	5	6	7	7	7	5	8
10% Management of Short Term Risk	9	8	8	8	8	8	8	6	5
10% Implementability	8	7	6	6	4	4	4	5	2
10% Consideration of Public Concerns	3	4	5	5	6	5	5	5	3
MTCA Overall Benefit Score (1-10)	**4.8**	**5.2**	**5.7**	**6.1**	**6.8**	**6.4**	**6.4**	**5.8**	**6.9**
Disproportionate Cost Analysis									
Estimated Remedy Cost	$2,800,000	$4,600,000	$6,000,000	$5,200,000	$7,800,000	$8,000,000	$8,200,000	$6,800,000	$18,100,000
Estimated Remedy Cost	$1,000,000	$2,300,000	$3,700,000	$2,900,000	$3,000,000	$5,900,000	$6,100,000	$4,500,000	$16,300,000
Sparge Curtain Cost[(1)]	--	--	--	--	$2,500,000	--	--	--	--
Estimated Vapor Mitigation Cost	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$200,000
Estimated Compliance Monitoring Cost[(2)]	$1,500,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$1,800,000	$1,800,000	$2,000,000	$1,600,000
Relative Benefit to Cost Ratio (multiplied by 1,000,000)	1.7	1.1	1.0	1.2	0.9	0.8	0.8	0.9	0.4
Estimated Contingency Cost	$1,800,000	$1,800,000	$1,300,000	$1,300,000	$0	$1,300,000	$1,300,000	$1,300,000	$0
Evaluation of Restoration Time Frame									
Time to Achieve RAOs	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	>1000 Years	1000 Years
Estimated Time to Achieve VI CULs	25 Years	25 Years	20 Years	20 Years	20 Years	20 Years	20 Years	20 Years	20 Years
Estimated Time to Achieve cVOC SW CULs at Waterway	55 Years	50 Years	50 Years	50 Years	35 Years	40 Years	35 Years	50 Years	30 Years
Estimated Time to Achieve cVOC SW CULs	55 Years	50 Years	50 Years	50 Years	50 Years	40 Years	40 Years	50 Years	40 Years
Estimated Time to Achieve metals SW CULs	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	>1000 Years	1000 Years
Provides for a Reasonable Restoration Time Frame	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes:

Remedial Alternative cost details in Appendix E.

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

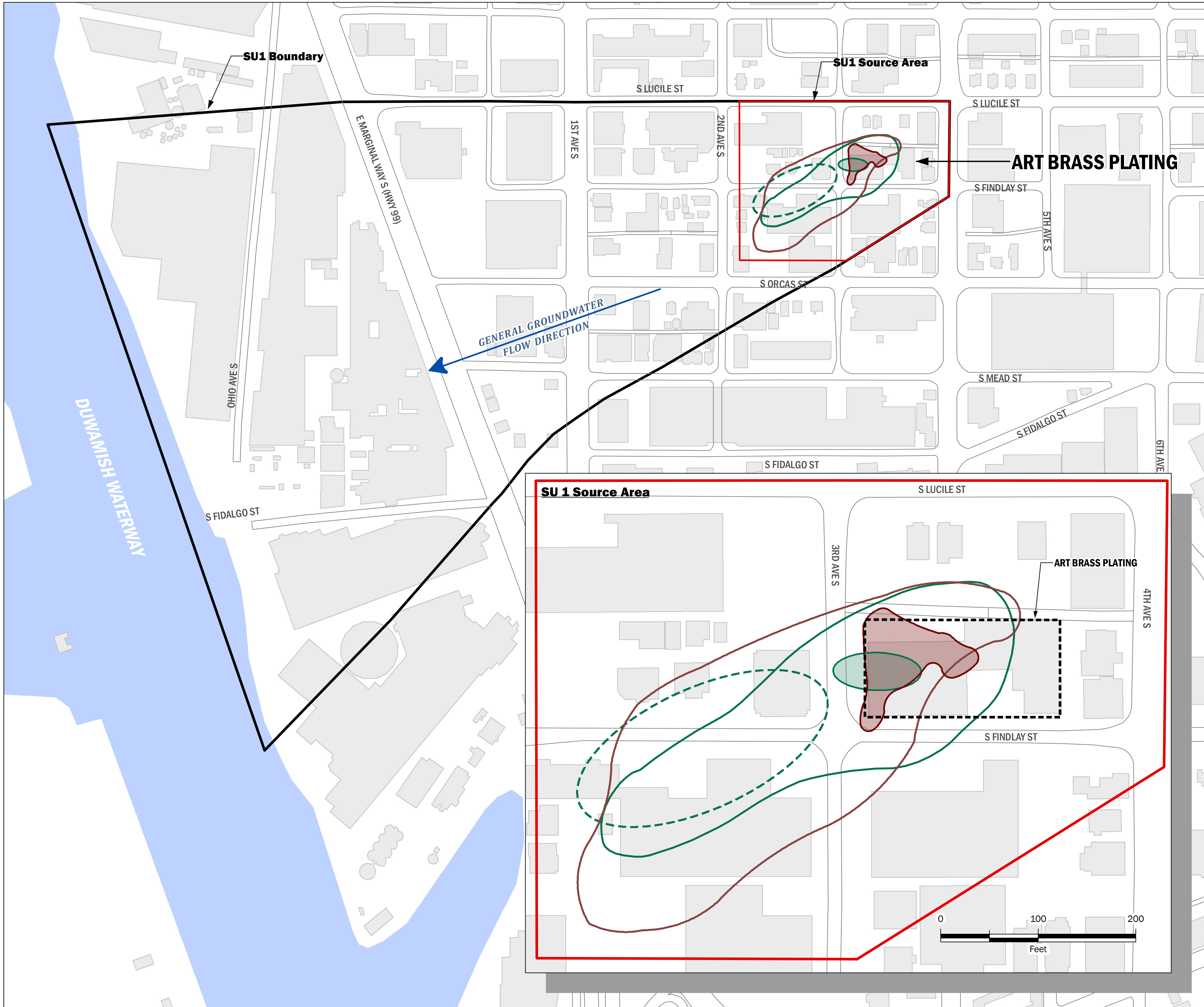
FIGURES



Site Diagram

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JAN-2016	BY: PPW	FIGURE:
	PROJECT NO. 050067	REVISED BY: EAC	ES-1



TCE Isoconcentration Line at 0.03 mg/kg Cleanup Level in Soil (for Protection of Air Quality)

Nickel Isoconcentration Line at 48 mg/kg Cleanup Level in Soil (for Protection of Surface Water)

TCE Isoconcentration Line at 6.9 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Water Table Groundwater (for Protection of Surface Water)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

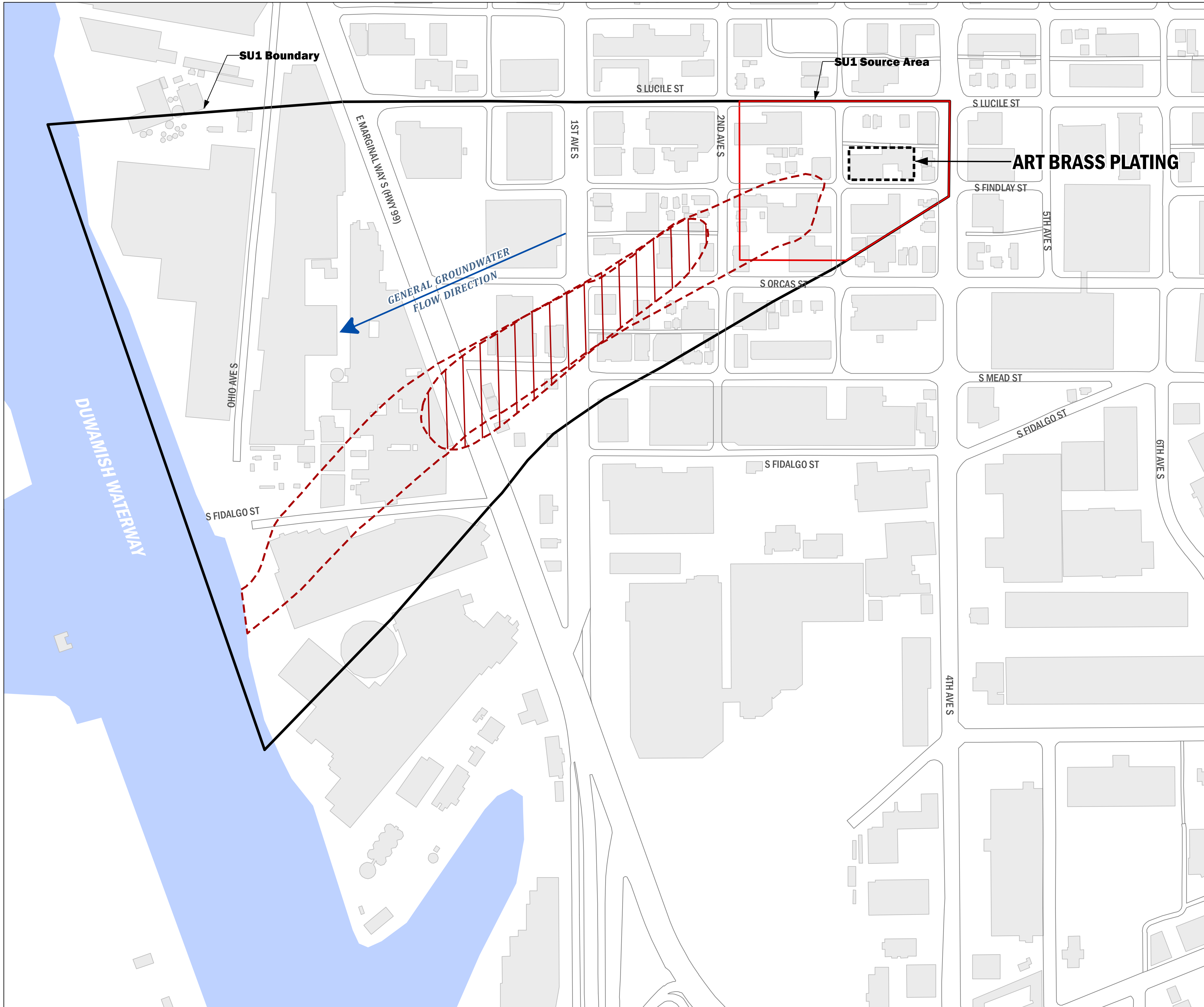
0 300 600
Feet

TCE and Nickel in Source Area Soil and Groundwater

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING | JAN-2016 | BY: PPW | FIGURE NO.
PROJECT NO. 050067 | REVISED BY: EAC | ES-2

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\ES-2 TCE and Nickel in Soil and GW.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/15/2016 || User: ecrumbaker || Print Date: 1/15/2016



TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

0 300 600
Feet

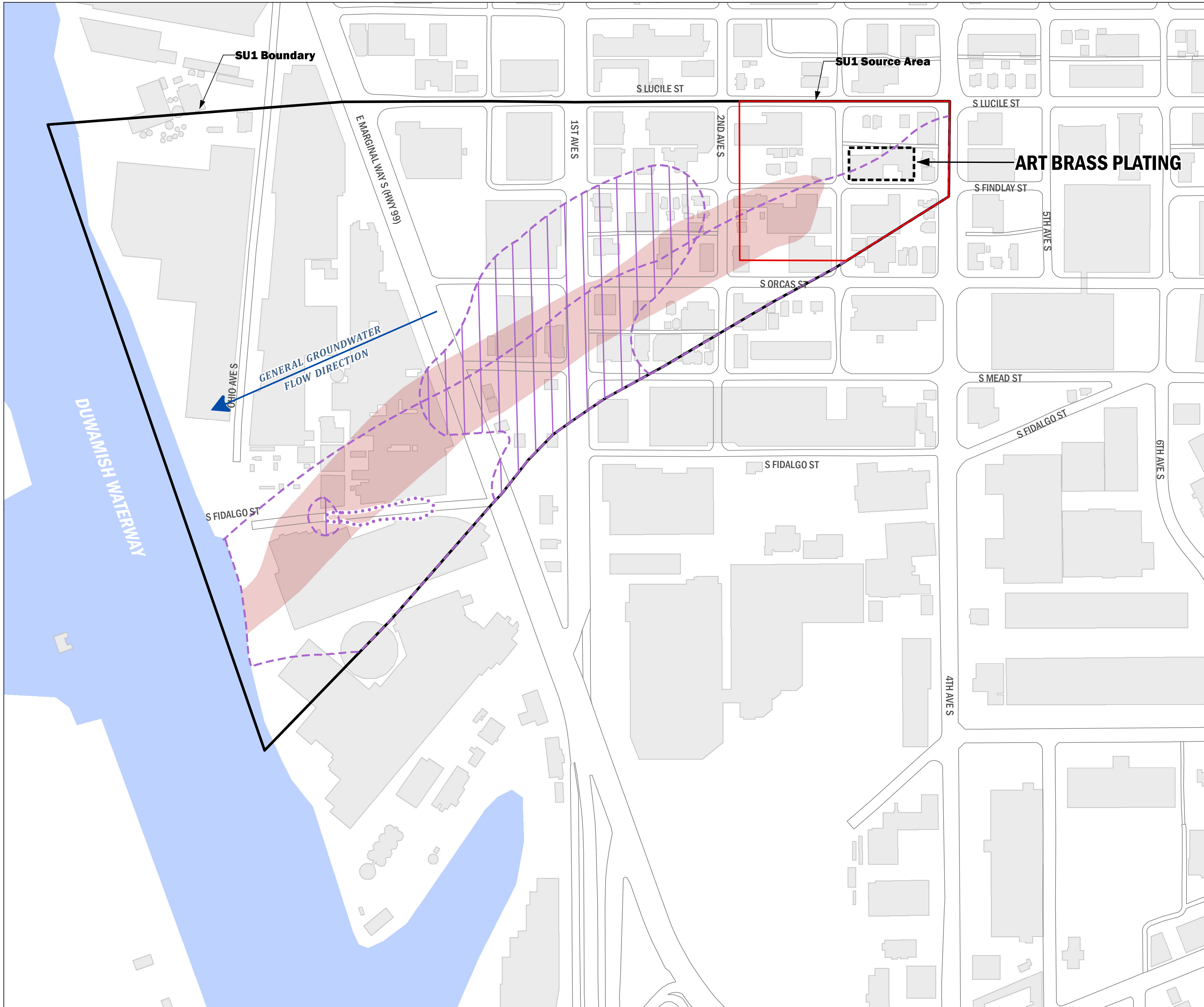
Downgradient TCE Plume in Shallow and Intermediate Groundwater

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JAN-2016	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REVISED BY: EAC	ES-3

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\ES-3 Downgradient TCE Plumes in GW.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/15/2016 || User: ecrumbaker || Print Date: 1/15/2016



Vinyl Chloride Isoconcentration Line at 1.6 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Vinyl Chloride Isoconcentration Line at 1.6 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Vinyl Chloride Isoconcentration Line at 1.3 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

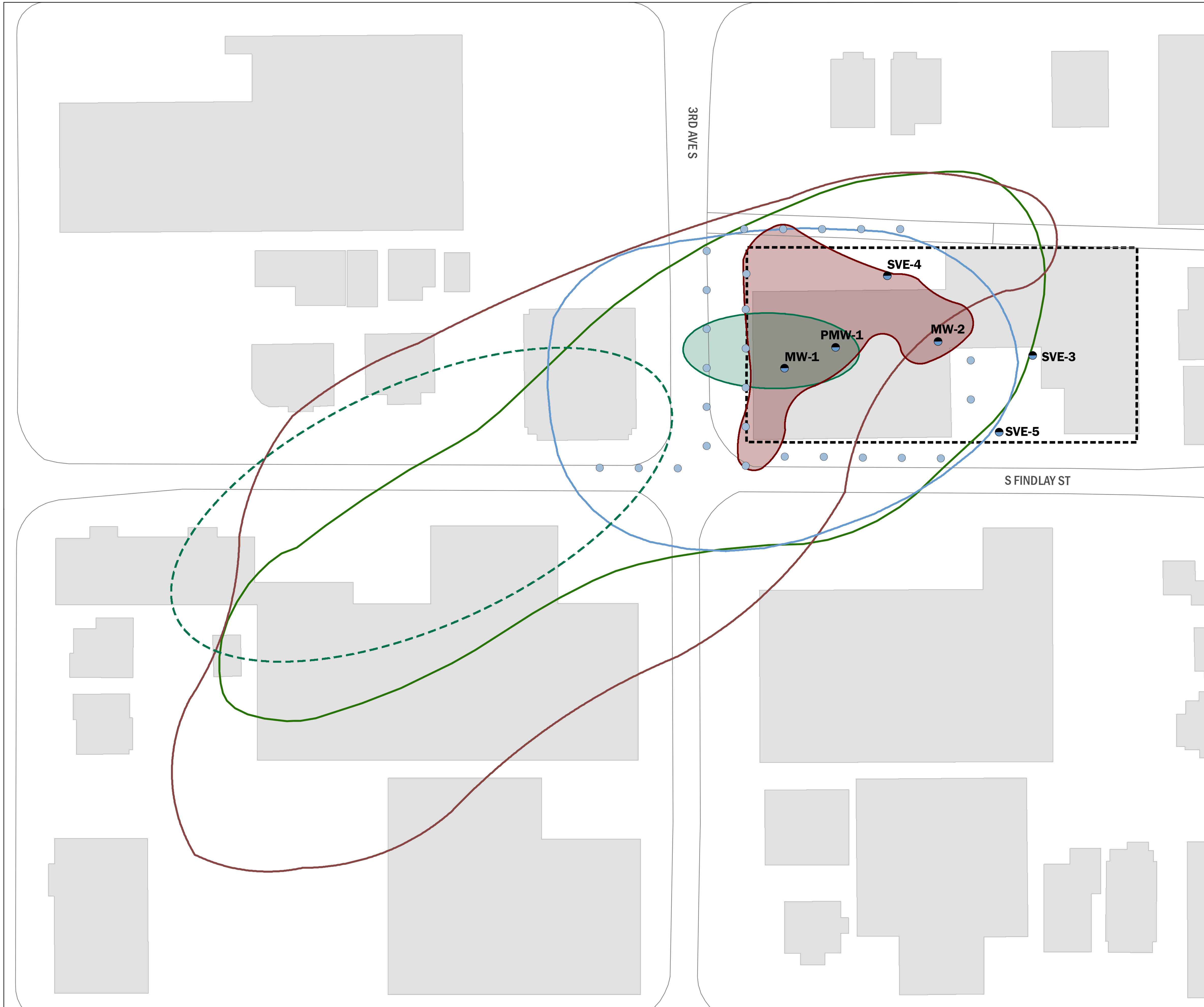
Downgradient TCE Plumes (Refer to Figure 6.2)

Art Brass Plating Property Boundary (Approx.)

0 300 600
Feet

Vinyl Chloride Plumes
W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING | JAN-2016 | BY: PPW | FIGURE NO.
PROJECT NO. 050067 | REVISED BY: EAC | **ES-4**



TCE Isoconcentration Line at 0.03 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Air Quality)

TCE Isoconcentration Line at 6.9 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Nickel Isoconcentration Line at 48 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Surface Water)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Water Table Groundwater (for Protection of Surface Water)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Water Table Groundwater pH < 6

Proposed pH Neutralization Solution Injection Well

Existing pH Neutralization Solution Injection Well

Art Brass Plating Property Boundary (Approx.)

N

0 50 100

Feet

Remedial Design Concept in Source Area Alternatives 1 and 2

W4 Group - Site Unit 1 FS

Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	ES-5

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_1 Alternative 1 and 2.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016

1 Introduction

1.1 Purpose

The W4 Group Site Unit 1 Feasibility Study report has been prepared on behalf of potentially liable parties (PLPs) [Art Brass Plating (ABP), Blaser Die Casting (BDC), Capital Industries (CI), and Stericycle Environmental Solutions, Inc. (Stericycle) [3]] 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.

For the purposes of the FS, the W4 Site has been divided into two site units, Site Unit 1 (SU1; ABP and Stericycle) and Site Unit 2 (SU2; BDC, CI and Stericycle), as described in the AO. Figure 1-1 shows the ABP Facility locations of the four PLPs and the SU1 and SU2 boundaries.

This draft SU1 FS develops and evaluates remedial alternatives to address contaminated media at SU1 in accordance with Washington Administrative Code (WAC) 173-340-350(8), to enable Ecology to select a cleanup action. The FS process includes identifying applicable or relevant and appropriate requirements (ARARs) for cleanup, establishing cleanup standards that are protective of human health and the environment, identifying extents of contaminated media where remedial action is needed, identifying and evaluating potentially applicable remedial technologies for those media, and assembling remedial technologies into remedial alternatives. The remedial alternatives are then evaluated against specific Model Toxics Control Act (MTCA) criteria (protectiveness, effectiveness, permanence, implementability, cost, and consideration of public concerns) to inform selection of a preferred remedial alternative.

This draft FS integrates and builds upon information developed in previous technical memoranda, including:

- *Revised Preliminary Site Cleanup Standards* (Farallon, 2014);
- *Site Conceptual Model Technical Memorandum (Revised)* (Aspect, 2014b);
- *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); and

[3] Burlington Environmental, LLC is a wholly owned subsidiary of PSC Environmental Services, LLC, which is a wholly owned subsidiary of Stericycle Environmental Solutions, Inc., hereafter referred to in this document as “Stericycle” for simplicity.

- *Draft Remedial Alternatives Technical Memorandum for Site Unit 1* (Aspect, 2015b).

These documents are available for reference on the W4 website (http://clients.aspectconsulting.com/W4/).

1.2 Report Organization

This report is organized as follows:

- Section 1 describes the purpose of the FS and the organization of this report.
- Section 2 contains background information about SU1, including potential sources of contamination and the nature and extent of contamination.
- Section 3 summarizes interim actions that have been or are being conducted at SU1.
- Section 4 summarizes data that has been collected after completion of the Remedial Investigation.
- Section 5 identifies the Remedial Action Objectives (RAOs), cleanup levels (CULs), points of compliance, and other ARARs.
- Section 6 identifies and screens technologies appropriate for SU1.
- Section 7 develops and describes potential remedial alternatives for SU1.
- Section 8 evaluates and compares the alternatives being considered for remediation of SU1, and discusses potential uncertainties associated with remedy evaluation and selection.
- Section 9 identifies a preferred alternative, and describes the proposed cleanup action.
- Section 10 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-RI investigations, groundwater modeling details, and supporting information for cost estimates.

2 Background

SU1 is located in the Georgetown neighborhood of Seattle. SU1 extends from 4th Avenue South to the Duwamish Waterway (the Waterway), a distance of about 2,200 feet, and is generally flat with a gradual slope to the west. SU1 includes a mixture of commercial, industrial, and residential land uses.

A remedial investigation (RI) was completed to characterize SU1 conditions and collect the information needed to prepare this FS, as documented in the *Remedial Investigation Report, Art Brass Plating* (hereafter: ABP RI Report; Aspect, 2012). Additional characterization data for SU1 and SU2 are available in the RI reports prepared by CI (Farallon, 2012), BDC (PGG, 2012), and Stericycle (PSC, 2003).

The *Site Conceptual Model Technical Memo* (SCM; Aspect, 2014b) identifies the sources of constituents of concern (COCs), nature and extent of contamination[4], and known and potential exposure pathways and receptors. A summary of SU1 COCs, potential sources, and groundwater flow conditions are provided below to aid the reader.

2.1 Constituents of Concern

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

Chlorinated Volatile Organic Compounds (cVOCs)
- Tetrachloroethene (PCE)
- Trichloroethene (TCE)
- cis-1,2-Dichloroethene (cis-DCE)
- trans-1,2-Dichloroethene (trans-DCE)
- 1,1-Dichloroethene (1,1-DCE)
- Vinyl chloride (VC)

Plating Metals
- Cadmium
- Copper
- Nickel
- Zinc

Non-plating Metals (aka Redox-Sensitive Metals)
- Arsenic
- Barium
- Iron

[4] Since preparation of the SCM memorandum, preliminary cleanup standards have been updated based on revisions to the Ambient Water Quality Criteria. The changes resulted in little change to the isoconcentration lines presented in the SCM memorandum figures, with one exception. The TCE soil cleanup level for protection of surface water quality changed from 0.15 milligrams per kilograms (mg/kg) to 0.057 mg/kg. The edited isoconcentration line looks similar to the isoconcentration line for the TCE soil cleanup level protective of air quality (based on protection of groundwater as potable drinking water), which is 0.03 mg/kg.

- Manganese

Other

- 1,4-Dioxane

Suspected sources of COCs in SU1 include the ABP Facility as well as other area sources. TCE was used at the ABP Facility for vapor degreasing from approximately 1983 to February 2004. VC and the three DCE isomers are degradation products of TCE. However, PCE is not a degradation product, 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. In addition, low concentrations of TCE and its degradation products have been detected in groundwater upgradient of the ABP Facility, apparently due to migration of contaminated groundwater originating from areas east of 4th Avenue South.

The ABP Facility is the presumed source of the elevated concentrations of plating metals detected in soil and groundwater. However, elevated concentrations of the non-plating metals in groundwater are due to microbial degradation of organic materials in the aquifer matrix (either naturally occurring or anthropogenically released) that has resulted in generally anaerobic conditions. These conditions in the aquifer favor the dissolution of the non-plating metal COCs from the native aquifer materials.

The presence of 1,4-dioxane in SU1 groundwater is due to migration of contaminated groundwater originating from areas east of 4th Avenue South (East of 4th Area) and is being addressed by Stericycle under AO DE 7347. 1,4-dioxane is a colorless, volatile, cyclic ether that has primarily been used as a metal inhibitor and an acid acceptor to maximize the effectiveness of 1,1,1-trichloroethane (1,1,1-TCA) as a cleaning and degreasing agent. It is miscible with water, most organic solvents, aromatic hydrocarbons, and oils, and is characterized by a low affinity for sorption to soils and organic matter. It readily leaches from and through soil following its release to the environment and is highly mobile and persistent in groundwater.

Stericycle is in the process of designing a contingent remedy (Remedial Design) to reduce concentrations of 1,4-dioxane in groundwater (Amec Foster Wheeler, 2015). The highest concentrations of 1,4-dioxane in groundwater have been detected in samples collected east of 4th Avenue South and south of South Lucile Street. The technologies being evaluated as part of the Remedial Design include: *in-situ* chemical oxidation (ISCO) implemented by injecting of a slurry of water and chemical oxidant (PersulfOx™, a proprietary formulation of sodium persulfate and chemical activator) into groundwater; and *in-situ* enhanced anaerobic bioremediation (EAnB) implemented by injecting a slurry of water and microorganisms and substrate into groundwater. Although the Remedial Design focuses on the area with the highest concentrations of 1,4-dioxane in the East of 4th Area, the remedial objective is to attain the CUL for 1,4-dioxane both east and west of 4th Avenue South within the reasonable restoration time frame established in AO DE 7347 as 2032. 1,4-Dioxane and non-plating metals are considered secondary COCs (not released by ABP), and are not explicitly considered in developing the remedial alternatives in this FS. However, the FS does consider the effects of each alternative on 1,4-dioxane and non-plating metals with respect to attainment of CULs and restoration time frame.

2.2 Environmental Setting

The environmental setting for the Site has been discussed in detail in the RI reports prepared by ABP (Aspect, 2012), BDC (PGG, 2012), CI (Farallon, 2012), and PSC (PSC, 2003) as well as the Site Conceptual Model Technical Memorandum (Revised) (Aspect, 2014b).

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. A description of these units is provided below.

- **Fill Unit** consists of heterogeneous layers of gravelly sand, silt, and silty sand with scattered bits of inert debris, such as glass shards or brick fragments. This unit extends up to a depth of 8 feet below ground surface (bgs); however, the boundary between the Fill Unit and the Younger Alluvium is difficult to distinguish.
- **Younger Alluvium (Qyal)** represents channel and overbank/floodplain deposits from the Duwamish River (Booth and Herman, 1998). At the Site, the Younger Alluvium consists of two subunits: a sandy silt or silty sand unit overlying slightly silty fine-medium sand unit. Scattered bits of wood and organic debris are also present. This unit is typically found within a few feet above or below the current sea level and extends to a depth of approximately 25 to 30 feet. Moving westward towards the Waterway, the Younger Alluvium extends to a depth of approximately 55 feet.
- **Older Alluvium (Qoal)** represents materials deposited in an estuarine and deltaic environment. The Older Alluvium consists of interbedded sequences of silty fine sand and sandy silt. A silt aquitard, likely a subunit of the Older Alluvium, and bedrock have been identified in deeper borings east of 4th Avenue South (PSC, 2003). These additional units were not encountered in the borings located at the Site. Based on a review of the Duwamish Valley cross sections available in Booth and Herman (1998), it is expected that the silt aquitard and bedrock are present at a depth greater than 150 feet.

The lithologic units discussed above correspond to the hydrogeologic units encountered at the Site. PLPs use a standardized nomenclature for groundwater monitoring and sampling intervals which are:

- **Water Table Interval.** This interval includes monitoring wells screened above 20 feet 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.

2.2.1 *Groundwater Flow and Tidal Variability*

Groundwater flow at the Site is to the west and southwest. Little seasonal variability in flow direction is observed. Vertical gradient between the Water Table and Shallow Intervals are typically downward. Vertical gradients between the Shallow and Intermediate Intervals fluctuate between upward and downward, except in the well clusters close to the Waterway located west of East Marginal Way. Upward gradients were typical in these well pairs.

Tidal studies are detailed in RI reports from ABP (Aspect, 2012) and CI (Farallon, 2012). Water levels in the Waterway are influenced by river flow and tidal effects from Puget Sound. High tides result in localized groundwater flow gradient reversal, although the time-averaged net groundwater flow direction is still toward the Waterway. The occurrence of localized and transient flow reversals is consistent with site characterization data collected at other similar sites in the Waterway, and with the Site RI data. Tidal influences on water levels diminish to 0.5 feet or less approximately 800 feet east/northeast (upgradient) of the Waterway.

3 SU1 Interim Actions

Chlorinated solvents in SU1 groundwater in the Water Table Interval 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 vapor intrusion mitigation program; and 2) source control interim action. These actions are described below.

3.1 Vapor Intrusion Mitigation Program

The vapor intrusion 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 decision process used to implement the IPIM Program. 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.

3.2 Source Control Interim Action

In September 2008, ABP installed an air sparging/soil vapor extraction (AS/SVE) system to remove chlorinated COCs 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; and

- 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 AS/SVE system has operated continuously (except for periodic shutdowns for monitoring and maintenance) since startup. In late 2011, the AS portion of the system was shut down to conduct a rebound analysis. Since October 2012, the AS has operated on an approximate six-month on-off pulsing schedule while the SVE system remains on continually. The system has removed approximately 87 pounds of TCE from the subsurface, and groundwater concentrations of TCE have declined 90 to 99 percent at wells in and around the treatment area. A full description of system monitoring and an analysis of system performance was provided in the ABP RI Report (Aspect, 2012).

4 Post-Remedial Investigation Data Collection

To address Ecology's comments on the ABP RI, supplemental work was completed that focused on assessing subsurface geochemical conditions at the ABP Facility. ABP outlined RI data gaps and proposed work in the *Revised Remedial Investigation Data Gaps and Supplemental Work Plan for Site Unit 1* (Work Plan, Aspect, 2014a). The Work Plan identified additional data and analyses needed to: 1) explain the nature and extent of oxidation-reduction (redox) or non-plating metals (i.e., why they are elevated in certain media at particular depths/locations), 2) identify and demonstrate the presence of metals attenuation mechanisms, and 3) speak to the irreversibility/stability of these attenuation processes. Work was completed in accordance with the Work Plan and Ecology's comments on the Work Plan dated October 10, 2015. This section provides an overview of the data collected with a more detailed discussion of the data provided in Appendix A.

Data were initially reported in the *Draft Fate and Transport Summary Memo* (Aspect, 2015a). Aspect Consulting, LLC (Aspect) and Anchor QEA have modified the fate and transport discussion based on Ecology comments on the draft (refer to Appendix B).

4.1 Soil Data Collection

As part of this investigation, three soil borings were advanced in September 2014 along a transect beginning near the ABP Facility and in the principal groundwater flow direction downgradient (SPO-53, SPO-54, and SPO-55, respectively). Cores were retrieved and characterized for metals concentrations, sulfide, and pH. Selected samples from these cores were also analyzed for bulk mineralogy by powder X-ray diffraction, selective sequential extraction, and acid-base accounting (Appendix B). Data are tabulated and discussed in Appendices A and B.

4.2 Groundwater Data Collection

Since completion of the ABP RI Report in 2012, ABP has continued collecting groundwater monitoring data, currently on a semiannual basis. In addition to this ongoing monitoring, the supplemental RI work included groundwater data collection to support the fate-and-transport modeling of plating metals: major anions, cations, and attenuation indicators. Data are tabulated and discussed in Appendices A and B.

4.3 Summary of Conclusions

The Work Plan outlined the hypotheses and objectives of the analyses to be completed to fill the identified RI data gaps. As discussed in Appendix B, hypotheses remain consistent with those outlined in the Work Plan, and data gaps have been sufficiently addressed to complete the FS. The following provides a summary of conclusions regarding metals fate and transport:

- Plating Metals
  - Metal oxide/hydroxide precipitation reduces plating metal mobility via surface sorption and precipitation mechanisms. Modeling predicts that nickel concentrations will not exceed the PCUL protective of surface water (8.2 micrograms per liter [µg/L]) at the Waterway for approximately 500 years. An analysis of copper and zinc data indicate these metals undergo similar attenuation mechanisms as those modeled with nickel, and these plating metals are attenuated near the source area.
  - Metal sulfide precipitation reduces plating metal mobility. Modeling predicts nickel concentrations will not exceed the PCUL protective of surface water at the Waterway for at least 1,000 years. An analysis of copper and zinc data indicate these metals undergo similar attenuation mechanisms as those modeled with nickel, and these plating metals are attenuated near the source area.
  - Subsurface processes neutralize and buffer acidic groundwater, limiting the mobility of dissolved metals. Analyses indicate that there remains a net neutralization potential downgradient of the source area and deeper in the soil column. Reactive transport modeling predicts that low pH conditions at the ABP facility will attenuate within a few decades.
  - Model simulations predict that, with all three processes operating (metal oxide/hydroxide precipitation, metal sulfide precipitation, and net neutralization potential), elevated nickel concentrations will not be transported downgradient and the plume will shrink over time. Sensitivity analyses indicate that even if sulfate reduction rates are three orders of magnitude lower than the base case, nickel concentrations in groundwater discharging to surface water will not exceed the CUL of 8.2 µg/L for at least 1,000 years.
- Non-Plating Metals
  - Iron and Manganese: Elevated concentrations of iron and manganese in SU1 groundwater are due to the naturally occurring, mildly to moderately reducing subsurface conditions and an iron- and manganese-rich aquifer matrix, and not a direct result of releases from the ABP facility.
  - Arsenic: Arsenic concentrations in groundwater above MTCA Method A background (5 µg/L) are localized to a small area in the vicinity of well

MW-9. Arsenic was not released or mobilized by ABP source area conditions. Iron is able to control the mobility of arsenic in the vicinity of MW-9 via ferric-arsenate precipitation reactions.

5 Basis for Remedial Action

This section identifies the ARARs, RAOs, and preliminary cleanup levels (PCULs) used as the basis for developing and evaluating remedial alternatives, as follows:

- Section 5.1 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 FS.
- Section 5.2 discusses the preliminary cleanup standards.
- Section 5.3 identifies three areas of SU1 with distinct characteristics that are targeted for remedial action.
- Section 5.4 identifies the RAOs that describe what the proposed remedy is expected to accomplish.

5.1 Applicable or Relevant and Appropriate Requirements (ARARs)

The MTCA (Chapter 70.105D Revised Code of Washington [RCW]) requires that cleanup actions comply with applicable state and federal laws (WAC 173-340-360(2)a(iii)), which include legally applicable requirements, as well as requirements that the department determines are relevant and appropriate. ARARs for cleanup actions often include various construction-related permits, air emission requirements, water discharge requirements, off-site disposal requirements, and other issues related to impacts in and around the site. ARARs can be categorized as follows:

- **Chemical-specific ARARs** are laws and requirements that establish health- or risk-based numerical values or methodologies for developing such values. These ARARs are used to establish the acceptable concentration of a chemical that may remain in or be discharged to the environment. As such, chemical-specific ARARs are considered in developing cleanup standards (Section 5.2).
- **Action-specific ARARs** are performance, design, or other requirements that may place controls or restrictions on a particular remedial action.
- **Location-specific ARARs** are requirements that are triggered based on the location of the remedial action to be undertaken.

The MTCA Cleanup Regulation (Chapter 173-340 WAC) authorizes Ecology to adopt cleanup standards for groundwater, soil, surface water, and air at sites where hazardous substances are present, and establishes processes for identifying, investigating, and cleaning up these sites.

Other potentially applicable regulatory requirements for SU1 cleanup actions include:

- The federal Clean Water Act (33 United States Code [USC] Section 1251);
- The Washington Water Pollution Control Act (Chapter 90.48 RCW; Chapter 173-201A WAC; Chapter 173-200 WAC);

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and All Appropriate Inquiries (AAI) (40 Code of Federal Regulations [CFR] Part 312);
- The Resource Conservation and Recovery Act (RCRA);
- Sediment Management Standards (Chapter 173-204 WAC);
- Washington Hazardous Waste Management Act (Chapter 70.105 RCW; Chapter 173-303 WAC);
- Federal and state Clean Air Acts (42 USC 7401 et seq.; 40 CFR 50; RCW 70.94; WAC 173-400, 403);
- The State Environmental Policy Act (SEPA) (RCW 43.21C; WAC 197-11);
- The Occupational Safety and Health Act (OSHA) (Part 1910 of Title 29 of the Code of Federal Regulations [29 CFR 1910]);
- General Occupational Health Standards (Chapter 296-62 WAC);
- Safety Standards for Construction Work (Chapter 296-155 WAC);
- Minimum Standards for Construction and Maintenance of Wells (Chapter 173-160 WAC);
- Underground Injection Control Program (Chapter 173-218 WAC); and
- Permits from local municipalities as required for activities at the Site[5]. Examples include King County and City of Seattle permits for sewer discharges, and City of Seattle grading permits, street-use permits, or shoreline permits.

ARARs typically applicable to particular remediation technologies were identified in the Revised Technology Screening Memo (PGG, 2015b). Many ARARs are commonly addressed through standard industry practices. For instance, construction of monitoring or remediation wells will be conducted by a Washington State licensed driller, and construction work is conducted under site-specific health and safety plans in compliance with applicable safety regulations. ARARs that are potentially relevant to the evaluation of remedial alternatives are identified for each alternative in Section 8.

5.2 Cleanup Standards

A cleanup standard includes both a 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). The proposed CULs and points of compliance for SU1 are

[5] For cleanup actions conducted under an AO or Consent Decree, procedural requirements of certain laws, including local permits, may be waived while complying with the substantive requirements of applicable laws.

described in the following subsections. The Cleanup Action Plan to be prepared for SU1 and SU2 will define the final CULs and points of compliance for SU1.

5.2.1 Preliminary Cleanup Levels

The W4 joint deliverable, Revised Preliminary Site Cleanup Standards (Farallon, 2014) outlined the preliminary cleanup standards for the Site. The PCULs for COCs are based on potential exposure pathways. In June 2015, the U.S. Environmental Protection Agency (EPA) updated the Ambient Water Quality Criteria for protection of human health, which resulted in edits to the PCULs for PCE, TCE, DCE, and VC. Table 5-1 provides the most recent version of the PCULs. As discussed in Appendix F, drinking water is not considered the highest beneficial use for Site groundwater; therefore, drinking water standards are not included in Table 5-1.

5.2.2 Points of Compliance

The following points of compliance are used to evaluate remedial alternatives.

5.2.2.1 Soil

- **Protection of Groundwater Quality** throughout SU1;
- **Protection of Air** from ground surface to the uppermost water table; and
- **Protection of Direct Contact** throughout SU1 to a depth of 15 feet bgs.

5.2.2.2 Groundwater

Standard point of compliance "…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; and
- **Protection of Indoor Air** at Water Table Interval throughout SU1.

5.2.2.3 Air

- Ambient air (indoor and outdoor air) throughout the site (WAC 173-340-750).

5.2.3 Remediation Levels

MTCA recognizes that a cleanup action may involve a combination of cleanup action components and provides that remediation levels 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). Remediation levels are concentration thresholds above which particular cleanup action components may be applied, and are usually specific to a particular remediation technology. Remediation levels may be applied if it is not practicable to achieve CULs at the standard point of compliance within a reasonable restoration time frame.

Potential remediation levels for TCE and VC are identified in Section 7.2.4.1 based on concentrations that are predicted to be protective of the surface water pathway (i.e., they would not result in concentrations exceeding the surface water CUL at the mudline in the Waterway). As discussed in Section 7, application of these remediation levels depends in part on a practicability analysis of achieving shorter restoration time frames. This analysis is included in this FS in Section 7 and Section 8.

5.3 Areas Targeted for Remedial Action

The nature and extent of contamination for the Site is provided in the Site Conceptual Model Technical Memorandum (Revised) (Aspect, 2014b). For the purposes of this FS, three generalized areas within SU1 have been defined for consideration of remedial actions. These areas and their drivers for cleanup are as follows:

- **Source Area:** As shown on Figure 5-1, the Source Area includes the ABP Facility and its immediate vicinity. Soil and groundwater in the Source Area are impacted by cVOCs[6] and plating metals. The estimated areal extent of TCE and nickel CUL exceedances are depicted on the figure. TCE is the “driver” for cVOC COCs other than VC, since the estimated areal extent of TCE CUL exceedances generally encompasses CUL exceedances for the DCE isomers. Similarly, nickel is the driver for plating metal COCs, since the estimated areal extent of nickel CUL exceedances generally encompasses CUL exceedances for the other plating metals.

- **Downgradient TCE Plume:** The areal extent of TCE CUL exceedances in groundwater downgradient of the Source Area is shown on Figure 5-2. The TCE plume occurs in the Shallow and Intermediate Intervals and, similar to the Source Area, it generally encompasses downgradient CUL exceedances for the DCE isomers. As depicted on the figure, the northeast portion of the Downgradient TCE Plume in shallow groundwater overlaps with the Source Area. However, for the purposes of this FS these areas are essentially depth discrete, with the Downgradient TCE Plume situated deeper in the aquifer (Shallow and Intermediate Intervals).

- **Vinyl Chloride Plumes Outside SU1 Source Area and Downgradient TCE Plume:** As depicted on Figure 5-3, VC CUL exceedances in groundwater extend outside the two areas described above. And, unlike the other COCs, VC exceedances occur in shallower (Water Table Interval) as well as deeper groundwater outside the Source Area.

5.4 Remedial Action Objectives

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. General Site-wide RAOs for the W4 area are discussed in Section 5.4.1, and RAOs specific to SU1 are discussed in Section 5.4.2.

5.4.1 General Site-Wide Remedial Action Objectives

General Site-wide RAOs for the W4 area were provided in the *Revised Technology Screening Memo* (PGG, 2015b), including reducing concentrations of COCs to acceptable levels. Acceptable levels are the PCULs for each media, as defined in either the Revised Preliminary Site Cleanup Standards technical memo or in an interim

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

mitigation measure plan to reduce exposure to levels protective of receptors (Farallon, 2014). Acceptable levels of risk are the risks and/or hazard quotients corresponding to these PCULs. General Site-wide RAOs include:

- **RAO 1:** Reduce soil COC concentrations posing a potentially unacceptable direct contact health risk to acceptable levels. Or, if this is not practicable, reduce risks associated with contacting surface or subsurface soils to acceptable levels through the use of institutional controls or engineered barriers.

- **RAO 1A:** Reduce soil COC concentrations posing a potentially unacceptable health risk via dust inhalation to acceptable levels. Or, if this is not practicable, reduce risks associated with inhaling contaminated dust to acceptable levels through the use of institutional controls or engineered barriers.

- **RAO 2:** Reduce soil and shallow groundwater cVOC concentrations posing a potentially unacceptable vapor intrusion health risk to acceptable levels. Or, if this is not practicable, reduce risks associated with inhaling contaminated indoor air to acceptable levels through the use of institutional controls or engineered controls.

- **RAO 3:** Within a reasonable time frame, reduce soil and groundwater COC concentrations posing a potentially unacceptable health risk to human and ecological surface water receptors to acceptable levels. Or, if this is not practicable, reduce the health risks associated with COC exposure to acceptable levels through the use of institutional controls or engineered barriers.

- **RAO 4:** Reduce COC concentrations in groundwater discharging to surface water to acceptable levels.

5.4.2 Remedial Action Objectives for SU1

This section identifies RAOs for soil, groundwater, surface water, sediment, and air that are specific to SU1.

5.4.2.1 Soil

RAOs for soil in SU1, by pathway, are:

Direct Contact Pathway

- **SU1 RAO-1A:** Reduce concentrations of COCs in soil to meet MTCA Method B direct-contact PCULs at the standard point of compliance (i.e., throughout SU1) within a reasonable time; or

- **SU1 RAO-1B:** Use engineering controls to protect receptors from directly contacting soils with concentrations of COCs exceeding direct contact PCULs.

Surface Water Pathway

- **SU1 RAO-2A:** Reduce or immobilize concentrations of COCs in soil such that MTCA Method B groundwater CULs are achieved at the standard point of compliance within a reasonable restoration time frame; and

- **SU1 RAO-2B:** Reduce or immobilize concentrations of COCs in soil such that MTCA Method B CULs are achieved in groundwater approaching the Waterway (to protect Waterway receptors).

Air Pathway

- **SU1 RAO-3A:** Reduce concentrations of COCs in soil to meet MTCA Method B CULs protective of indoor and outdoor air quality; or
- **SU1 RAO-3B:** Use engineering controls to protect receptors.

5.4.2.2 Groundwater

RAOs for groundwater in SU1, by pathway, are:

Surface-Water Pathway

- **SU1 RAO-4A:** Reduce COC concentrations in groundwater to achieve MTCA Method B groundwater CULs at the standard point of compliance within a reasonable restoration time frame; and
- **SU1 RAO-4B:** Protect Waterway receptors by achieving MTCA Method B groundwater CULs for all COCs in groundwater approaching the Waterway.

Air Pathway

- **SU1 RAO-5A:** Reduce cVOC concentrations in groundwater in the Water Table Interval to meet MTCA Method B vapor intrusion (VI)-based groundwater PCULs at the standard point of compliance; and
- **SU1 RAO-5B:** Apply engineered controls to protect receptors until VI-based MTCA Method B PCULs are attained.

5.4.2.3 Air

- **SU1 RAO-6A:** Achieve MTCA Method B air CULs.
- **SU1 RAO-6B:** Apply engineered controls to protect receptors until MTCA Method B air CULs are attained.

5.4.2.4 Surface Water/Sediment

RAOs for surface water/sediment in SU1 include:

- **SU1 RAO-7A:** Reduce sediment porewater COC concentrations to achieve either natural background or MTCA Method B surface water criteria; and
- **SU1 RAO-7B:** Reduce or control groundwater COC concentrations to prevent sediment contamination.

6 Identification and Screening of Remedial Technologies

Potential remedial technologies for SU1 were identified, described, and screened in the *Revised Technology Screening Memo* (PGG, 2015b). Potentially viable technologies for each Site unit were retained as described in the *Revised Technology Screening Memo*. Remedial technologies retained for consideration in the FS for SU1 included the following:

In-Situ Technologies

- Monitored Natural Attenuation (MNA)
- *In-Situ* Chemical Oxidation (ISCO)
- *In-Situ* Chemical Reduction (ISCR)
- Air Sparging/Soil Vapor Extraction (AS/SVE)
- Enhanced Anaerobic Bioremediation (EAnB)
- Enhanced Aerobic Bioremediation
- *In-Situ* Solidification/Stabilization (ISS)
- pH Buffering/Neutralization
- Precipitation/Immobilization

Ex-Situ Technologies

- Excavation and Off-Site Disposal
- Groundwater Pump-and-Treat (P&T)

Mitigation Technologies

- Capping
- Institutional Controls
- Impermeable Barriers
- Subslab and Submembrane Depressurization

Retained technologies have been assembled into remedial alternatives as described in Section 7.

7 Development and Description of Alternatives

In this section, the remedial technologies retained in the *Revised Technology Screening Memo* (PGG, 2015b) as listed in Section 6 are assembled into seven remedial alternatives. These alternatives incorporate a range of potential approaches—including differing levels of passive and active treatment—to conduct a disproportionate cost analysis and determine whether a cleanup action uses permanent solutions to the maximum practicable, in accordance with MTCA (WAC 173-340-360(3)). This section includes the following:

- **Section 7.1: Assembly of Remedial Alternatives:** Retained technologies are assembled into remedial alternatives;
- **Section 7.2: Common Elements:** Discussion of considerations and assumptions common to most or all alternatives; and
- **Section 7.3: Description of Remedial Alternatives:** including conceptual design and implementation strategies.

7.1 Assembly of Remedial Alternatives

Remedial alternatives were assembled using the retained technologies from the *Revised Technology Screening Memo* (PGG, 2015b). Although there are access limitations in both areas, access to the Downgradient TCE Plume is more highly constrained for implementing active remedial technologies due to busy roadways, utility corridors, and large operational facilities. Therefore, remedial alternatives include distinct approaches and application methods in the Source Area and Downgradient TCE Plume.

Nine alternatives were developed for consideration in this FS from the initial set of six alternatives identified in the Remedial Alternative Technical Memo (Aspect, 2015b). These alternatives incorporate varying degrees of aggressiveness in their conceptual designs to achieve Site RAOs for COCs. Alternative 1 provides Source Area treatment for metals, while relying on MNA for cVOCs. Alternatives 2 through 9 include different combinations of technologies in the Source Area, and ISCR/EAnB in the Downgradient TCE Plume to evaluate where and how these technologies are optimally applied. These alternatives are summarized in Table 7-1 and include:

- **Alternative 1:** pH neutralization and MNA in the Source Area, and MNA for the downgradient TCE Plume (pH/MNA/MNA);
- **Alternative 2:** pH neutralization and MNA in the Source Area, and ISCR along South Fidalgo Street for the Downgradient TCE Plume (pH/MNA/ISCR @ Fidalgo);
- **Alternative 3:** pH neutralization and EAnB in the Source Area, and EAnB along South Fidalgo Street for the Downgradient TCE Plume (pH/EAnB/EAnB @ Fidalgo);

- **Alternative 4:** pH neutralization and ISCR in the Source Area, and ISCR along South Fidalgo Street for the Downgradient TCE Plume (pH/ISCR/ISCR @ Fidalgo);
- **Alternative 5:** pH neutralization and ISCR in the Source Area, and EAnB along South Fidalgo Street for the Downgradient TCE Plume (pH/ISCR/EAnB @ Fidalgo);
- **Alternative 6:** pH neutralization and ISCR in the Source Area, and ISCR along South Fidalgo Street and EMW for the Downgradient TCE Plume (pH/ISCR/ISCR @ Fidalgo and EMW);
- **Alternative 7:** pH neutralization and ISCR in the Source Area, and ISCR along South Fidalgo Street, EMW, and 1st Avenue South for the Downgradient TCE Plume (pH/ISCR/ISCR @ Fidalgo, EMW, and 1st Ave);
- **Alternative 8:** ISCO and groundwater P&T in the Source Area, and ISCR along South Fidalgo Street for the Downgradient TCE Plume (ISCO/P&T/ISCR @ Fidalgo); and
- **Alternative 9**: Excavation/off-Site disposal and ISS in the Source Area, and ISCR over the areal extent of the Downgradient TCE Plume (Excavation/ISS/ISCR).

Each of these alternatives include some degree of engineering and institutional controls, as well as MNA, to ultimately meet the RAOs. Alternative 9 is considered the most permanent alternative because it incorporates source removal and downgradient treatment as much as is technically feasible (i.e., without removal of existing structures) and will be considered as a baseline for comparison. Each of the alternatives will consider the standard point of compliance for each medium.

Each of the retained technologies was incorporated into one or more of the alternatives to address the Source Area, except for AS/SVE which has already been applied as an interim action and appears to have reached a point of diminishing returns.

In the Downgradient TCE Plume, AS/SVE, EAnB, and ISCR are the only treatment technologies incorporated into the alternatives, for the following reasons:

- Excavation and ISS are not applicable because impacts extend too deep, and significant portions of the Downgradient TCE Plume are not accessible, for these technologies. Furthermore, ISS is not suitable for treatment of cVOCs in groundwater;
- As stated in the Revised Technology Screening Memo (PGG, 2015b), ISCO and P&T are not considered suitable for treatment of widespread groundwater plumes such as the Downgradient TCE Plume.
- Enhanced aerobic bioremediation is not effective for treatment for the primary COC (TCE). However, this technology has potential application for treatment of VC if warranted as a contingency action (see Section 7.2.5).

AS/SVE, EAnB, and ISCR were incorporated into the alternatives on the following general basis:

- ISCR and EAnB are both considered potentially effective and applicable in areas of somewhat limited access (e.g., the operating ABP facility and street ROWs). ISCR is considered potentially more effective for VC and at minimizing VC generation compared to EAnB, and ISCR amendments have potentially greater longevity (i.e., less frequent injections are needed). ISCR, therefore, was incorporated into more alternatives. However, EAnB can be distributed through wells or direct-push borings (while ISCR requires direct-push injection) and typically uses cheaper amendments. Both of these technologies can significantly alter groundwater geochemistry in the vicinity of treatment by creating highly reducing conditions that can mobilize naturally occurring redox metals (e.g., iron, manganese, and arsenic). Therefore, these were not considered to be applied directly adjacent to the Waterway.

- AS/SVE was generally not incorporated in the Downgradient TCE Plume Area because restoration time frame modeling indicates that these systems may need to be operated for an extended period, and AS/SVE would require much more extensive infrastructure and operation and maintenance (O&M) demands compared to other *in-situ* technologies. In addition, AS has the potential to mobilize cVOCs from deeper groundwater through volatilization to the water table, and create a vapor concern in areas where there currently is none. However, this technology was incorporated for treatment along the shoreline because the groundwater geochemical effects (and potential impacts to water quality discharging to the Waterway) are much less. AS is also expected to be very effective—through both physical removal and biodegradation—at treating areas of elevated VC, which are found along the shoreline.

The technologies applied to the Downgradient TCE Plume Area for SU1 are generally consistent with technologies retained at other sites under similar hydrologic and geochemical conditions. In particular, the Fox Avenue Site (which is located adjacent to the Waterway just south of SU2; has similar access constraints, and whose primary COCs are PCE, TCE, DCE, and VC) retained EAnB and zero-valent iron (ZVI; i.e., ISCR) for groundwater treatment and included AS as a potential point-of-discharge treatment option (Floyd Snider, 2011)[7].

Pilot testing of the technologies incorporated into these alternatives is not planned prior to finalizing the FS. Pilot testing (bench- and/or field-scale) would be conducted to collect design parameters for full-scale implementation of EAnB, ISCR, or ISCO, depending on the preferred alternative selected in the FS. Alternatively, sequenced application of selected technologies and adaptive implementation may be appropriate to

[7] At the Fox Avenue Site, ISCO utilizing potassium permanganate was applied in a portion of the site to treat groundwater as an interim action, but had limited effectiveness (approximately 50 percent reduction in groundwater concentrations) and was not able to achieve RAOs (Floyd Snider, 2011). P&T was not considered cost-effective. Ultimately, the selected remedy at Fox Avenue included EAnB treatment of a portion of the groundwater plume until a remediation level of 250 ug/L total cVOCs was obtained, followed by MNA until CULs were obtained (projected to be approximately 50 years).

optimize remedy performance and ultimately achieve RAOs. The implementation strategy for each alternative is included in the alternative descriptions in Section 7.3.

7.2 Common Elements

This section describes considerations and assumptions that are common to most or all alternatives.

7.2.1 Land Use

The ABP Property is largely covered with buildings and operated as a plating facility. There are no plans to redevelop the property or to remove existing structures. For the purposes of this FS, it is assumed that current buildings and operations at the property will be maintained into the foreseeable future.

SU1 includes a mixture of commercial, industrial, and residential land uses. As described in Section 5, PCULs for SU1 consider all potential land uses including unrestricted use. However, certain interim action levels may be applied that are specific to a particular current use. For example, a decision to implement vapor controls at a property may depend on the current occupancy and use of that property.

7.2.2 Potential Generation of Hazardous Waste during Remediation

Based on cVOC concentrations detected to date, any soils removed during remedial activities (e.g., during drilling or excavation) are unlikely to classify as toxicity characteristic hazardous waste[8]. However, based on historical use of the ABP Property, soil and groundwater contaminated with TCE that are removed during remedial activities may be classified as listed hazardous waste under waste code F002, spent halogenated solvents. SU1 plating metal COCs (nickel, zinc, and copper) do not have hazardous waste toxicity characteristic criteria. In addition, the specific process or processes that resulted in the release of plating metals to the subsurface is not known. Therefore, it is assumed that metals-contaminated soil and groundwater removed during remedial activities would not classify as hazardous waste (unless they are classified F002 based on TCE).

For the purposes of cost estimating in the FS, the following assumptions were made:

- Removed soil would not classify as toxicity characteristic hazardous waste;
- Soils removed from within the footprint and depth interval of the TCE soil and groundwater plume would classify as F002 waste, but a contained-out determination would be obtained to allow disposal at a RCRA Subtitle D-permitted landfill or a permitted solid waste landfill in compliance with Chapter 173-351 WAC; and

[8] The Toxicity Characteristic Leaching Procedure (TCLP) is used to determine whether a solid waste classifies as a hazardous waste due to the characteristic of toxicity. For example, a TCE concentration at or above 0.5 milligrams per liter (mg/L) in the TCLP leachate is indicative of toxicity characteristic hazardous waste. Such a result is only possible when the TCE concentration in the soil sample itself is at least 10 mg/kg, which is only slightly less than the maximum TCE concentration detected in SU1 soil (12 mg/kg in a sample collected from beneath the ABP Facility). Therefore, soil removed from areas where high TCE concentrations are expected (e.g., beneath the ABP Facility) would likely require TCLP testing to determine proper waste classification.

- Groundwater contaminated with TCE would classify as F002 waste.

7.2.3 Mitigation Methods

All remedial alternatives include mitigation methods such as engineering and institutional controls as temporary cleanup measures to maintain protectiveness until RAOs are achieved. Remedial alternatives that leave contamination above CULs in place for an extended period of time also include formal land-use restrictions. As described in Section 7.2.4, COC concentrations above Method B CULs are expected to persist for an extended period of time for all alternatives. Specific mitigation methods for SU1 alternatives include:

- Maintaining existing caps (including building foundations and pavement) on the ABP Property to reduce migration of contaminant vapors into overlying structures[9].
- Implementing vapor monitoring and/or mitigation in areas of shallow soil or groundwater exceeding levels potentially protective of the indoor air pathway. Vapor mitigation may include operating and monitoring a subslab depressurization system or conducting periodic vapor intrusion monitoring. Existing properties where active mitigation is currently being conducted and would continue being operated on the ABP Property and at 218 and 220 Findlay Street[10].
- Notifications to utility companies who may conduct subsurface trenching work in the area of shallow impacted soil or groundwater. Notifications would be maintained until contamination in the vadose zone and Water Table Interval are below Site CULs.
- An environmental covenant for the ABP Property that restricts or places requirements regarding underground activities and certain property uses that have the potential to present an exposure risk to contaminated materials.
- Implementing institutional controls (if needed)[11] to restrict shellfish harvesting in the area of contaminated groundwater discharge.

All of these mitigation methods are expected to be applied to all alternatives. Alternative 9, which involves removal and *in-situ* solidification of contaminated soils, may not require active vapor mitigation and fewer restrictions on underground activities and/or

[9] TCE has been detected slightly above the cleanup level for direct contact based on unrestricted use in localized areas beneath the ABP Facility (see the SCM Memo for specific locations). In the event that land use changes, caps may also need to be prevent direct contact with contaminated soil in these areas. This requirement would be addressed in an environmental covenant for the ABP Property.

[10] Active mitigation may be transitioned to passive mitigation and monitoring using the evaluation process described in the VIAMM Plan (see Section 3.1).

[11] A Site-specific risk assessment presented in the RI did not identify a potential unacceptable risk from shellfish consumption under current conditions. This assessment may be updated in the future if conditions change.

property use. However, due to potential access issues, some contaminated materials (e.g., beneath building footings) will likely remain in place.

7.2.4 Modeling Tools for Alternative Development

Groundwater modeling was used to define areas to target for active treatment and to identify concentrations at which it may be appropriate to transition from active treatment to MNA (i.e., when remediation levels are met; see Section 5.2.3). This requires consideration of: 1) concentrations for COCs that are protective of the surface water pathway; and 2) the practicability of achieving a shorter restoration time frame. For the purposes of this FS, these elements were evaluated using contaminant fate-and-transport modeling to predict future behavior of the contaminant plume under various scenarios. Modeling of cVOCs was performed using the BIOCHLOR spreadsheet model (Aziz and Newell, 2002). Modeling of metals was performed using the numerical groundwater flow and transport simulator PHAST (Parkhurst et al., 2010).

Two different modeling approaches and parameters were used with the BIOCHLOR model to support development of remediation levels and evaluation of restoration time frame, as follows:

- A set of BIOCHLOR models were developed to estimate remediation levels at different locations protective of the surface water pathway under MNA; and
- A set of BIOCHLOR models were developed to estimate restoration time frame (the time until CULs are met everywhere at SU1).

The modeling approach used to estimate remediation levels involves conservative assumptions—including a constant concentration, non-decaying source—to increase certainty about the protectiveness of the remediation levels. However, these assumptions were not used for the purposes of estimating restoration time frame, since data indicate source decay (consistent with groundwater flushing) is ongoing, and to assume no source decay would not allow calculation of restoration time frames for source constituents that currently exceed CULs.

BIOCHLOR model details are described in Appendix C. PHAST model details are described in Appendices B and D. A summary of model approach, results, and how the results were used in constructing alternatives is provided below.

7.2.4.1 Modeling of cVOC Remediation Levels for MNA

To estimate remediation levels at which MNA would be protective of the surface water pathway, five BIOCHLOR models were developed to assess plume attenuation downgradient from the following locations: the ABP Facility, 2nd Avenue South, 1st Avenue South, EMW, and South Fidalgo Street. A sixth BIOCHLOR model was developed to assess plume attenuation downgradient of the VC “hot spot” located south of the ABP plume on 1st Avenue South and defined by well PSC-CG-141-40.

Each of the six BIOCHLOR models was developed to define a cVOC “source area” at the location where a remediation level was to be estimated (e.g., ABP Facility, 1st Avenue South, 2nd Avenue South, etc.). Initial source-area cVOC concentrations were selected based on recent groundwater monitoring data. In several locations within the TCE Plume (e.g., the ABP Facility, 2nd Avenue South, 1st Avenue South), there is little or no detectable VC. In these cases, in order to develop a remediation level for VC, an initial VC concentration equal to ten percent of the DCE concentration at that location was selected. The model source area was treated as a constant concentration, non-decaying source, and the model was run forward in time until modeled concentrations at the waterway approached steady-state conditions. If modeled concentrations exceeded applicable surface water CULs, the source-area concentrations were reduced (while maintaining the observed ratios between cVOC constituents) until modeled concentrations at the waterway were less than CULs. The final set of source-area concentrations that did not result in modeled exceedances at the waterway was selected as the remediation levels for a given location. Table 7-2 summarizes the calculated remediation levels.

The remediation levels calculated for the cVOCs do not represent unique solutions, and there are other combinations of cVOC concentrations that would also be protective of surface water CULs. A second set of remediation levels for 1st Avenue South and EMW South was calculated for an area of primarily VC contamination near the SU1/SU2 boundary (including wells CG-140-40 and CG-141-40). These remediation levels are included in Table 7-2. Current concentrations at CG-141-40 are below the calculated remediation level, but recent VC concentrations at CG-140-40 exceed the remediation level. Therefore, treatment of this area along EMW South was included in two alternatives (Alternatives 6 and 7). Because calculated remediation levels depend on the ratio of cVOCs, remediation levels may need to be revisited depending on future observed ratios of cVOC constituents.

7.2.4.2 Modeling of Restoration Time Frame for cVOCs

A second set of BIOCHLOR models were developed to estimate the restoration time frame under various remedial options. The BIOCHLOR models were developed to estimate when cVOC concentrations in groundwater would meet CULs everywhere within SU1. The models were developed to account for cVOC mass at the ABP Facility and at downgradient "sources" or hot spots. The models also account for the effects of remedial actions on cVOC concentrations, including the effects of active treatment at accessible public ROWs (i.e., 2nd Avenue South, 1st Avenue South, EMW, and South Fidalgo Street), Source Area removal/stabilization at the ABP Facility, and additional groundwater treatment on private property outside building footprints.

To allow for evaluation of the effects of different remedial actions at different locations in the cVOC plume, the plume was divided into multiple source areas. These source areas were defined based on where remedial actions could potentially take place (e.g., treatment along public ROWs) and where cVOCs exceeding CULs were detected in groundwater. Source-area concentrations were assigned as the maximum detected cVOC concentrations in that area since Q1 2014. Model source areas and associated source-area concentrations were defined as the following locations and using concentration data from the listed wells:

- The ABP Facility east of 3rd Avenue South (well PMW-1);
- The area between 2nd Avenue South and 3rd Avenue South (well MW-16-40);

- The area between 1st Avenue South and 2nd Avenue South (well MW-17-60);
- The area between EMW and 1st Avenue South (well MW-25-50); and
- The area between South Fidalgo Street and EMW (well MW-24-30).

BIOCHLOR does not directly simulate multiple source areas. To address this, separate BIOCHLOR models were developed for each source area and the model results were then combined through superposition to arrive at a final cVOC concentration profile from the ABP Facility to the waterway, accounting for the contribution of all source areas to total groundwater concentrations.

Modeling restoration time frames requires that the cVOC concentrations in the model source areas decrease (decay) over time, whether through natural flushing and attenuation or through active remedial measures. With a nondecaying (constant) source-area concentrations, such as was used in the remediation-level models, modeled concentrations would never meet CULs. However, as shown by groundwater monitoring data, source-area concentrations east of 1st Avenue South are declining due to physical, chemical, and biological processes, while concentrations west of 1st Avenue South have remained stable as cVOCs present in upgradient soil and groundwater are flushed through the system. Source-area concentration decay rates accounting for flushing were estimated using a mass balance approach, as described in Appendix C.

The effects of remedial actions were incorporated into the model results by applying an expected cVOC concentration reduction to modeled output to account for the effect of potential remedial actions. For example, if a permeable reactive barrier (PRB) were installed at 2nd Avenue South, it is expected to reduce incoming concentrations by 80 percent, and the modeled concentrations west of 2nd Avenue South associated with the ABP Facility Source Area would be reduced by 80 percent.

Once the effects of remedial actions were incorporated into the individual model results, the concentrations of the individual models were summed to arrive at a total concentration profile between the ABP Facility and the waterway for multiple times. The concentration profiles were then compared to applicable CULs to assess the likely restoration time frame.

7.2.4.3 Areas Targeted for Active Treatment of cVOCs

As described in Section 8.1, each alternative considers distinct active remedial approaches to contamination in two different treatment areas, the Source Area and the Downgradient TCE Plume. Contamination outside of these areas is generally addressed through MNA for all alternatives, except Alternatives 6 and 7, which also include treatment of elevated VC near well CG-140-40. For the purposes of the FS, specific treatment locations were defined by conducting a practicability analysis of achieving shorter restoration time frames using the groundwater modeling tools described above. The specific treatment locations would be further refined during remedial design.

For each treatment area, the model was used to estimate the time to achieve CULs for cVOCs for a range of scenarios that included:

- MNA with no active treatment;

- Treatment of the Source Area (ABP Facility and adjacent ROWs);
- Treatment of the Source Area and including accessible areas of the 220 Findlay property;
- Treatment area boundaries limited to areas downgradient of EMW;
- Treatment area boundaries limited to areas downgradient of 1st Avenue South;
- Treatment area boundaries set to include areas with cVOC concentrations exceeding remediation levels (areas downgradient of 2nd Avenue South);
- Treatment area boundaries increased to include areas with cVOC concentrations exceeding the PCULs (ABP Facility and downgradient areas); and
- Treatment area boundaries to include areas with cVOC concentrations exceeding the PCULs, with additional soil source area stabilization or removal at the ABP Facility and treatment on private property outside building footprints.
- A separate model was developed to assess restoration time frame at the PSC-CG-141-40 VC hot spot, located south of the ABP TCE plume, under MNA conditions.

The BIOCHLOR models were applied to each of these scenarios, assuming active treatment (e.g., reactive barrier wall) at each of the public ROWs listed above. The final scenario includes treatment on private property; the effectiveness of this treatment was assumed to be proportional to the accessible area outside building footprints in each treatment area. Additional details are provided in Appendix C.

The different areas assessed under these scenarios are shown on Figure C-1 in Appendix C. As a sensitivity analysis, results were obtained for a range of treatment efficiencies (i.e., the assumed reduction in cVOC concentrations within the area of application[12]) of 50 to 90 percent. This range is based on discussions with applicable *in-situ* treatment technology vendors regarding expected treatment efficiencies.[13]

Additional details of restoration time-frame modeling are summarized in Section 7.2.3.2 and provided in Appendix C. Predicted restoration time frames for all the modeled scenarios are summarized in Table C-5 of Appendix C. Note that because of the

[12] Note that reactive barrier walls employing EAnB will enhance degradation not only at the point of application but for some distance downgradient, which would potentially shorten the restoration time frame. However, the estimated distance over which EAnB would be enhanced, based on typical values for organic amendment half-lives and site flow velocities, is approximately 40 feet, which is not expected to significantly affect model results.

[13] A range of *in-situ* treatment efficiencies was evaluated because uncertainties in site-specific performance of potential technologies prevent a precise estimation of treatment effectiveness for the FS. Treatment effectiveness will be further estimated and measured during design and implementation of the selected remedy; however, for the purposes of this FS, a range of potential effectiveness was deemed adequate to select a preferred alternative. For remedial alternative restoration time-frame estimates, an 80-percent treatment efficiency over the area of application was assumed for EAnB, ISCR, and ISCO, and a 100-percent treatment efficiency over the area of application was assumed of excavation and ISS.

uncertainty of groundwater modeling and the need for simplifying assumptions, the results are best used as a relative comparison tool for constructing and evaluating remedial alternatives, and should be considered only an approximate estimate of an absolute restoration time frame.

Conclusions based the modeling results and resulting assumptions for the FS are as follows:

- Treatment of the 220 Findlay property did not substantially reduce the restoration time frame for VI downgradient of the ABP Property.
- Scenarios including active treatment along ROWs perpendicular to the groundwater plume reduce the restoration time frames by 10 to 35 percent compared to MNA only. When compared to applying treatment only at South Fidalgo Street and EMW, adding treatment at public ROWs upgradient of EMW (e.g., at 1st Avenue South and/or 2nd Avenue South) has a negligible effect on the overall restoration time frame in SU1, but reduces the time to achieve surface water-based CULs at the Waterway from 50 to 35 or 40 years. Treatment along EMW is included in Alternatives 6 and 7, and treatment along 1st Avenue South is included in Alternative 7. Treatment of all public ROWs (as well as accessible private property) within the Downgradient TCE Plume was retained for Alternative 9, the most permanent cleanup alternative.
- Treatment of accessible areas of private properties combined with source removal/stabilization at the ABP Facility is predicted to reduce the restoration time frame by only about 15 percent (from 35 to 30 years) compared to treatment at public ROWs only, but would require applying treatment over four acres of accessible properties, compared with about 600 to 1,200 linear feet of treatment walls in public ROWs. Therefore, treatment on downgradient private properties was deemed not likely to be cost-effective, and application of treatment technologies downgradient from the ABP property was assumed to be confined to within ROWs for Alternatives 2 through 8. Treatment of downgradient private properties was retained for Alternative 9, the most permanent cleanup alternative.
- The restoration time frame for the VC hot spot at PSC-CG-141-40 under MNA is less than (20 versus 25 to 55 years), the restoration time frame for the TCE plume for all treatment scenarios considered. Therefore, treatment of this hot spot is not expected to significantly affect restoration time frame, and was not included for active treatment in the FS alternatives[14].

In general, the model predicts that active treatment options in the Source Area and Downgradient TCE Plume Area offer somewhat limited improvements on the time to achieve CULs when compared to MNA. Notably, even multiple downgradient treatment lines, including with treatment along the shoreline (Alternative 5) is not predicted to

[14] Although the VC hot spot exceeds the calculated remediation levels for VC, the remediation levels are non-unique solutions as discussed in Section 7.2.4.1. Applying the BIOCHLOR model described in Section 7.2.4.1 to the measured distribution of TCE, DCE, and VC indicates that the concentrations in the VC hotspot would degrade to below cleanup levels prior to discharging to the Waterway.

achieve CULs at the Waterway for 35 years. This is largely because of limited access to large areas of the plume, and somewhat due to inherent effectiveness limitations of *in-situ* treatment due to challenges in application, distribution of amendments, and complications from heterogeneous soils, making it very difficult to achieve high treatment efficiencies[15]. Other *in-situ* technologies that were eliminated during technology screening and not incorporated into remedial alternatives would have the same inherent limitations to effectiveness in SU1.

The model was not varied based on treatment technology (i.e., the effectiveness of the sparge curtain under Alternative 5; ISCR PRBs under Alternatives 2, 4, 6, 7, and 8, and EAnB PRBs under Alternatives 3 and 5 were assumed to be the same). In reality, some variability in treatment effectiveness is expected between technologies based on location and COC; for instance, VC may be more effectively treated by ISCR than EAnB; and air sparging may be very effective for VC, through both physical (stripping) and biological (enhanced aerobic bioremediation) means, but less effective for TCE, which would only be removed by physical means. However, the specific range of effectiveness is not known and cannot be reliably estimated before design and pilot testing. Therefore, potential differences in effectiveness between technologies were considered qualitatively in the alternatives evaluation (see Section 8).

7.2.4.4 Metals Fate-and-Transport Modeling

The metals fate-and-transport model, as completed by Anchor QEA, is summarized in Appendix B. The same modeling approach described in Appendix B was used to evaluate the following:

- The potential for plating metals[16] to reach the Waterway without treatment;
- The effect of pH neutralization in the Source Area (Alternatives 1 through 8) on plume extent and restoration time frame; and
- The effect of Source Area removal/*in-situ* solidification (Alternative 9) on plume extent and restoration time frame.

Modeling results for the scenarios above are summarized in Appendix D[17]. Model results indicated the following:

- Without treatment, nickel concentrations have the potential to reach the Waterway, although the projected time frame is greater than 1,000 years.

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[15] Long restoration time frames are also likely due to the conservativeness of the model, which assumes relatively low attenuation rates.

[16] For fate-and-transport modeling of plating metals, nickel was used as a surrogate for other metals for the reasons provided in Section 5.3. The fate-and-transport behavior of other plating metals (copper and zinc) is expected to be similar to nickel (see Appendix B).

[17] Metals fate-and-transport modeling assumed ambient groundwater geochemical conditions not affected by other remedial actions (e.g., AS, EAnB, ISCO). These other technologies can have a short-term effect on redox conditions, but are not expected to significantly affect the results of the fate-and-transport analysis (Appendix D).

- With pH neutralization, the nickel plume does not expand significantly beyond the Source Area, and nickel concentrations achieve surface water CULs in groundwater in approximately 280 years.
- With Source Area removal/*in-situ* solidification, the nickel plume migrates downgradient from the Source Area approximately 740 feet[18], and nickel concentrations achieve surface water CULs in groundwater in approximately 1,000 years.

Copper and zinc are attenuated by the same processes; they are adsorbed on iron oxides similar to nickel and can form sulfide solids. Since copper and zinc concentrations are much lower than nickel in the Source Area, these plating metals are attenuated near the Source Area.

Given the long restoration time frame for plating metals, the consequences resulting from a significant future release of acidic wastewater needs to be considered. The acid neutralizing capacity of aquifer soil is sufficient to attenuate the acidity of the existing plume within a few feet. Therefore, although hypothetical future releases of acidic solution could potentially remobilize plating metals near the Source Area, modeling indicates concentrations would be attenuated within a few feet downgradient. Existing attenuation processes (metal oxide/hydroxide precipitation, metal sulfide precipitation, and net neutralization potential) would continue to operate in the aquifer.

Site groundwater is unlikely to be used as a drinking water in the foreseeable future. If this were to change in the long-term, modeling indicates that with pH adjustment, nickel concentrations do not exceed Maximum Contaminant Levels (MCLs) standards set by Washington State for drinking water quality beyond the Source Area by 10 years. Copper concentrations in groundwater are below the MCL of 1,300 µg/L, and are not expected to increase in the future. An MCL has not been set for zinc.

It is assumed that certain remedial actions employed in some of the alternatives, particularly ISCR, could reduce the time frame somewhat compared to pH neutralization alone. However, these technologies are not expected to greatly reduce the overall restoration time frame (see Appendix D), and the estimated restoration time frame for all alternatives except Alternative 9 is approximately 400 years.

7.2.5 Contingency Actions

Each remedial alternative includes contingency actions that would be implemented if performance monitoring indicates the cleanup action is insufficiently protective or will not achieve RAOs. In areas where restoration relies on natural attenuation, monitoring will be used to assess compliance with RAOs. If monitoring indicates a significantly longer time frame than estimated, the need for additional actions will be assessed based on evaluation of potential risks from a longer restoration time frame, the ability to achieve a significantly shorter time frame using active methods, and the cost of doing

[18] Even after source removal/*in-situ* solidification, the nickel plume continues to migrate downgradient for a period of time because not all of the source would be removed.

so[19]. All alternatives include monitoring to evaluate remedy protectiveness. Potential exposures via VI and shellfish consumption will be monitored and mitigated as described in Section 7.2.3.

Potential contingency technologies are described briefly below[20].

7.2.5.1 Contingency Actions in the Source Area

For alternatives that rely on MNA of cVOCs in the Source Area, potential contingency actions include the active treatment measures that are incorporated into other alternatives, which include ISCR, EAnB, and P&T/ISCO. Source Area actions for Alternative 9 (excavation and ISS) were not considered as potential contingency actions based on their extremely high cost and disruptiveness.

7.2.5.2 Contingency Actions in the Downgradient Area

Potential contingency actions in the downgradient area include active treatment measures that are already incorporated into several alternatives, namely ISCR and EAnB applied in street ROWs to treat cVOCs. In addition, several other technologies may be applicable as contingency actions if needed to maintain protectiveness, or RAOs are not being achieved within a reasonable restoration time frame. These include sparge curtains, enhanced aerobic biodegradation, and P&T with a slurry wall, which are described below.

Sparge Curtains

A sparge curtain at the Waterway may be considered for additional protection of the surface water pathway from cVOCs in groundwater pending performance of the selected cleanup action. Air sparging can be applied to rapidly strip TCE out of groundwater and/or aerobically degrade VC. Considerations for the use of this technology include the requirement for aboveground equipment, which may require one or more access agreements on private property, and the fact that introduced oxygen would be counterproductive to natural reductive dechlorination of TCE as well as the EAnB and ISCR technologies proposed under some alternatives for downgradient treatment of the cVOC plume.

Enhanced Aerobic Biodegradation

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[19] For example, in the Cleanup Action Plan (Ecology, 2012) for the Fox Avenue Site (which is also located along the Waterway, and contains cVOCs with similar VI and surface-water protection concerns as SU1), potential contingency actions include: vapor mitigation, if warranted; active treatment, if treated concentrations rebound to above remediation levels; and a site-specific risk assessment (e.g., through shellfish tissue sampling), if surface water cleanup levels are not met at the point of discharge within the expected time frame to determine if additional treatment as close to the point of discharge as practicable is warranted.

[20] In addition to the three technologies listed, ISCR and EAnB could be considered potential contingency actions for alternatives that do not already include those technologies. The effect of ISCR and EAnB technologies, which have the potential for creating stronger reducing conditions and mobilizing naturally occurring, redox-sensitive metals such as iron, on the geochemistry of groundwater discharging to the Waterway would need to be evaluated prior to implementation along the shoreline.

Enhanced aerobic biodegradation may be considered for additional protection of the surface water and/or vapor pathway from VC pending the performance of the selected cleanup action. An oxygen-releasing amendment could be applied via direct push injection in areas around the edges of the groundwater plume to aerobically degrade VC. One consideration for the use of this technology is that aerobic treatment would be counterproductive to natural reductive dechlorination of TCE as well as the EAnB and ISCR technologies proposed under some alternatives for downgradient treatment of the cVOC plume.

Slurry/Cutoff Wall and P&T

Slurry/cutoff walls (i.e., impermeable barriers) could be used for protection of the surface water pathway from cVOCs and metals at the Waterway, pending performance of the selected cleanup action. A slurry wall could be applied as a physical containment measure to prevent the migration of cVOCs in groundwater. This technology would likely need to be implemented in tandem with hydraulic controls (groundwater P&T) to limit the potential for groundwater mounding and the flow of cVOC impacted groundwater over and/or around the wall. Considerations for this combination of technologies include: significant disturbance of private property to install a cutoff wall and P&T infrastructure along the shoreline, and a requirement for a sewer authorization or NPDES permit to discharge treated water.

Cost-Benefit Analysis of Potential Contingency Actions at the Waterway

To evaluate the practicability of potential contingency actions, costs for intercepting and treating cVOCs along the shoreline were estimated for each technology. For the purposes of this evaluation, interception of the cVOC plume above CULs at the shoreline (a transect approximately 300 feet long and 40 feet deep) was assumed. Contingency actions were also assumed to be necessary starting at 15 years and be maintained through year 35. Additional assumptions and cost estimate details are included in Appendix E. Initial capital costs ranged from $300,000 for a sparge curtain, to $500,000 for enhanced aerobic bioremediation, to $900,000 for Slurry/Cutoff Wall and P&T. Annual O&M costs ranged from $50,000 for a sparge curtain to $110,000 for a Slurry/Cutoff Wall and P&T, while enhanced aerobic bioremediation would have to be reapplied annual at a cost of approximately $85,000. While all three actions are potentially effective at reducing cVOC concentrations to protect the Waterway[21], aerobic bioremediation and sparge curtains are more implementable than a slurry/cutoff wall with P&T which would require significant disturbance of private property to install the required infrastructure. The cost for a slurry/cutoff wall with P&T are much higher than other potential actions and are disproportionate to its benefit. Based on this analysis, enhanced aerobic bioremediation and sparge curtains were retained as potential contingency actions for protection of surface water (in addition to ISCR and EAnB, which are included in some remedial alternatives but are potential contingencies for other alternatives).

[21] Enhanced aerobic bioremediation would not be effective to treat TCE, but may be applied if treatment of VC but not TCE is warranted.

7.3 Description of Remedial Alternatives

Remedial alternatives were assembled for the Site, as described in Section 7.1. Alternative components are summarized in Table 7-1, and a summary of how these components achieve RAOs for each alternative is provided in Table 7-3. Model-estimated time frames to achieve remediation levels and CULs in different areas are summarized for each alternative in Table 7-4. The following sections describe the alternatives, as well as an overview of how the alternatives are expected to address the RAOs for the Site.

7.3.1 Alternative 1— pH/MNA/MNA

Alternative 1 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. This alternative includes the following elements:

- Application of 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 following pH neutralization.
- Implementing engineering 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 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.

7.3.1.1 AS/SVE Assumptions

The existing AS/SVE system has been in operation since 2008, and is considered to be at a point of diminishing returns. Pulsed operation of the AS system has been conducted since 2012, and only modest rebound has been observed during shutdown periods. Concentrations of cVOCs in groundwater are below remediation levels in the Source Area. It is assumed that the AS system will be shut down after selection of the cleanup action and before application of pH neutralization.

As described in the SCM Memo, 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. The transition will include shutting off flow from wells and trenches west of 3rd Avenue South. 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.

7.3.1.2 Source Area pH Neutralization Application and Assumptions

Figure 7-1 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. Solid-, liquid-, and gas-phase agents have been used to neutralize groundwater pH at cleanup sites, and multiple *in-situ* implementation strategies are available for introducing these agents to the aquifer. For the purposes of this FS, it is assumed that injection wells are used in Alternative 1 to continuously introduce an aqueous pH neutralization solution.

Commercially available pH neutralization products that are highly soluble include nonproprietary chemicals such as sodium bicarbonate, as well as proprietary carbonate blends such as NuBuff from Redox Tech. The selected product will be prepared as an aqueous solution to be compatible with injection well applications. Sodium bicarbonate is a strong candidate for the following reasons: it would likely be lower in cost than proprietary products; and may be preferred over other nonproprietary chemicals (e.g., sodium or potassium carbonate or hydroxide) because it has a relatively low equilibrium pH, and is therefore less likely to overshoot the desired pH range. Overshooting the desired pH range could cause toxicity to microorganisms and/or precipitation of secondary minerals that could foul well infrastructure and detrimentally affect implementation.

The pH neutralization product, solution strength and injection rate, injection method, solution preparation/delivery system, and other application details will be determined during remedial design. Remedial design will likely include bench- and/or pilot-scale testing to evaluate treatment performance and better understand effects on groundwater geochemistry. For the purposes of this FS, it is assumed that 6 existing wells within the footprint of the ABP Facility will be utilized, and 27 new four-inch-diameter injection wells will be installed at the locations shown on Figure 7-1 for application of the buffer solution. The new injection wells are assumed to be 20 feet deep and screened in the 10- to 20-foot depth (Water Table Interval). Sodium bicarbonate solution would be prepared in a tank, from which it would gravity-feed to a piping manifold connected to the individual injection wells. 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. Multiple injections may be needed to achieve sufficient distribution and the desired pH shift.

7.3.1.3 Monitoring, Engineering, and Institutional Controls Assumptions

Engineering 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 Findlay properties would be operated until groundwater in the Water Table Interval achieves CULs protective of VI (approximately 15 years for Art Brass Plating and 25 years for 218 and 220 Findlay based on modeling: see Appendix C, Table C-6). A VI assessment, monitoring, and mitigation program will continue to be a part of this engineering control as long as 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 annually until CULs are attained across the Site (approximately 55 years for cVOCs and 280 years for metals, based on modeling). Performance monitoring would be conducted at wells in the Source Area during pH adjustment to evaluate effectiveness and modify neutralization applications as appropriate. 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.

7.3.1.4 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 Net Present Value (NPV) analysis assuming a discount rate of 1.6 percent, based on the values published in the Office of Management and Budget (OMB) Appendix C of the Circular A-94. Cost estimates include construction, 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, as described in Appendix C.

The estimated cost for Alternative 1 is $2.8 million (M). Details are provided in Appendix E. The estimated time to achieve all SU1 RAOs, including surface water CULs in groundwater at the standard point of compliance is approximately 55 years for cVOCs and 280 years for metals.

7.3.1.5 Potential Contingency Actions

This remedial alterative includes measures to achieve all RAOs, but relies heavily on MNA. As described in Section 7.2.5, 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 surface water-based CULs in groundwater discharging to the Waterway. Therefore, this alternative includes potential contingency actions for addressing cVOCs in the Source Area and the Waterway. For the purposes of the FS, hypothetical contingency actions identified for this alternative were ISCR in the Source Area to further address cVOCs (based on its potentially higher effectiveness for all contaminants and lower cost compared to EAnB or ISCO), and a sparge curtain for the protection of the Waterway (based on its potentially higher effectiveness for treating a mixture of TCE and VC compared to enhanced aerobic bioremediation, and potentially lesser impact to surface water quality from geochemical effects, compared to ISCR or EAnB).

The estimated cost for Source Area treatment at year 15[22] is $500,000. The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include O&M costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

7.3.2 Alternative 2— pH/MNA/ISCR @ Fidalgo

Alternative 2 includes the same Source Area components as Alternative 1, but adds ISCR treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area. This alternative includes the following additional elements:

- Application of an ISCR amendment as a PRB along South Fidalgo Street in the Downgradient TCE Plume Area to treat cVOCs in saturated soil and groundwater through enhanced reductive dechlorination (ERD).

pH neutralization, monitoring, and engineering and institutional controls would be applied as in Alternative 1, with additional performance monitoring of groundwater in the downgradient ISCR treatment area to evaluate effectiveness and optimize application of amendments. Vapor mitigation and compliance monitoring time frames have been adjusted accordingly. Application of ISCR in the Downgradient TCE Plume Area is described below.

7.3.2.1 Downgradient TCE Plume ISCR Application and Assumptions

The purpose of treatment of the TCE Plume along South Fidalgo Street is to reduce groundwater concentrations of cVOCs approaching the Waterway. Groundwater modeling predicts that with 80 percent treatment at this location, concentrations approaching the Waterway will be significantly reduced, but will not achieve surface water-based CULs for approximately 50 years (see Table 7-4). Ongoing treatment during

[22] It is assumed that by year 15, sufficient monitoring data will have been collected to reevaluate the restoration time frame and whether it is reasonable.

this period will likely be required to prevent rebound from contamination migrating from upgradient areas.

Direct-push injection is the assumed application method for the ISCR amendment in the Downgradient TCE Plume because the product contains ZVI and is prepared as a slurry. For the purposes of this FS, one row of injection points spaced 10 feet on-center is the assumed configuration for the application along the length of the PRB. Injections will be performed in a top-down fashion over the Shallow Interval (20 to 40 feet bgs). The conceptual layout for the PRB is shown on Figure 7-2 as a 300-foot-long wall along South Fidalgo Street.

The specific ISCR amendment, injection rate, preparation/delivery system, and other application details will be determined during remedial design. Remedial design will likely include bench- and/or pilot-scale testing to evaluate treatment performance and better understand effects on groundwater geochemistry.

For the purposes of cost estimating, the following assumptions were made, based on information provided by potential vendors:

- ISCR amendment would consist of a reagent that combines ZVI and a carbon source[23], to stimulate treatment of the downgradient volatile organic compound (VOC) plume.
- Amendments would be injected under high pressure (e.g., direct-push injection).
- Applications would be repeated at 10, 20, 30, and 40 years until groundwater achieves remediation levels at South Fidalgo Street (approximately 45 years based on modeling).

7.3.2.2 Cost and Restoration Time Frame

The estimated cost for Alternative 2 is $4.6 M. Details are provided in Appendix E. 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.

7.3.2.3 Potential Contingency Actions

This remedial alterative relies on MNA to achieve RAOs for cVOCs in the Source Area and downgradient of South Fidalgo Street. Therefore, this alternative includes potential contingency actions for the Source Area and the Waterway. For the purposes of the FS, hypothetical contingency actions identified for this alternative were ISCR in the Source Area to further address cVOCs, and a sparge curtain for the protection of the Waterway.

The estimated cost for Source Area treatment at year 15 is $500,000. The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include O&M costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

[23] For instance, Provectus' Provect IR product.

7.3.3 Alternative 3— pH/EAnB/EAnB @ Fidalgo

Alternative 3 uses EAnB in the Source Area to address cVOC impacts in groundwater and soil, in addition to pH neutralization to immobilize dissolved metals in groundwater as described in Alternative 1. This Source Area component is paired with EAnB treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area. This alternative includes the following additional elements:

- Application of an EAnB amendment throughout the Source Area via injection points to treat cVOCs in saturated soil and groundwater through ERD.
- Application of an EAnB amendment as a PRB along South Fidalgo Street in the Downgradient TCE Plume Area to treat cVOCs in saturated soil and groundwater through ERD.

pH neutralization, monitoring, and engineering and institutional controls would be applied as in Alternative 1, with additional performance monitoring of groundwater in the EAnB treatment areas to evaluate effectiveness and optimize application of EAnB amendments. Vapor mitigation and compliance monitoring time frames have been adjusted accordingly. Application of EAnB is described below.

7.3.3.1 Source Area EAnB Application and Assumptions

cVOC concentrations in the Source Area are below remediation levels, and based on groundwater modeling (see Section 7.2.4), MNA of Source Area cVOCs does not drive the overall restoration time frame for SU1. The purpose of active treatment in the Source Area under this alternative is to reduce the time frame to achieve groundwater CULs protective of indoor air and eliminate the need for associated engineering controls.

Injection wells installed for pH neutralization can also potentially be used for injection of EAnB amendments[24]. However, additional EAnB amendment injection wells are needed outside the area of depressed pH. For the purposes of this FS, it is assumed that 24 additional four-inch-diameter injection wells[25] are installed at the locations shown on Figure 7-3[26]. The injection wells are assumed to be 20 feet deep and screened in the 10- to 20-foot depth interval.

Injection of EAnB amendments would require an underground injection control (UIC) permit or approval from Ecology. The specific EAnB amendment, injection rate, injection method, preparation/delivery system, and other application details will be determined during remedial design. Remedial design will likely include bench- and/or

[24] It may be appropriate to initially inject only the pH neutralization solution, and to phase in the EAnB amendment after pH conditions become more amenable to microbial growth. Because EAnB can depress pH due to microbial activity, some supplemental pH neutralization may be needed during the EAnB application time frame.

[25] Amendments may also be injected at temporary points using direct-push drilling equipment. The cost-benefit of injection wells versus temporary points will depend on the number of applications needed.

[26] As discussed in Section 7.2.4, including the 220 Findlay property in the treatment area does not significantly reduce the time frame to achieve VI-based CULs downgradient of the ABP facility, based on groundwater modeling. Therefore, for the purposes of the FS, cVOC treatment was assumed to be applied on the ABP property and adjacent ROWs.

pilot-scale testing to evaluate treatment performance and better understand effects on groundwater geochemistry. Application of EAnB in the Downgradient TCE Plume under this alternative would likely occur first (concurrent with pH neutralization of the Source Area), and performance of EAnB in the Downgradient TCE Plume could be used to inform the design of Source Area treatment. For the purposes of cost estimating, the following assumptions were made, based on information provided by potential vendors:

- EAnB amendment would consist of a combination of a colloidal biomatrix, electron donor, and bioaugmentation culture[27].
- Amendments would be injected under low pressure (e.g., gravity feed or low-pressure pumping).
- Applications of electron donor and bioaugmentation culture may need to be repeated, pending performance monitoring, for groundwater in the Water Table Interval to achieve CULs protective of VI within the area of treatment (approximately 15 years based on modeling).

7.3.3.2 Downgradient TCE Plume EAnB Application and Assumptions

Injection wells are the assumed application method for the EAnB amendment in the Downgradient TCE Plume Area because multiple injection events are considered likely over the course of the cleanup, and permanent wells will provide continuous access. For purposes of this FS, one row of injection wells spaced 20 feet on-centers is the assumed configuration for application along the length of the PRB. Clusters of injection wells will be constructed with multiple screen intervals (all within the same hydrogeologic unit) to facilitate injection of amendments at discrete 10 foot intervals. Injection wells will have two screen intervals in the Shallow Interval (17.5 to 27.5 feet and 30 to 40 feet bgs). The conceptual layout for the PRBs is shown on Figure 7-2 as a 300-foot-long wall along South Fidalgo Street.

The specific EAnB amendment, injection rate, injection method, preparation/delivery system, and other application details will be determined during remedial design. Remedial design will likely include bench- and/or pilot-scale testing to evaluate treatment performance and better understand effects on groundwater geochemistry.

For the purposes of cost estimating, the following assumptions were made, based on information provided potential vendors:

- EAnB amendment would consist of a combination of a colloidal biomatrix, electron donor, and bioaugmentation culture;
- Amendments would be injected under low pressure (e.g., gravity feed or low-pressure pumping);
- Applications of electron donor and bioaugmentation culture may need to be repeated pending performance monitoring until groundwater achieves

[27] For example, Regensis' Plumestop product.

remediation levels at South Fidalgo Street (approximately 45 years based on modeling).

7.3.3.3 Cost and Restoration Time Frame

The estimated cost for Alternative 3 is $6.0 M. Details are provided in Appendix E. 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.

7.3.3.4 Potential Contingency Actions

This remedial alterative includes active measures to achieve RAOs in the Source Area and in the South Fidalgo Street ROW, but relies on MNA downgradient of South Fidalgo Street. Therefore, this alternative includes a potential contingency action for the Waterway to protect receptors, if it becomes apparent the remedy will not attain RAOs over 15 years. Potential contingency actions include a sparge curtain for the protection of the Waterway.

The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include operation and maintenance costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

7.3.4 Alternative 4—pH/ISCR/ISCR @ Fidalgo

Alternative 4 uses ISCR in the Source Area to address cVOC and metals impacts in groundwater and soil, in addition to pH neutralization to immobilize dissolved metals in groundwater as described in Alternative 1. This Source Area component is paired with ISCR treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area, as described in Alternative 2. This alternative includes the following additional elements:

- Application of an ISCR amendment throughout the Source Area to treat cVOCs, by creating highly reducing aquifer conditions and supporting ERD of cVOCs through abiotic and biotic reactions, and enhancing chemical precipitation/immobilization of metals[28].

The pH neutralization, monitoring, and engineering and institutional controls would be applied as in Alternative 1, and ISCR would be applied in the Downgradient TCE Plume Area as in Alternative 2, with additional performance monitoring of groundwater in the ISCR treatment areas to evaluate effectiveness and optimize application of amendments. Vapor mitigation and compliance monitoring time frames have been adjusted accordingly. Application of ISCR in the Source Area is described below.

7.3.4.1 Source Area ISCR Application and Assumptions

Direct push injection is the assumed application method for ISCR amendments because the product contains ZVI and is prepared as a slurry, which is not effectively injected through a well screen. For the purposes of this FS, it is assumed that 112 direct-push injection points are performed at a nominal spacing of 12 feet on-center over the area shown on Figure 7-4. The injection points are assumed to be 20 feet deep with application of the amendment over the 5- to 20-foot depth interval. Application of material under pressure will be carefully monitored and pressure controlled to avoid

[28] ISCR is also expected to help immobilize plating metals, but the effectiveness and irreversibility of this treatment for metals is uncertain.

daylighting of injected material, particularly around utilities. Storm drains and sewer lines in the vicinity of application will be monitored to ensure that injected material does not enter these utilities.

Injection of ISCR amendments would require an UIC permit or approval from Ecology. The specific ISCR amendment, injection rate, preparation/delivery system, and other application details will be determined during remedial design. Remedial design will likely include bench- and/or pilot-scale testing to evaluate treatment performance and better understand effects on groundwater geochemistry. Application of ISCR in the Downgradient TCE Plume under this alternative would likely occur first (concurrent with pH neutralization of the Source Area), and performance of ISCR in the Downgradient TCE Plume could be used to inform the design of Source Area treatment. For the purposes of cost estimating, the following assumptions were made, based on information provided potential vendors:

- ISCR amendment would consist of a reagent that combines ZVI, a carbon source, and a sulfate source[29]—would be used in the Source Area because this specific formulation includes a source of slow-release sulfate to further sequester metals.
- Amendments would be injected under high pressure (e.g., direct-push injection).
- Under this scenario, it is assumed application would only be required once for groundwater in the Water Table Interval to achieve CULs protective of vapor intrusion in the area of treatment (approximately 15 years based on modeling).

7.3.4.2 Cost and Restoration Time Frame

The estimated cost for Alternative 4 is $5.2 M. Details are provided in Appendix E. 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.

7.3.4.3 Potential Contingency Actions

This remedial alterative includes active measures to achieve RAOs in the Source Area, but relies on MNA downgradient of South Fidalgo Street. Therefore, this alternative includes a potential contingency action for the Waterway. Potential contingency actions include a sparge curtain for the protection of the Waterway.

The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include O&M costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

7.3.5 Alternative 5—pH/ISCR/EAnB @ Fidalgo

Alternative 5 uses pH neutralization and ISCR in the Source Area to address cVOC and metals impacts in groundwater and saturated soil, as described in Alternatives 1 and 4. This Source Area component is paired with EAnB treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area, as described in Alternative 3. This alternative also

[29] For instance, Provectus' Provect IRM product.

includes a sparge curtain at the shoreline to more aggressively treat groundwater discharging to the Waterway. This alternative includes the following additional elements:

- Installation of a sparge curtain at the shoreline to strip TCE out of groundwater and/or aerobically degrade VC.

pH neutralization, monitoring, and engineering and institutional controls would be applied as in Alternative 1, with additional performance monitoring of groundwater in the EAnB and ISCR treatment areas to evaluate effectiveness and optimize application of amendments. ISCR in the Source Area would be applied as in Alternative 4, and EAnB in the Downgradient TCE Plume Area would be applied as in Alternative 3. Vapor mitigation and compliance monitoring time frames have been adjusted accordingly. Application of the sparge curtain at the Waterway is described below.

7.3.5.1 Sparge Curtain Application and Assumptions

Direct-push techniques are the assumed installation method for air sparge wells. For the purposes of this FS, it is assumed that 20 air sparge wells will be installed at a minimal spacing of 15 feet on-center adjacent to the Waterway, as shown on Figure 7-5. The air sparge wells are assumed to be 40 feet deep and screened from 35 to 40 feet bgs[30]. A perforated vapor collection line would be installed above the wells. Additional aboveground equipment includes an air compressor, blower, controls, condensate collection system, sound enclosure, and a small building to protect the equipment. Operation of air sparge wells would require an UIC permit or approval from Ecology.

7.3.5.2 Cost and Restoration Time Frame

The estimated cost for Alternative 5 is $7.8 M. Details are provided in Appendix E. 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.

7.3.5.3 Potential Contingency Actions

This remedial alternative already includes active measures in the Source Area and along the Shoreline to achieve RAOs, therefore potential contingency actions are not included.

7.3.6 Alternative 6—pH/ISCR/ISCR @ Fidalgo and EMW

Alternative 6 includes the same Source and Downgradient TCE Plume Area components as Alternative 4, with additional ISCR treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area. This alternative includes the following additional elements:

- Application of an ISCR amendment as a PRB along EMW in the Downgradient TCE Plume Area to treat cVOCs in saturated soil and groundwater through ERD.

pH neutralization, monitoring, and engineering and institutional controls would be applied as in Alternative 1, and ISCR would be applied along South Fidalgo Street in the Downgradient TCE Plume Area as in Alternative 2, with additional performance monitoring of groundwater in the ISCR treatment areas to evaluate effectiveness and optimize application of amendments. Vapor mitigation and compliance monitoring time

[30] These wells will require a variance from Ecology if installed by direct-push methods.

frames have been adjusted accordingly. Application of ISCR along EMW is described below.

7.3.6.1 Downgradient TCE Plume ISCR Application and Assumptions

The same application method is assumed for EMW as for South Fidalgo Street. The primary difference being injections span the Shallow and Intermediate Intervals (20 to 60 feet bgs). The conceptual layout for the PRB is shown on Figure 7-6 as a 450-foot-long wall along EMW to treat areas of TCE and VC above remediation levels. The purpose of this PRB is to reduce concentrations downgradient of EMW and reduce the restoration time frame in this area. It also would result, with subsequent treatment by the South Fidalgo Street PRB, faster achievement of surface water-based CULs at the Waterway than with the South Fidalgo Street PRB alone (based on groundwater modeling, Section 7.2.4).

For the purposes of cost estimating, applications are assumed to be repeated along EMW at 10, 20, and 30 years based on the estimated time to meet remediation levels there following Source Area treatment (approximately 35 years based on modeling). As a result of additional upgradient treatment, the PRB at South Fidalgo Street is assumed to only need to be maintained for 30 years instead of 40 years.

7.3.6.2 Cost and Restoration Time Frame

The estimated cost for Alternative 6 is $8.0 M. Details are provided in Appendix E. The estimated time to achieve all SU1 RAOs, including surface water CULs at the standard point of compliance, is approximately 40 years for cVOCs and 280 years for metals.

7.3.6.3 Potential Contingency Actions

This remedial alterative includes measures to achieve RAOs, but relies on MNA for the area downgradient of South Fidalgo Street. For the purposes of the FS, a hypothetical contingency action of a sparge curtain for the protection of the Waterway was assumed.

The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include O&M costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

7.3.7 Alternative 7—pH/ISCR/ISCR @ Fidalgo, EMW, and 1st Ave

Alternative 7 includes the same Source and Downgradient TCE Plume Area components as Alternatives 2, 4, and 6, with additional ISCR treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area. This alternative includes the following additional elements:

- Application of an ISCR amendment as a PRB along 1st Avenue South in the Downgradient TCE Plume Area to treat cVOCs in saturated soil and groundwater through ERD.

pH neutralization, monitoring, and engineering and institutional controls would be applied as in Alternative 1, and ISCR would be applied along South Fidalgo Street and EMW in the Downgradient TCE Plume Area as in Alternatives 2, 4, and 6, with additional performance monitoring of groundwater in the ISCR treatment areas to evaluate effectiveness and optimize application of amendments. Vapor mitigation and compliance monitoring time frames have been adjusted accordingly. Application of ISCR along 1st Avenue South is described below.

7.3.7.1 Downgradient TCE Plume ISCR Application and Assumptions

The same application method is assumed for 1st Avenue South as for EMW, with injections spanning the Shallow and Intermediate Intervals (20 to 60 feet bgs). The conceptual layout for the PRB is shown on Figure 7-7 as a 300-foot-long wall along 1st Avenue South to treat areas of TCE and VC above remediation levels. The purpose of this PRB is to reduce concentrations downgradient of 1st Avenue South and reduce the restoration time frame in this area. It also would result, with subsequent treatment by the South Fidalgo Street PRB, faster achievement of surface water-based CULs at the Waterway than with the South Fidalgo Street PRB alone (based on groundwater modeling).

For the purposes of FS cost estimating, applications are assumed to be repeated along 1st Avenue South at 10 years, based on the estimated time to meet remediation levels there following Source Area treatment (approximately 15 years based on modeling). As a result of additional upgradient treatment, the PRB at EMW is assumed to only need to be maintained for 30 years instead of 35 years. Maintenance of the South Fidalgo Street PRB is assumed to still be required for 30 years as in Alternative 6.

7.3.7.2 Cost and Restoration Time Frame

The estimated cost for Alternative 7 is $8.2 M. Details are provided in Appendix E. The estimated time to achieve all SU1 RAOs, including surface water CULs at the standard point of compliance, is approximately 40 years for cVOCs and 280 years for metals.

7.3.7.3 Potential Contingency Actions

This remedial alterative includes measures to achieve RAOs, but relies on MNA for the area downgradient of South Fidalgo Street. Therefore, this alternative includes a potential contingency action to protect the Waterway, if needed. For the purposes of the FS, a hypothetical contingency action of a sparge curtain for the protection of the Waterway was assumed.

The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include operation and maintenance costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

7.3.8 Alternative 8—ISCO/P&T/ISCR @ Fidalgo

Alternative 8 uses ISCO in the Source Area to reduce concentrations of cVOC impacts in saturated soil and groundwater. Groundwater P&T technology will be used in conjunction with ISCO to distribute the oxidant, remove dissolved plating metals, and provide containment of groundwater in the Source Area. This Source Area component is paired with ISCR treatment of dissolved cVOC impacts in the Downgradient TCE Plume Area, as described in Alternative 2. This alternative includes the following elements:

- Injection of an ISCO amendment in the Source Area around the ABP Facility to chemically degrade cVOCs. Groundwater P&T is included with this alternative to assist is distribution of the oxidant (through recirculation), and provide extraction of dissolved phase plating metals. The combination of these technologies addresses direct-contact, surface water, and air pathways by providing treatment of COCs in saturated soil and groundwater.

- Application of an ISCR amendment as a PRB along South Fidalgo Street in the Downgradient TCE Plume Area to treat cVOCs in saturated soil and groundwater through ERD.

Monitoring, and engineering and institutional controls would be applied as described in Alternative 1, with additional performance monitoring of groundwater in the ISCO and ISCR treatment areas to evaluate effectiveness and optimize application of amendments. ISCR in the Downgradient TCE Plume Area would be applied as in Alternative 2. Vapor mitigation and compliance monitoring time frames have been adjusted accordingly. Application of ISCO/P&T in the Source Area is described below.

7.3.8.1 Source Area ISCO/P&T Application and Assumptions

Potassium permanganate is a suitable ISCO amendment as it is effective in a wide range of pH (3.5 to 12) and amenable to recirculation applications. Recirculation is recommended because direct contact with cVOCs is necessary for ISCO to be effective, and adequate coverage of the Source Area using other injection techniques is not realistic given spatial limitations.

For purposes of this FS, it is assumed that a pair of injection wells and a pair of extraction wells are installed at the locations shown on Figure 7-8. The wells are assumed to be 25 feet deep and screened in the 10- to 25-foot depth interval to provide capture of groundwater impacts depicted on Figure 7-8, distribute amendment through the treatment area, and reduce concentrations of cVOCs and metals in groundwater. It is not expected that a large percentage of contaminant mass would be removed by P&T, particularly for metals that partition strongly to soil; rather, P&T is primarily used as a mechanism for oxidant distribution. Injection ISCO amendments would require an UIC permit or approval from Ecology.

Additional aboveground equipment required includes a mixing tank for the permanganate solution and an injection system. Extraction wells will provide capture and containment of groundwater. Groundwater containing potentially low pH, unreacted permanganate, and dissolved metals will be pumped back to a treatment system. The treatment system will include particulate filtration, a neutralization tank for pH and permanganate, and ion-exchange resin beds to remove metals before being recirculated back into the permanganate mixing tank and injection system.

Considerations for ISCO include:

- ISCO is not considered conducive to the natural attenuation processes already taking place in the vicinity of the Source Area[31] and could extend the restoration

[31] As evidenced by the presence of TCE-daughter products in the Source Area.

time frame if it were to disrupt the groundwater geochemistry. However, pH in groundwater in much of the Source Area may already severely limit EAnB.

- ISCO may mobilize other non-plating metals in the treatment area.
- The aboveground treatment equipment will likely require a substantial footprint. Given the spatial constraints at the Site and potential limitations for weight on the roof of the ABP building, this may present a challenge.
- The treatment system will be designed to ultimately treat cVOCs and metals in extracted water to below CULs before reinjection; however, there are many factors that can affect a treatment system's effectiveness, and the feasibility of treating current nickel concentrations to CULs would be evaluated during design.

7.3.8.2 Cost and Restoration Time Frame

The estimated cost for Alternative 8 is $6.8 M. Details are provided in Appendix E. 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 greater than 1,000 years for metals. However, this estimate does not consider the hydraulic effects of Source Area P&T, which may reduce flushing through the Downgradient TCE Plume Area and extend the restoration time frame.

7.3.8.3 Potential Contingency Actions

This remedial alterative relies on MNA downgradient of South Fidalgo Street. Therefore, this alternative includes a potential contingency action, if needed, to protect the Waterway. For the purposes of the FS, a hypothetical contingency action of a sparge curtain for the protection of the Waterway was assumed.

The cost for the sparge curtain at the Waterway is estimated at $1.3 M. These costs include O&M costs for 20 years beyond implementation. Costs and assumptions for potential contingency actions are provided in Appendix E.

7.3.9 Alternative 9—Excavation/ISS/ISCR

Alternative 9 uses excavation above the water table and ISS below the water table in the Source Area to reduce concentrations and immobilize cVOCs and plating metal impacts in soil and groundwater. This Source Area component is paired with ISCR treatment of dissolved cVOC impacts in all potentially accessible portions of the Downgradient TCE Plume Area. This alternative includes the following elements:

- Excavation of accessible soil above CULs above the water table, and in-ISS of accessible contaminated soils below the water table, to remove and immobilize cVOCs and plating metals.
- Application of an ISCR amendment using direct-push injection over the accessible areal extent of the Downgradient TCE Plume Area to treat cVOCs by creating highly reducing aquifer conditions and supporting reductive dechlorination of cVOCs through abiotic and biotic reactions.
- MNA of cVOCs and plating metals in soil and groundwater following Excavation/ISS and ISCR.

- Implementing engineering and institutional controls and monitoring until RAOs are achieved, including:
  - Maintaining existing vapor mitigation systems at 218 and 220 Findlay Street until cVOC concentrations in soil and groundwater are protective of air.
  - 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.

7.3.9.1 Source Area Excavation/ISS Application and Assumptions

To facilitate excavation and solidification to the extent practicable, areas inside the ABP Facility would be cleared of equipment and materials. Building foundation elements and significant utilities in the ROWs would be left in place. The excavation area assumed for purposes of this FS is shown on Figure 7-9. Soils below an approximate depth of 8 feet (below the water table) will require ISS to an approximate depth of up to 20 feet, based on the extent of nickel impacts in the treatment area.

7.3.9.2 Downgradient TCE Plume ISCR Application and Assumptions

Direct-push injection is the assumed application method for the ISCR amendment in the Downgradient TCE Plume for reasons previously stated. For the purposes of this FS, it is assumed that 1,075 direct-push injection points are performed at a nominal spacing of 15 feet on-center over the area shown on Figure 7-10[32]. The injection points are assumed to be 40 feet deep in the Shallow Interval (385 injection points), and 60 feet deep within Intermediate Interval (690 injection points). Application of ISCR amendment is assumed to be top-down injection from 20 to 40 feet in the Shallow Interval and 20 to 60 feet in the Intermediate Interval.

The specific ISCR amendment, injection rate, preparation/delivery system, and other application details will be determined during remedial design. Remedial design will likely include bench- and/or pilot-scale testing to evaluate treatment performance and better understand effects on groundwater geochemistry.

7.3.9.3 Monitoring, Engineering and Institutional Controls Assumptions

Engineering 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 218 and 220 Findlay properties would be operated until groundwater in the Water Table Interval achieves CULs protective of vapor intrusion (20 years based on modeling).

[32] As discussed in Section 7.2.4.2, treatment for Alternative 9 would be implemented in all accessible areas, rather than transects, to reduce the restoration time frame as much as is technically feasible.

- A restrictive covenant would be placed on the ABP Property to address contamination that was immobilized in place or inaccessible to removal/solidification.
- Groundwater monitoring in SU1 would be conducted annually for 5 years, followed by once every 5 years until CULs are attained at the standard point of compliance (approximately 40 years based on modeling).

7.3.9.4 Cost and Restoration Time Frame

The estimated cost for Alternative 9 is $18.1 M. Details are provided in Appendix E. The estimated time to achieve all SU1 RAOs, including surface water CULs at the standard point of compliance, is approximately 40 years for cVOCs and 1,000 years for metals.

7.3.9.5 Potential Contingency Actions

This remedial alternative already includes extensive active measures, therefore potential contingency actions are not included.

7.4 Effect of Alternatives on Secondary COCs

The AO requires the FS to consider the effect of each alternative on secondary COCs, which include 1,4-dioxane and non-plating metals (see Section 2.1). Potential effects are discussed below.

7.4.1 1,4-Dioxane

In accordance with AO DE 10402, the likely effect of each of the six alternatives considered for implementation within SU1 on the concentrations of 1,4-dioxane in groundwater is discussed below:

- Alternative 1 (pH/MNA/MNA)—The cleanup action elements of Alternative 1 are unlikely to reduce concentrations of 1,4-dioxane in groundwater. It is also unlikely that implementation of Alternative 1 would interfere with ongoing attenuation of 1,4-dioxane concentrations in groundwater or interfere with Stericycle’s contingent remedy.
- Alternative 2 (pH/MNA/ISCR @ Fidalgo), Alternative 4 (pH/ISCR/ISCR @ Fidalgo), Alternative 6 (pH/ISCR/ISCR @ Fidalgo and EMW), and Alternative 7 (pH/ISCR/ISCR @ Fidalgo, EMW, and 1st)—The ISCR cleanup action element of Alternatives 2, 4, 6, and 7 has the potential to reduce concentrations of 1,4-dioxane in groundwater by promoting biodegradation. The remaining cleanup action elements of these alternatives (pH) are unlikely to reduce concentrations of 1,4-dioxane in groundwater, but they are also unlikely to interfere with ongoing attenuation of 1,4-dioxane concentrations in groundwater or with Stericycle’s contingent remedy. It is unlikely that implementation of Alternative 2, 4, 6, or 7 would interfere with ongoing attenuation of 1,4-dioxane or interfere with Stericycle’s contingent remedy.
- Alternative 3 (pH/EAnB/EAnB @ Fidalgo) and Alternative 5 (pH/ISCR/EAnB @ Fidalgo)—EAnB is a cleanup action element currently being evaluated by Stericycle in the Remedial Design in the East of 4th Area. Implementation of EAnB as part of Alternative 3 or EAnB and ISCR as part of Alternative 5 have

the potential to reduce concentrations of 1,4-dioxane in groundwater in SU1 by promoting biodegradation. It is unlikely that implementation of Alternative 3 or Alternative 5 would interfere with ongoing attenuation of 1,4-dioxane or interfere with Stericycle's contingent remedy.

- Alternative 8 (ISCO/P&T/ISCR @ Fidalgo)—ISCO is a cleanup action element currently being evaluated by Stericycle in the Remedial Design in the East of 4th Area. Implementation of ISCO as part of Alternative 8 has the potential to reduce concentrations of 1,4-dioxane in groundwater in SU1 through direct oxidation. However, the implementation of the P&T element of Alternative 8 has the potential to influence the groundwater flow direction and induce migration of groundwater with higher concentrations of 1,4-dioxane. Implementation of the P&T component of Alternative 8 has the potential to interfere with ongoing attenuation of 1,4-dioxane and interfere with Stericycle's contingent remedy.

- Alternative 9 (Excavation/ISS/ISCR)—The ISCR cleanup action element of Alternative 6 has the potential to reduce concentrations of 1,4-dioxane in groundwater by promoting biodegradation. The remaining cleanup action elements of Alternative 9 (Excavation and ISS) are unlikely to reduce concentrations of 1,4-dioxane in groundwater, but they are also unlikely to interfere with ongoing attenuation of 1,4-dioxane concentrations in groundwater or with Stericycle's contingent remedy. It is unlikely that implementation of Alternative 9 would interfere with ongoing attenuation of 1,4-dioxane or interfere with Stericycle's contingent remedy.

In SU1, laboratory analysis of groundwater samples have not detected 1,4-dioxane at concentrations exceeding its PCUL since before 2011. On the basis of the 1,4-dioxane plume configuration and current groundwater gradient and flow direction, future migration of groundwater with 1,4-dioxane concentrations above the PCUL into SU1 is unlikely. The implementation of Stericycle's contingent remedy further reduces the potential for future exceedances of the 1,4-dioxane PCUL in SU1 groundwater. Alternatives 1 through 7 and 9 either have the potential to reduce concentrations of 1,4-dioxane in groundwater or are unlikely to interfere with ongoing attenuation. Since concentrations of 1,4-dioxane in groundwater are already below its PCUL, implementation of Alternatives 1 through 7 and 9 are not expected affect the time frame for attaining the CUL. Implementation of the P&T component of Alternative 8 has the potential extend the time frame to CUL attainment by inducing the migration of groundwater with concentrations of 1,4-dioxane that exceed the PCUL, and could interfere with the implementation of Stericycle's contingent remedy in the East of 4th Area.

7.4.2 Non-plating Metals

Non-plating metals include arsenic, barium, iron, and manganese. These are redox-sensitive metals that can be mobilized with changes in geochemical conditions. The anticipated effect of each alternative on these metals is as follows:

- Alternatives 1 and 2 are expected to overall reduce concentrations of non-plating metals in groundwater (compared to prior to implementing remedial actions) because pH neutralization would reduce mobility of these metals. Short-term increases in these metals may be observed after air sparging is shut down, as redox conditions within the Source Area return to more ambient low-redox conditions. However, these effects are expected to be localized and not to extend beyond the Source Area.

- Alternatives 3 through 7 involve implementation of EAnB or ISCR in the Source Area, Alternatives 2 through 8 involve implementation of EAnB or ISCR in the Downgradient TCE Plume, and Alternatives 8 and 9 involve implementation of ISCR in the Downgradient TCE Plume. These technologies typically lower redox conditions in the area of treatment and mobilize non-plating metal COCs through chemical reduction and/or biological reduction. Based on other sites, these effects are not expected to result in significant migration of non-plating metal COCs far beyond the treatment area, though pilot testing will evaluate this potential. Ultimately, when EAnB treatment is halted to transition to MNA, groundwater redox conditions and non-plating metal concentrations in the treatment areas are expected to transition back to ambient conditions. As with Alternative 1, pH neutralization as part of all alternatives is also expected to ultimately reduce concentrations of non-plating metals in the Source Area.

- Alternative 8 involves implementation of ISCO in the Source Area, which likely will result in short-term decreases in non-plating metals; though after treatment stops, conditions would likely return to ambient conditions and concentrations may rebound. As with Alternative 1, pH neutralization is also expected to ultimately reduce concentrations of non-plating metals in the Source Area.

- Alternative 9 involves implementation of excavation and ISS in the Source Area, which will likely result in more permanent decreases in non-plating metals in this area because carbon sources that fuel biologically-mediated reactions in fill materials would be removed or stabilized. However, after treatment, conditions downgradient of the removal/stabilization area would likely return to ambient conditions and non-plating metal concentrations may still be elevated.

In general, impacts to non-plating metals are expected to be localized and are not expected to result in unacceptable risk to human health and the environment. Further evaluation of impacts from EAnB and ISCR would be conducted as part of design.

8 Evaluation of Remedial Alternatives

In this section, the nine remedial alternatives described in Section 7 are evaluated with respect to MTCA criteria. A summary of this evaluation is provided in Table 8-1.

8.1 Feasibility Study Evaluation Criteria

This section discusses the minimum requirements and procedures for selecting cleanup actions under MTCA (WAC 173-340-360).

8.1.1 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; and
- Provide for compliance monitoring.

8.1.2 MTCA Selection Criteria

When selecting from remedial alternatives that meet the threshold requirements, the following three criteria, identified in WAC 173-340-360(2)(b), must be evaluated:

- **Use permanent solutions to the maximum extent practicable.** A disproportionate cost analysis (DCA) is conducted to assess the extent to which the remedial alternatives address this criterion. The general procedure for conducting a DCA is described in Section 8.1.3.
- **Provide a 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).
- **Consider public concerns.** Consideration of public concerns is an inherent part of the Site cleanup process under MTCA. The Draft FS report is issued for public review and comment, and Ecology determines whether changes to the report are needed in response to public comments.

8.1.3 MTCA Disproportionate Cost Analysis

A DCA is conducted to determine whether a cleanup action uses permanent solutions to the maximum extent practicable. This is done by evaluating the relative benefits and costs of remedial alternatives. Seven criteria are considered in the evaluation as specified in WAC173-340-360(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 based on a comparative evaluation of an alternative’s cost against the other six criteria (environmental benefits). Per WAC 173-340-360(3)(e)(i), cost is disproportionate to benefits if the incremental cost of an alternative over that of a lower-cost alternative exceeds the incremental degree of benefits achieved by the alternative over that of the lower-cost alternative.

8.2 Evaluation with Respect to MTCA Threshold Requirements

The nine remedial alternatives are evaluated for compliance with the MTCA threshold criteria in this section. Evaluation results are summarized in Table 8-1.

8.2.1 Protection of Human Health and the Environment

All alternatives would provide protection of human health and the environment through a combination of: 1) treatment of cVOC-contaminated soil and groundwater; 2) treatment of metals-contaminated soil and groundwater; 3) MNA of groundwater contamination, with groundwater compliance monitoring and contingency actions included, if needed to be protective; and 4) institutional controls. The specific methods of achieving protectiveness RAOs under each alternative are summarized in Table 7-3.

8.2.2 Compliance with Cleanup Standards

All alternatives would comply with cleanup standards through treatment, natural attenuation, and containment of soils and groundwater exceeding CULs. All alternatives include the potential for soil and groundwater CULs to be exceeded for an extended period of time. These exceedances will require containment measures (i.e., engineering and/or institutional controls) during the restoration time frame.

Compliance with groundwater cleanup standards would be ultimately achieved by attaining CULs at the standard point of compliance. The mechanisms (i.e., treatment, attenuation, or a combination thereof) to achieve CULs for each alternative is summarized in Table 7-3. The time to achieve groundwater CULs in different areas of SU1 [including: 1) the time to achieve VI-based CULs in the Water Table Interval; 2) the time to achieve surface water-based CULs at the shoreline; 3) the time to achieve surface water-based CULs for cVOCs across SU1; and 4) the time to achieve surface water-based CULs for metals across SU1] for each alternative is summarized in Table 8-1.

Compliance with soil cleanup standards would be obtained through a combination of treatment, attenuation, and implementation of engineering and institutional controls (i.e., containment). Per WAC 173-340-355(2), a cleanup action involving containment of soils exceeding CULs at the point of compliance may be determined to comply with cleanup standards, provided the requirements of WAC 173-340-740(6)(f) are met. Those requirements are[33]:

- The selected remedy is permanent to the maximum extent practicable;
- The cleanup action is protective of human health and terrestrial ecological receptors;
- Institutional controls are put in place that prohibit or limit activities that could interfere with the long-term integrity of the containment system;
- Compliance monitoring and periodic reviews are designed to ensure the long-term integrity of the containment system; and
- The types, levels, and amount of hazardous substances remaining on-site and the measures that will be used to prevent migration and contact with those substances are specified in the Draft Cleanup Action Plan.

[33] The requirements of WAC 173-340-740(6)(f) are paraphrased here; refer to the MTCA regulation for the complete language.

All alternatives would be designed and implemented such that the above requirements would be met. Therefore, all alternatives would comply with soil cleanup standards upon completion of remedy construction.

Soil CULs for cVOCs are currently exceeded on the ABP Property for cVOCs (TCE and VC) and on the ABP Property and adjacent ROWs for plating metals (nickel, copper, and zinc). The relative degree to which soil CULs are assumed to be attained through treatment versus containment are as follows:

- cVOCs: Alternatives 1 and 2 rely on attenuation to achieve soil CULs, and are expected to require containment measures for a long period of time[34]. Alternatives 3 through 8 involve treatment of groundwater, which will also treat soil that is seasonally saturated.[35] However, containment measures will be required for cVOCs in soil above the seasonal high water table for a long period of time. Alternative 9 largely addresses cVOCs through treatment or removal, although some localized areas of contamination (e.g., beneath building footings or utilities) that are inaccessible to excavation may be left in place and also require long-term containment measures.

- Plating Metals: Alternatives 1 through 7 rely on containment measures to address soil above CULs. Alternative 8 will slightly reduce soil concentrations through P&T, but is also expected to require containment measures to address soil above CULs. Alternative 9 largely reduces soil concentrations through removal or treatment, although some localized areas of contamination (e.g., beneath building footings or utilities) that are inaccessible to excavation may be left in place and also require long-term containment measures.

Figures 8-1 and 8-2 summarize areas that are assumed to require institutional and engineering controls, respectively, after remedy implementation for each alternative. These figures also identify the types of controls (e.g., vapor mitigation, capping) that are expected to be required.

8.2.3 Compliance with Applicable State and Federal Laws

Through identification of ARARs (Section 5.1) and compliance with the MTCA regulation, Alternatives 1 through 9 would all comply with applicable state and federal laws.

8.2.4 Provisions for Compliance Monitoring

All nine alternatives would provide for compliance monitoring. Health and safety protocols outlined in a Site-specific health and safety plan (required in all alternatives) would provide protection monitoring. All nine alternatives would also include soil and groundwater monitoring to evaluate performance of treatment and removal actions. Periodic groundwater sampling and analysis would provide both performance and confirmation monitoring for all alternatives.

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[34] The restoration time frame of cVOCs in soil via attenuation processes has not been modeled, but is expected to take decades.

[35] This treatment is expected to include treatment of a portion of the 'vadose zone,' defined in the Site Conceptual Model Memorandum (Aspect, 2014b) as 0 to 8 feet, that is seasonally saturated.

8.2.5 Conclusion Regarding Compliance with Threshold Requirements

Based on the above evaluation, Alternatives 1 through 9 are all expected to comply with the MTCA threshold criteria. Therefore, all nine alternatives are carried forward to the next stage of evaluation.

8.3 Evaluation with Respect to Reasonable Restoration Time Frame

A cleanup action is considered to have achieved restoration once cleanup standards have been met. As discussed in Section 8.2.2, 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 protection at the standard point of compliance. The restoration time frames for each alternative are summarized in Table 8-1. Restoration time frames for surface water protection for cVOCs range from 30 years for Alternative 9 to 55 years for Alternative 1[36]. Restoration time frames for surface water protection for plating metals range from 280 to more than 1,000 years.

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; and
- 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)).

[36] As discussed in Section 7.2.4.2, 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.

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);
- Engineering 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[37]; and
- 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 range as follows:

- The time to achieve VI-based CULs is estimated at 20 years for Alternatives 3 through 9, versus 25 years for Alternatives 1 and 2.
- The time to achieve surface water-based CULs discharging to the Waterway is estimated at 30 years for Alternative 9; 35 to 40 years for Alternatives 5, 6, and 7; 45 to 50 years for Alternatives 2, 3, 4, and 8; and 55 years for Alternative 1.
- The time to achieve surface water-based CULs everywhere ranges from more than 1,000 years for Alternative 8 and approximately 1,000 years for Alternative 9 to 280 years for Alternatives 1 and 2, while Alternatives 3 through 7 are expected to be close to 280 years[38].

In sum, all alternatives—including the most permanent alternative (Alternative 9)—are expected to have extended restoration time frames. Some incremental benefit in restoration time frame can be achieved through implementation of additional treatment measures, but these measures are relatively costly relative to the incremental reduction in restoration time frame. The practicability of achieving a shorter restoration time frame depends on the DCA described in Section 8.4. All nine alternatives potentially provide for a reasonable restoration time frame.

It should be noted that the calculated restoration time frames are based on groundwater modeling that has inherent uncertainty and is highly sensitive to assumed hydraulic parameters, biodegradation rates, and treatment efficiencies, as described in Section 7.2.4. Actual restoration time frame for any alternative could be lower or higher than the

[37] The effectiveness of engineering and institutional controls relies, in part, on owner willingness to allow the controls to be implemented and operated.
[38] Alternatives 3 through 8 include active measures that may reduce the restoration time frame for metals, but the effects are not likely significant.

model-predicted time frame. The modeled time frames are used in this FS 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.

8.4 Disproportionate Cost Analysis

As described in Section 8.1.3, a DCA is performed to evaluate whether a cleanup action uses permanent solutions to the maximum extent practicable. The DCA quantifies the environmental benefits of each 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.

The DCA is performed in the following sections and summarized in Table 8-1. Environmental benefit is quantified by first rating the alternatives with respect to six of the seven criteria discussed in Section 8.1.3[39]. 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; and
- 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. 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[40].

[39] Cost is not considered in quantifying environmental benefit.
[40] 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 SU2 FS and to be consistent with Ecology’s preference at other sites. Other DCA methods include quantitative analysis with different weighting systems or purely qualitative analyses.

8.4.1 Overall Protectiveness

The remedial alternatives would all be protective of human health and the environment, but vary in the technologies used to achieve that protectiveness. Alternative 1 relies primarily on treatment of the Source Area and MNA, while Alternative 2 also includes *in-situ* treatment of the Downgradient TCE Plume. Alternatives 3 through 8 would rely primarily on *in-situ* treatment and MNA of contaminated soils and groundwater, combined with institutional controls, in both the Source Area and Downgradient TCE Plume. Alternative 9 would also implement removal in the Source Area to remove a portion of the contaminated soil. Although removal is not inherently more protective than technologies such as containment that leave contamination in place, it does provide a higher level of certainty that protectiveness will be maintained in the long-term.

Groundwater concentrations slightly 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 under all alternatives except Alternative 5 (which includes treatment along the shoreline); 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.

Groundwater concentrations exceed CULs protective of indoor air in the Water Table Interval beneath several occupied structures; however, monitoring and/or mitigation programs are in place. Groundwater monitoring suggests that the groundwater plume is stable or shrinking[41]. Alternatives 2 through 9—which provide active treatment of the Downgradient TCE Plume closest to the Waterway—provide more certainty that protectiveness will be maintained without the need for contingency actions.

A summary of differences in achieving protectiveness-based RAOs by exposure pathway for each alternative is as follows:

- **Direct Contact.** Exceedances of the direct contact-based CULs are limited to the ABP Property. Alternatives 1 through 8 address this pathway in a similar manner, primarily through capping and institutional controls. Alternative 9 involves removal of much or all of soil exceeding the direct contact-based CULs and would minimize or eliminate the need for controls. However, the extent of soil exceeding direct contact-based CULs is limited, and the associated benefit to overall alternative protectiveness is small.

- **Inhalation of Contaminated Soil (Dust).** Alternatives 1 through 8 address this pathway in a similar manner, primarily through capping and institutional controls. Alternative 9 reduces potential future exposures and would minimize or eliminate the need for controls. However, the extent of soil exceeding direct contact-based CULs is limited, and the associated benefit to overall alternative protectiveness is small.

- **Inhalation of Contaminated Air due to VI from Soils.** Exceedances of VI-protective levels of cVOCs in soil are limited to the ABP Property. Alternatives 1 through 8 address this pathway in a similar manner, primarily through capping,

[41] As noted in Appendix C, none of the wells exhibit statistically significant increasing trends, and cVOC concentrations at several wells in the Downgradient TCE Plume Area exhibit decreasing trends.

vapor mitigation, and institutional controls. Alternative 9 reduces potential future exposures through removal of contaminated soils, which would minimize or eliminate the need for controls and likely significantly shorten the time frame to achieve VI-protective cVOC concentrations.

- **Groundwater/Surface Water exposures due to Migration of Vadose Zone Soil Contamination to the Water Table.** Exceedances of groundwater-protective levels of cVOCs in vadose-zone soil are limited to the ABP Property. Alternatives 1 through 8 address this pathway in a similar manner, primarily through capping, vapor mitigation, and institutional controls. Alternative 9 reduces potential future exposures through removal of contaminated soils and would minimize or eliminate the need for controls.

- **Inhalation of Contaminated Air due to VI from Groundwater.** Exceedances of VI-protective levels of cVOCs in groundwater are limited to the water-table zone extending from the ABP Property to approximately 2nd Avenue South. Alternatives 1 and 2 rely primarily on attenuation with monitoring and controls to address this pathway, and are expected to achieve VI-based CULs in approximately 25 years. Alternatives 3 through 9 use a combination of active groundwater treatment in the Source Area with monitoring and controls, and are expected to achieve VI-based CULs in approximately 20 years. Alternatives with substantially shorter restoration time frames are considered more protective, as there are fewer uncertainties regarding future exposure considerations and performance of long-term monitoring and maintenance. Therefore, Alternatives 3 through 9 are considered more protective than Alternatives 1 and 2 for this pathway.

- **Waterway Receptors Exposures (Human and Ecological) due to Surface Water Contamination.** Surface water CULs in groundwater at the shoreline are predicted to be achieved in 55 years for Alternative 1; 50 years for Alternatives 2, 3, 4, and 8; 40 years for Alternative 6; 35 years for Alternatives 5 and 7; and 30 years for Alternative 9. Alternatives with substantially shorter restoration time frames are considered more protective, as there are fewer uncertainties regarding future exposure considerations and performance of long-term monitoring and maintenance.

Based on the above considerations, Alternative 1 was given a rating of 4 for overall protectiveness. Alternative 2 reduces the restoration time frame and provides greater certainty that the Waterway receptors will be protected, and was given a rating of 5. Alternatives 3, 4, and 8 reduce the time to achieve levels protective of indoor air and at the Waterway, and were given ratings of 6. Alternatives 6 and 7 achieved surface water CULs at the Waterway 10 to 15 years faster than Alternatives 3, 4, and 8, and were given a rating of 7. Alternative 5 achieves surface water CULs at the Waterway much faster through shoreline treatment, and was given a rating of 8. Alternative 9 was given a rating of 9 since cleanup standards would be obtained faster, and removal of contaminated vadose zone soils from the Source Area would slightly improve protectiveness relative to other alternatives.

8.4.2 Permanence

All alternatives are considered to have a relatively high permanence because in general: 1) cVOCs are ultimately destroyed through a combination of active treatment and natural attenuation; and 2) 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. Alternatives were differentiated primarily on the irreversibility of immobilization, and were rated as follows:

- Alternatives 1, 2, and 3 rely on pH neutralization and natural attenuation to immobilize plating metals in the Source Area. As described in the *SU1 Fate and Transport Memorandum* (Aspect, 2015b), this is predicted to result in sorption of metals initially as ferrihydrite (which are prone to dissolution under changed geochemical conditions), and ultimately to more stable/less reversible precipitates such as millerite. These alternatives are most subject to rerelease of plating metals if geochemical conditions change; however, the very slow rate of movement, even under current conditions, allows more-than-adequate time to implement contingency actions if needed. These alternatives were given a rating of 5.

- Alternatives 4 through 7 use ISCR in the Source Area, which will provide additional chemical treatment to precipitate and immobilize plating metals[42], reducing the potential for future dissolution and migration. These alternatives were given a rating of 6.

- Alternative 8 uses ISCO in the Source Area, which may also assist in precipitating and immobilizing metals. It also uses P&T to permanently remove more plating metals mass from the aquifer. This alternative was given a rating of 7, slightly higher than Alternatives 4 through 7.

- Alternative 9 is considered the most permanent alternative because all accessible contaminated soils would be removed from Source Area and contained in an engineered landfill, and *in-situ* treatment would be applied across all accessible portions of the Source Area and Downgradient TCE Plume. Removal and *in-situ* solidification of metals-contaminated soil from the Source Area would provide more permanent immobilization of these contaminants. cVOCs removed from the Source Area would not be treated in the short-term, but are expected to be reliably contained and to slowly attenuate over time within the landfill. This alternative was given a rating of 8.

8.4.3 Long-Term Effectiveness

Alternatives 1 through 9 involve treatment technologies that, coupled with natural attenuation, are all considered highly likely to maintain protectiveness during the cleanup period and ultimately achieve cleanup standards. 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

[42] ISCO has been shown to result in short-term mobilization of some naturally occurring metals such as chromium. However, as indicated in the Revised Technology Screening Memo (PGG, 2015b), manganese precipitates may help immobilize some metals including nickel. Testing would be required to evaluate the effect of ISCO on metals mobility in SU1.

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 BMPs when appropriate.

All alternatives include engineering and institutional controls to maintain protectiveness during the restoration period. The long-term effectiveness of the alternatives, as measured by the reliability of controls during the restoration time and the potential need for interim mitigation or contingency actions, varies depending on the extent of active treatment and the technologies applied. The long-term effectiveness also depends on the restoration time frame for which particular controls may be needed; longer time frames typically involve more uncertainty in future conditions and exposure pathways, and correspondingly lower ratings for long-term effectiveness. All alternatives have estimated restoration time frames of at least 30 years for cVOCs and 280 years for plating metals.

In general, treatment or attenuation processes that permanently destroy contamination are considered more effective than immobilization or containment options. Therefore, alternatives that involve more treatment are generally considered to have greater long-term effectiveness. The effectiveness of each alternative at meeting RAOs for soil, Source Area groundwater, and Downgradient groundwater was evaluated as follows:

- **Soil-related RAOs.** Alternatives 1 through 8 rely heavily on containment/controls to address vadose-zone soil contamination. Alternative 9 includes removal that will greatly reduce or eliminate the need for long-term controls.
- **Source Area Groundwater-related RAOs.** Alternatives 1 and 2 rely on attenuation—which has a longer restoration time frame than active treatment—and controls to address Source Area groundwater. Alternative 3, which uses EAnB, and Alternatives 4 through 7, which use ISCR to treat Source Area groundwater, will reduce the restoration time frame and the potential need for vapor controls. ISCR and EAnB are expected to have similar level of effectiveness at achieving RAOs in this area. Alternative 8 may have a slightly lower effectiveness because ISCO requires direct contact between the oxidant and the contaminant, which may be limited by the heterogeneous shallow soils. Inadequate contact can result in contaminant concentration rebound when treatment stops. Alternative 9, which has the highest degree of removal and treatment, is expected to have the highest long-term effectiveness in this area.
- **Downgradient Groundwater-related RAOs.**
  - Alternative 1 relies on attenuation and has the longest restoration time frame for cVOCs. This alternative also has the highest potential need for implementing contingency actions, if concentrations approaching the Waterway do not decline within a reasonable time frame.
  - Alternatives 2, 3, 4, and 8 include treatment at South Fidalgo Street, which reduces the restoration time frame and the potential need for contingency actions. Alternative 3 uses EAnB, while Alternatives 2, 4, and 8 utilize ISCR. ISCR, which provides chemical reduction of TCE,

DCE, and VC, is considered potentially more effective at reducing VC concentrations downgradient of the treatment area (which can be generated through application of EAnB if complete reductive dechlorination is not achieved). Therefore, Alternatives 2, 4, and 8 are considered to have slightly higher long-term effectiveness than Alternative 3 for these RAOs.

- Alternative 5 includes treatment along the shoreline, which significantly reduces the time frame to achieve surface water CULs at the Waterway and the potential need for contingency actions. However, operating a sparge curtain for 40 years is expected to have significant maintenance challenges, and there is some uncertainty in its long-term effectiveness for this period.
- Alternatives 6 and 7 reduce the time to achieve surface water CULs at the Waterway compared to Alternatives 2, 3, 4, and 8, and are considered to have slightly higher long-term effectiveness.
- Alternative 9 provides the most extensive active treatment and, correspondingly, the fastest restoration time frame, and is considered to have the greatest long-term effectiveness for these RAOs.

One of the factors considered for long-term effectiveness is the potential need for implementing contingency actions. Contingency actions are generally more likely to be needed for alternatives that rely on natural attenuation to address a particular RAO; in SU1, the most likely RAOs that may warrant triggering of a contingency action are achievement of VI-based CULs in shallow groundwater and achievement of surface water-based CULs at the Waterway. Alternative 1 relies on MNA for both of these RAOs, and is considered the most likely to require contingency actions. Alternative 2 relies on MNA[43] to achieve VI-based RAOs, and relies on natural attenuation of VC in the CG-140-40 area to achieve surface water-based RAOs, but includes treatment of TCE upgradient of the Waterway at South Fidalgo Street, and is considered somewhat less likely to require contingency actions. Alternatives 3, 4, and 8 include Source Area treatment to achieve VI-based RAOs, and is considered further less likely to require contingency actions. Alternatives 6 and 7 include additional active treatment of TCE upgradient of South Fidalgo Street and of VC in the CG-140-40 area, and are considered unlikely to require contingency actions. Alternatives 5 and 9, which include Source Area treatment and treatment adjacent to the Waterway, are the least likely to require contingency actions.

Alternatives were rated as follows:

- Alternative 1, which applies active treatment technologies to a more limited extent in the Source Area, would rely more on long-term engineering and institutional controls, including a greater potential for ongoing vapor assessment and/or mitigation at properties immediately downgradient of the ABP Facility. Alternative 1 also applies MNA to the Downgradient TCE Plume, which involves more uncertainty that protectiveness will be maintained until monitoring

[43] Source Area treatment of cVOCs via AS/SVE has already been completed as an interim action.

demonstrates the plume is shrinking, and has the longest time frame (55 years) to achieve surface water CULs at the Waterway. This Alternative was rated low (3).

- Alternative 2, which applies active treatment technologies to the Downgradient TCE Plume, reduces uncertainty that protectiveness will be maintained until monitoring demonstrates the plume is shrinking, and slightly reduces the time frame to achieve surface water CULs at the Waterway. This Alternative was rated moderate (4), slightly higher than Alternative 1.
- Alternatives 3, 4, and 8 address contamination using different combinations of technologies, but are expected to have similar restoration time frames and reliability of controls. Alternative 4, which utilizes ISCR in both the Source Area and the Downgradient TCE Plume, is expected to have a slightly higher effectiveness compared to Alternative 3 (which uses EAnB in both areas) and Alternative 8 (which uses ISCO in the Source Area). Alternatives 3 and 8 were rated moderate (5), slightly higher than Alternative 2, because source treatment is expected to reduce the degree that controls are required in the Source Area. Alternative 4 was also rated moderate (6), slightly higher than Alternatives 3 and 8.
- Alternative 5 addresses contamination similar to Alternatives 3 and 4, but includes treatment along the Waterway, which significantly reduces the time frame to achieve surface water CULs at the Waterway. This alternative was rated high (7).
- Alternatives 6 and 7 include additional treatment, compared to Alternative 4, of the Downgradient TCE Plume, and reduces the time frame to achieve surface water CULs at the Waterway. This alternative was also rated high (7).
- Alternative 9 includes more aggressive treatment of Source Area soil through removal and *in-situ* solidification, and would rely less on long-term engineering and institutional controls than on other alternatives. This alternative was rated high (8).

8.4.4 Short-Term Risk Management

For all alternatives, the short-term risks to workers and the public can generally be managed using appropriate BMPs. Alternative 1 involves limited activities and handling of low toxicity pH buffer materials (e.g., sodium bicarbonate) and was rated very high (9). Alternatives 2 through 7 also involve handling of relatively low toxicity materials (EAnB or ISCR amendments) and low-risk construction activities (well drilling, amendment injection), and are rated high (8) for short-term risk management. Implementation of Alternative 8 involves mixing and injection of a strong oxidizer (potassium permanganate) that presents a hazard in the event of spills, so this alternative was given a rating of 6. Alternative 6 involves the greatest short-term risks (e.g., worker safety concerns, dust and erosion control) due to removal of contaminated soils in the Source Area and was rated somewhat lower (5).

8.4.5 Implementability

Alternatives 1 through 8 target areas that are considered relatively accessible[44] 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. Alternatives 1 through 8 were differentiated and rated as follows:

- Alternative 1 is considered the easiest to implement as it includes Source Area treatment in areas that have previously been accessed and treated via AS/SVE. This alternative was rated high (8).
- Alternative 2 involves the same Source Area treatment as Alternative 1 and also includes activities in a non-arterial ROW (South Fidalgo Street) that has previously been accessed during investigations. ISCR in South Fidalgo Street is anticipated to result in localized impacts to groundwater geochemistry (e.g., elevated pH, dissolved iron), which may limit how close to the Waterway it can be implemented.[45] This Alternative was also rated high, slightly lower than Alternative 1 due to potential geochemical impacts (7).
- Alternatives 3 and 4 also include ISCR or EAnB (which also would result in potential geochemical impacts to groundwater) in South Fidalgo Street. These alternatives also require additional work for cVOC treatment within active operational areas of the ABP Facility, compared to Alternative 2, and were given ratings of 6.
- Alternative 5 would pose additional implementability challenges compared to Alternatives 3 and 4 because of the need to install a sparge curtain on private property and operate/maintain the system for a relatively long period of time (45 years). Maintenance of a sparging system for this long, particularly in a reducing environment, is expected to result in maintenance difficulties due to iron fouling. This alternative was given a rating of moderate (4).
- Alternatives 6 and 7 would pose additional implementability challenges compared to Alternatives 3 and 4 because of the need to provide active treatment within arterial ROWs with significant utility and traffic control restrictions. These alternatives were also rated moderate (4).
- Alternative 8 would have similar implementability challenges as Alternatives 2 through 4, but would also require administrative approval for treatment and reinjection of contaminated groundwater as part of the ISCO recirculation program. The recirculation system can also provide technical challenges associated with maintaining the groundwater treatment system and preventing

[44] Alternatives 1 through 4 involve drilling on the ABP Property and on street ROWs, which are commonly allowed under street-use permits.
[45] Geochemical impacts and injection locations would be assessed during design, which would likely include bench or pilot testing.

plugging of reinjection wells or trenches. Therefore, Alternative 5 was rated moderate (5).

- Alternative 9 involves substantial implementability challenges, including: 1) excavation and *in-situ* solidification beneath ABP Facility, which would require temporary shutdown or moving of operations; 2) excavation and *in-situ* solidification adjacent to multiple utilities in the street ROWs; and 3) negotiating access agreements with multiple property owners for injecting on downgradient properties. Alternative 6 was rated low (2) because of these technical, logistical, and administrative complexities.

8.4.6 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; and 4) be reluctant to allow free access to private property for implementation of remediation and monitoring. Based on these expectations, alternatives were rated as follows:

- Alternative 1 was rated low (3) due to its reliance on attenuation and long restoration time frame for groundwater discharging to the Waterway.
- Alternatives 2 was rated moderate (4), slightly higher than Alternative 1, due to its treatment near the Waterway.
- Alternatives 3, 4, 6, 7, and 8 were rated moderate (5), slightly higher than Alternative 2, due to more active treatment in the Source Area and reduced reliance on controls.
- Alternative 5 was also rated moderate (6), slightly higher than Alternatives 3 and 4, due to its shorter restoration time frame for groundwater discharging to the Waterway.
- Alternative 9 was rated low (3), due to its potential disruption of the ROWs and extensive requirements for access to private property.

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

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

The MTCA benefits rankings, estimated costs, and benefit/cost ratios for the four remedial alternatives are presented at the bottom of Table 8-1 and graphically on Figure 9-1. 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 range from a low of 4.8 for Alternative 1 to a high of 6.9 for Alternative 9.

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 1 has the highest benefit/cost ratio, at 1.7 (Table 8-1).

8.4.8 Disproportionate Cost Analysis Conclusion

Based on the results of the DCA presented above, Alternative 1 is the most cost effective of the seven remedial alternatives evaluated in this FS. Therefore, this alternative is deemed to satisfy the MTCA requirement for an alternative to be permanent to the maximum extent practicable.

8.5 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; and
- Effectiveness, cost, reliability, restoration time frame, and protectiveness of FS alternatives.

For example, FS-level cost estimates are generally prepared to a target accuracy of +50/-30 percent, reflecting uncertainties in Site characterization (e.g., over what area a technology needs to be applied), effort needed to achieve desired treatment efficiencies (e.g., number of wells or injection points, quantities of amendments), and time required for treatment and monitoring until RAOs are achieved. The effectiveness of remedial technologies, particular *in-situ* treatment technologies that are incorporated into all of the remedial alternatives, is highly dependent on specific application and Site conditions, and can only be approximately estimated at the FS stage of a project. Sensitivity analyses for groundwater modeling show that restoration time frames are sensitive to factors, such as biodegradation rate and groundwater flow rate, which are difficult to accurately measure and are often highly variable across the affected area. Many uncertainties can be significantly reduced (although never completely eliminated) during remedy design by collecting additional data specific to the selected cleanup action, which may include bench- or pilot-testing to confirm or revise assumptions made in the FS.

Although there are uncertainties in future land use and exposure pathways, these are addressed through ongoing monitoring of remedy protectiveness. If monitoring indicates that ongoing or completed cleanup actions may not be sufficiently protective, all alternatives provide for the consideration of contingency actions to be implemented to ensure remedy protectiveness. Therefore, most uncertainties are ultimately reflected in the total remedy cost and/or time required to achieve RAOs.

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 discussed above is less critical when evaluating alternatives on a relative basis. Although specific metrics, such as cost, restoration time frame, and treatment effectiveness may vary from the estimates provided in the FS, it is likely that key conclusions reached are still valid, since inaccuracies in assumptions often apply to a greater or lesser extent to all alternatives. Some alternatives have greater uncertainty, particularly those employing technologies for which effectiveness is highly Site dependent. These uncertainties are typically addressed by applying conservativism to the analysis (e.g., identifying remediation levels based on conservative modeling assumptions, or applying larger cost contingencies for technologies of higher uncertainty).

9 Conclusions and Recommendations

Nine remedial alternatives that provide a range of treatment options for metals and cVOC contamination in SU1 were developed and evaluated. All alternatives meet MTCA Threshold Requirements, including protection of human health and the environment. Additionally, the interim actions to date have substantially reduced cVOC concentrations in the Source Area.

Alternative 1 is the recommended cleanup action for SU1 based on the analysis and considerations presented in this Feasibility Study. Alternative 1 (pH/MNA/MNA) has the highest benefit-to-cost ratio, and is deemed to satisfy the MTCA requirement to be permanent the maximum extent practicable. This alternative is protective of human health and the environment, and is significantly less expensive than other alternatives, while achieving a restoration time frame that is marginally longer than most alternatives and only moderately longer than the most aggressive alternative (Alternative 9). Important components of this alternative include the structured implementation of a groundwater monitoring program and negotiated criteria for triggering contingency actions. Expansion of active remediation via the implementation of specific contingency actions should be based on empirical groundwater quality trends, as opposed to predictive modeling results. We recommend development of data-driven contingency action triggers and review schedule as elements of the DCAP. This approach ensures protection of human health and the environment, while implementing the most practicable remedy.

Because of its reliance on MNA, Alternative 1 has the greatest chance of needing contingency actions. Possible contingency actions include active treatment along the shoreline to protect Waterway receptors, and active treatment of cVOCs in the Source Area to reduce the time to achieve cleanup levels protective of the vapor pathway. These actions are similar to active treatment measures included in other alternatives. However, even if these contingency actions are implemented, Alternative 1 would be less expensive (on a net present-value basis) than the next-most-costly alternative (Alternative 2).

The conceptual implementation of Alternative 1 is discussed in Section 7.3.1. As discussed in Section 8.5, although the information provided in this FS is adequate to evaluate alternatives on a relative basis, there are a number of uncertainties regarding implementation of this alternative that still need to be addressed. It is anticipated that a phased, adaptive design and implementation process will be appropriate. This may involve bench-, pilot-, or limited-scale application and testing of potential amendments and distribution techniques prior to full-scale construction and operation. Groundwater 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. As discussed above, there is some uncertainty in estimated restoration time frames due to modeling assumptions that simplify a complex system. Monitoring data will be used to confirm or revise model predictions of restoration time frame and determine if contingency actions are appropriate.

10 References

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11 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 5-1 - Preliminary Cleanup Levels

Project No. 050067

West of 4th, Site Unit 1, Seattle, Washington

		Preliminary Cleanup Levels													
		Soil					Groundwater				Air		Surface Water		Sediment
Constituent of Concern	Carcinogen or Non-Carcinogen	Puget Sound Background Concentrations for Metals[1]	Soil Cleanup Level Protective of Direct Contact Pathway (Unrestricted Land Use)[2]	Soil Cleanup Level Protective of Direct Contact Pathway (Industrial Land Use)[2]	Soil Cleanup Level Protective of Air Quality based on Protection of Groundwater as Potable Drinking Water[3]	Soil Cleanup Level Protective of Groundwater Concentrations Protective of Surface Water Quality[4]	Groundwater Cleanup Level Protective of Air Quality Water Table Zone (Unrestricted Land Use)[5]	Groundwater Cleanup Level Protective of Air Quality Water Table Zone (Industrial Land Use)[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)[2]	Air Cleanup Level Protective of Inhalation Pathway (Industrial Land Use)[2]	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	--	476	21,000	0.08	0.44	116	482	29	36,000	9.6	40	29	--	190
Trichloroethene	Carcinogen	--	12	1,750	0.03	0.057	6.9	37	7	4,760,000	0.37	2	7	194 [12]	8,950
cis-1,2-Dichloroethene	Non-Carcinogen	--	160	7,000	--	--	--	--	--	--	--	--	--	--	--
trans-1,2-Dichloroethene	Non-Carcinogen	--	1,600	70,000	0.59	62	559	1,224	4,000	--	27.4	60	4,000	--	--
1,1-Dichloroethene	Non-Carcinogen	--	4,000	175,000	0.055	0.025	538	1,176	3.2	--	91.4	200	3.2	--	--
Vinyl chloride	Carcinogen	--	0.67	87.5	0.002	0.010	1.3	12.7	1.6	543,000	0.28	2.8	1.6	210 [13]	202
1,4-Dioxane	Carcinogen	--	10	1,310	0.004	0.32	2,551	25,510	78	--	0.5	5	78	--	--
Arsenic	Carcinogen	20	20	87.5	Not Applicable	0.082	Not Applicable	Not Applicable	0.14 / 5 [10]	241	Not Applicable	Not Applicable	0.14 / 5 [10]	36 [14]	7
Barium	Non-Carcinogen	--	16,000	700,000	Not Applicable	824	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	--	--	--
Cadmium	Non-Carcinogen	1	80	3,500	Not Applicable	1.2	Not Applicable	Not Applicable	8.8	760	Not Applicable	Not Applicable	--	8.8 [15]	5.1
Copper	Non-Carcinogen	36	3,200	140,000	Not Applicable	1.1	Not Applicable	Not Applicable	3.1 [11]	18,000	Not Applicable	Not Applicable	--	3.1 [15]	390
Iron	Non-Carcinogen	58,700	58,700	2,450,000	Not Applicable	--	Not Applicable	Not Applicable	--	--	Not Applicable	Not Applicable	1,000	--	--
Manganese	Non-Carcinogen	1,200	11,200	490,000	Not Applicable	--	Not Applicable	Not Applicable	100	--	Not Applicable	Not Applicable	100	--	--
Nickel	Non-Carcinogen	48	1,600	70,000	Not Applicable	11	Not Applicable	Not Applicable	8.2	2,200	Not Applicable	Not Applicable	4,600	8.2 [15]	15.9
Zinc	Non-Carcinogen	85	24,000	1,050,000	Not Applicable	101	Not Applicable	Not Applicable	81	6,600	Not Applicable	Not Applicable	26,000	81 [15]	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] Backgound metals values from Ecology Publication No. 94-115, Natural Background Soil Metals Concentrations in Washington State. Arsenic background from MTCA, Table 740-1 Method A Soil Cleanup Levels for Unrestricted Land Uses.

[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] Soil 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 for unrestricted and industrial land uses.

[4] Soil cleanup levels for protection of surface water quality are calculated using MTCA Equation 747-1 where the groundwater cleanup level protective of surface water in this table was used as Cw.

[5] Groundwater cleanup levels protective of the air pathway for unrestricted land use (residential and commercial sites) and industrial land use were derived using the following equation: Gwcul = Aircul/GIVF.

[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. Koc and Kd values are from MTCA. Fraction of carbon assumed at 0.02 based on Lower Duwamish Waterway Feasibility Study (AECOM, 2012).

[8] The most stringent exposure pathway for human health receptors are for consumption of fish. Listed values are based on ARARs listed in CLARC with one exception. 1,4-dioxane is derived from MTCA Method B default values

[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 Sediment Managment Standards (WAC 173-204) either. EPA Region 3 BTAG Marine Sediment Ecological Screening Benchmarks (EPA 2006) have been listed for nickel, TCE and PCE. EPA Region 3 has no value listed for vinyl chloride therefore the older Region 5 benchmarks were used (EPA 2003).

[10] Arsenic Cleanup level of 5 ug/L based on background concentrations for state of Washington (MTCA Table 720-1)

[11] The surface water cleanup level for copper had previously been tabulated as 2.4ug/L; however this value is based on an approach using site-specific water effects ratio which has not been determined. We have replaced this with 3.1 ug/L, National Recommended Water Quality Criteria published by EPA under 304 of the Federal Clean Water Act - Aquatic Life Criteria Tab

[12] Oak Ridge Nation Laboratory (ORNL) Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota

[13] Peer Review Literature - DeRooij et al., 2004, *Euro Chlor Risk Assessment for the Marine Environment OSPARCOM Region – North Sea – Environmental Monitoring and Assessment*

[14] WAC- 173-201A-240

[15] 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 and 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).

Table 7-1 - Assembly of Technologies into Remedial Alternatives

Project No. 050067

West of 4th, Site Unit 1, Seattle, Washington

Area of Concern[1]	General Response Actions	Remedial Technologies[2]	Contaminants Addressed	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9
				Source pH neutralization, Monitored Natural Attenuation	**Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)**	**Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)**	**Source Excavation+ISS, Downgradient ISCR (Areal Coverage)**
SU1 Source Area	Mitigation	Capping	cVOCs and Metals	X	X	X	X	X	X	X	X	X
		Institutional Controls		X	X	X	X	X	X	X	X	X
		Subslab and Submembrane Depressurization	cVOCs	X	X	X	X	X	X	X	X	X
	In Situ Treatment	Monitored Natural Attenuation	cVOCs and Metals	X	X	X	X	X	X	X	X	X
		In-Situ Chemical Reduction		--	--	--	X	X	X	X	--	--
		Enhanced Anaerobic Biodegradation[3]	cVOCs	--	--	X	--	--	--	--	--	--
		In-Situ Chemical Oxidation		--	--	--	--	--	--	--	X	--
		Solidification/Stabilization	Metals	--	--	--	--	--	--	--	--	X
		pH Buffering/Neutralization		X	X	X	X	X	X	X	--	--
	Ex Situ Technologies	Groundwater Pump-and-Treat[4]	cVOCs and Metals	--	--	--	--	--	--	--	X	--
		Excavation & Off-Site Disposal		--	--	--	--	--	--	--	--	X
Downgradient TCE Plumes	Mitigation	Institutional Controls	cVOCs	X	X	X	X	X	X	X	X	X
	In Situ Treatment	Monitored Natural Attenuation	cVOCs	X	X	X	X	X	X	X	X	X
		In-Situ Chemical Reduction		--	X	--	X	--	X	X	X	X
		Enhanced Anaerobic Biodegradation[3]		--	--	X	--	X	--	--	--	--
		Sparge Curtain[5]		--	--	--	--	X	--	--	--	--
Vinyl Chloride Plumes Outside the Above Areas	Mitigation	Institutional Controls	Vinyl Chloride	X	X	X	X	X	X	X	X	X
	In Situ Treatment	Monitored Natural Attenuation	Vinyl Chloride	X	X	X	X	X	X	X	X	X
Potential Contingency Actions	*In Situ* Treatment	Enhanced Anaerobic Biodegradation[3]	cVOCs	--	--	--	--	--	--	--	--	--
		In-Situ Chemical Reduction		Source Area	Source Area	--	--	--	--	--	--	--
		Sparge Curtain[5]		Waterway	Waterway	Waterway	Waterway	--	Waterway	Waterway	Waterway	--
		pH Buffering/Neutralization	Metals	--	--	--	--	--	--	--	--	--
		Enhanced Aerobic Biodegradation	Vinyl Chloride	--	--	--	--	--	--	--	--	--

Notes:

1) The areas of concern called out in this column are depicted on Figures 5-1 through 5-3.

2) Precipitation/immobilization of metals is a retained remedial technology that is not called out separately in this table. However, it can be achieved through pH buffering/neutralization and/or in-situ chemical reduction.

3) Application of this technology may include bioaugmentation.

4) Application of this technology may include slurry/cutoff walls.

5) Sparge curtain is not called out in Section 6 as a retained remedial technology, but it is a specific application of air sparging (a retained technology).

Definitions:

ISCR = In Situ Chemical Reduction

EAnB = Enhanced Anaerobic Biodegredation

ISCO = In Situ Chemical Oxidation

PRB = Permeable Reactive Barrier

ISS = In Situ Stablization

Shaded cells indicate new alternative or element

-- Dashes indicate the action is not included in the alternative except as a possible contingency action, to be evaluated in the event that additional measures are necessary to control plume migration.

Table 7-2 - Remediation Levels for cVOCs by Location

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

	Remediation Level in µg/L		
Location	**TCE**	**DCE**	**VC**
ABP Facility	1,380	1,620	162
Second Avenue	430	68	7
First Avenue	90	10	2
E Marginal Way S	30	4	2
S Fidalgo Street	4	5	1.6
Surface Water CUL	*7*	*4,000*	*1.6*

Note:
Remediation Levels derived using BIOCHOLOR modeling and are non-unique solutions for combinations of TCE, DCE, and VC. Remediation levels can be less than cleanup levels due to conversion of TCE or DCE to VC. Refer to Appendix C for details.

Table 7-3 - Summary of How the Remedial Alternatives Address the RAOs

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

Area of Concern[1]	Media	Remedial Action Objectives for Site Unit 1[2]	Alternative 1 Source pH neutralization, Monitored Natural Attenuation	Alternative 2 Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)	Alternative 3 Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)	Alternative 4 Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)	Alternative 5 Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)	Alternative 6 Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)	Alternative 7 Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)	Alternative 8 Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)	Alternative 9 Source Excavation+ISS, Downgradient ISCR (Areal Coverage)
SU1 Source Area	Soil	**SU1 RAO-1A** - Reduce concentrations of COCs in soil to meet Model Toxics Control Act (MTCA) Method B direct contact PCULs at the standard point of compliance (i.e., throughout SU1) within a reasonable time; or	MNA	MNA	EAnB until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCO until VI CULs for cVOC COCs are achieved in groundwater; then MNA	Excavate cVOC COCs that exceed CULs above the water table; ISS below water table
		SU1 RAO-1B - Use engineering controls to protect receptors from directly contacting soils with concentrations of COCs exceeding direct contact PCULs.									
		SU1 RAO-2A - Reduce or immobilize concentrations of COCs in soil such that MTCA Method B groundwater cleanup levels are achieved at the standard point of compliance within a reasonable time.	MNA	MNA	EAnB until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCO until VI CULs for cVOC COCs are achieved in groundwater; then MNA	Excavate cVOC COCs that exceed CULs in soil above the water table; ISS below water table; then MNA
		SU1 RAO-2B - Reduce or immobilize concentrations of COCs in soil such that MTCA Method B cleanup levels are achieved in groundwater approaching the Waterway (to protect Waterway receptors).	pH adjustment until pH neutral, then MNA	pH adjustment until pH neutral, then MNA	pH adjustment until pH neutral, then MNA	pH adjustment until pH neutral, ISCR until cVOCs achieve SU1 RAO6; then MNA	pH adjustment until pH neutral, ISCR until cVOCs achieve SU1 RAO6; then MNA	pH adjustment until pH neutral, ISCR until cVOCs achieve SU1 RAO6; then MNA	pH adjustment until pH neutral, ISCR until cVOCs achieve SU1 RAO6; then MNA	pH adjustment until pH neutral, ISCO until cVOCs achieve SU1 RAO6; then MNA	Excavation and ISS of accessible metals-contaminated soil; then MNA
		SU1 RAO-3A - Reduce concentrations of COCs in soil to meet MTCA Method B cleanup levels protective of indoor and outdoor air quality; or	MNA	MNA	EAnB until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCO until VI CULs for cVOC COCs are achieved in groundwater; then MNA	Excavate cVOC COCs that exceed CULs above the water table; ISS below water table; then MNA
		SU1 RAO-3B - Use engineering controls to protect receptors.[4]	Capping for direct contact protection; SSDS/SMDS for VI protection until SU1 RAO-3A achieved								
	Groundwater	**SU1 RAO-4A** - Reduce COC concentrations in groundwater to achieve MTCA Method B groundwater cleanup levels at the standard point of compliance within a reasonable restoration time frame.	MNA	MNA	EAnB until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCR until VI CULs for cVOC COCs are achieved in groundwater; then MNA	ISCO until VI CULs for cVOC COCs are achieved in groundwater; then MNA	Excavate cVOC COCs that exceed CULs above the water table; ISS below water table; then MNA
		SU1 RAO-4B - Protect waterway receptors by achieving MTCA Method B groundwater cleanup levels for all COCs in groundwater approaching the Waterway.	Monitoring, with contingency actions if warranted								
		SU1 RAO-5A - Reduce cVOC concentrations in Water Table Interval groundwater to meet MTCA Method B VI-based groundwater PCULs at the standard point of compliance.	MNA	MNA	EAnB	ISCR	ISCR	ISCR	ISCR	ISCO	Excavate cVOC COCs that exceed CULs above the water table; ISS below water table, MNA
		SU1 RAO-5B - Apply engineered controls to protect receptors until VI-based MTCA Method B PCULs are attained.[4]	SSDS/SMDS for VI protection								
	Air	**SU1 RAO-6** - Achieve MTCA Method B air cleanup levels.	MNA	MNA	EAnB	ISCR	ISCR	ISCR	ISCR	ISCO	Excavate cVOC COCs that exceed CULs above the water table; ISS below water table, MNA
	Surface Water /Sediment	**SU1 RAO-7A** - Reduce sediment pore water COC concentrations to achieve either natural background or MTCA Method B surface water criteria.									
		SU1 RAO-7B - Reduce or control groundwater COC concentrations to prevent sediment contamination.									

Table 7-3 - Summary of How the Remedial Alternatives Address the RAOs

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

Area of Concern[1]	Media	Remedial Action Objectives for Site Unit 1[2]	Alternative 1 Source pH neutralization, Monitored Natural Attenuation	Alternative 2 Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)	Alternative 3 Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)	Alternative 4 Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)	Alternative 5 Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)	Alternative 6 Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)	Alternative 7 Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)	Alternative 8 Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)	Alternative 9 Source Excavation+ISS, Downgradient ISCR (Areal Coverage)
Downgradient TCE Plumes	Soil	**SU1 RAO-1A** - Reduce concentrations of COCs in soil to meet Model Toxics Control Act (MTCA) Method B direct contact PCULs at the standard point of compliance (i.e., throughout SU1) within a reasonable time; or									
		SU1 RAO-1B - Use engineering controls to protect receptors from directly contacting soils with concentrations of COCs exceeding direct contact PCULs.									
		SU1 RAO-2A - Reduce or immobilize concentrations of COCs in soil such that MTCA Method B groundwater cleanup levels are achieved at the standard point of compliance within a reasonable time.	MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA
		SU1 RAO-2B - Reduce or immobilize concentrations of COCs in soil such that MTCA Method B cleanup levels are achieved in groundwater approaching the Waterway (to protect Waterway receptors).									
		SU1 RAO-3A - Reduce concentrations of COCs in soil to meet MTCA Method B cleanup levels protective of indoor and outdoor air quality; or									
		SU1 RAO-3B - Use engineering controls to protect receptors.[4]									
	Groundwater	**SU1 RAO-4A** - Reduce COC concentrations in groundwater to achieve MTCA Method B groundwater cleanup levels at the standard point of compliance within a reasonable restoration time frame.	MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA
		SU1 RAO-4B - Protect waterway receptors by achieving MTCA Method B groundwater cleanup levels for all COCs in groundwater approaching the Waterway.	Monitoring, with contingency actions if warranted				Sparge curtain until groundwater cleanup levels are achieved at Waterway.	Monitoring, with contingency actions if warranted			
		SU1 RAO-5A - Reduce cVOC concentrations in Water Table Interval groundwater to meet MTCA Method B VI-based groundwater PCULs at the standard point of compliance.	MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA
		SU1 RAO-5B - Apply engineered controls to protect receptors until VI-based MTCA Method B PCULs are attained.[4]	Monitoring, with mitigation if warranted.								
	Air	**SU1 RAO-6** - Achieve MTCA Method B air cleanup levels.					EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA				
	Surface Water /Sediment	**SU1 RAO-7A** - Reduce sediment pore water COC concentrations to achieve either natural background or MTCA Method B surface water criteria.	MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	EAnB until RLs for cVOC COCs are achieved in groundwater; then MNA. Sparge curtain until groundwater cleanup levels are achieved at Waterway.	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA	ISCR until RLs for cVOC COCs are achieved in groundwater; then MNA
		SU1 RAO-7B - Reduce or control groundwater COC concentrations to prevent sediment contamination.									

Table 7-3 - Summary of How the Remedial Alternatives Address the RAOs

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

<table>
<tr><th rowspan="2">Area of Concern[1]</th><th rowspan="2">Media</th><th rowspan="2">Remedial Action Objectives for Site Unit 1[2]</th><th>Alternative 1</th><th>Alternative 2</th><th>Alternative 3</th><th>Alternative 4</th><th>Alternative 5</th><th>Alternative 6</th><th>Alternative 7</th><th>Alternative 8</th><th>Alternative 9</th></tr>
<tr><th>Source pH neutralization, Monitored Natural Attenuation</th><th>Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)</th><th>Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)</th><th>Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)</th><th>Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)</th><th>Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)</th><th>Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)</th><th>Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)</th><th>Source Excavation+ISS, Downgradient ISCR (Areal Coverage)</th></tr>
<tr><td rowspan="15">Vinyl Chloride Plumes Outside the Above Areas</td><td rowspan="6">Soil</td><td>SU1 RAO-1A - Reduce concentrations of COCs in soil to meet Model Toxics Control Act (MTCA) Method B direct contact PCULs at the standard point of compliance (i.e., throughout SU1) within a reasonable time; or</td><td colspan="9" rowspan="6"></td></tr>
<tr><td>SU1 RAO-1B - Use engineering controls to protect receptors from directly contacting soils with concentrations of COCs exceeding direct contact PCULs.</td></tr>
<tr><td>SU1 RAO-2A - Reduce or immobilize concentrations of COCs in soil such that MTCA Method B groundwater cleanup levels are achieved at the standard point of compliance within a reasonable time.</td></tr>
<tr><td>SU1 RAO-2B - Reduce or immobilize concentrations of COCs in soil such that MTCA Method B cleanup levels are achieved in groundwater approaching the Waterway (to protect Waterway receptors).</td></tr>
<tr><td>SU1 RAO-3A - Reduce concentrations of COCs in soil to meet MTCA Method B cleanup levels protective of indoor and outdoor air quality; or</td></tr>
<tr><td>SU1 RAO-3B - Use engineering controls to protect receptors.[4]</td></tr>
<tr><td rowspan="4">Groundwater</td><td>SU1 RAO-4A - Reduce COC concentrations in groundwater to achieve MTCA Method B groundwater cleanup levels at the standard point of compliance within a reasonable restoration time frame.</td><td colspan="9">MNA[5]</td></tr>
<tr><td>SU1 RAO-4B - Protect waterway receptors by achieving MTCA Method B groundwater cleanup levels for all COCs in groundwater approaching the Waterway.</td><td colspan="4">MNA[5]</td><td>Sparge curtain until groundwater cleanup levels are achieved at Waterway.</td><td colspan="4">MNA[5]</td></tr>
<tr><td>SU1 RAO-5A - Reduce cVOC concentrations in Water Table Interval groundwater to meet MTCA Method B VI-based groundwater PCULs at the standard point of compliance.</td><td colspan="9">MNA[5]</td></tr>
<tr><td>SU1 RAO-5B - Apply engineered controls to protect receptors until VI-based MTCA Method B PCULs are attained.[4]</td><td colspan="9">Monitoring, with mitigation if warranted.</td></tr>
<tr><td>Air</td><td>SU1 RAO-6 - Achieve MTCA Method B air cleanup levels.</td><td colspan="9">MNA[5]</td></tr>
<tr><td rowspan="2">Surface Water /Sediment</td><td>SU1 RAO-7A - Reduce sediment pore water COC concentrations to achieve either natural background or MTCA Method B surface water criteria.</td><td colspan="4">MNA[5]</td><td>Sparge curtain until groundwater cleanup levels are achieved at Waterway.</td><td colspan="4">MNA[5]</td></tr>
<tr><td>SU1 RAO-7B - Reduce or control groundwater COC concentrations to prevent sediment contamination.</td><td colspan="4">MNA[5]</td><td>Sparge curtain until groundwater cleanup levels are achieved at Waterway.</td><td colspan="4">MNA[5]</td></tr>
</table>

Notes:
1) The areas of concern called out in this column are depicted on Figures 5-1 through 5-3.
2) Achieving the RAOs for Site Unit 1 will also achieve the general site-wide RAOs described in Section 5.1.
3) Gray-shading indicates that the RAO is not applicable to that Area of Concern.
4) Receptors are protected through the use of institutional controls as well as engineering controls.
5) Contingency actions will be considered if monitoring indicates that MNA may not be sufficiently protective or may not achieve desired concentration reductions in a reasonable restoration time frame.

Table 7-4 - Summary of Restoration Time Frames

Project No. 050067

West of 4th, Site Unit 1, Seattle, Washington

Alternative	Time to Meet Cleanup Levels in Years							Time to Meet Remediation Levels in Years			
	ABP Facility	2nd Ave	1st Ave	EMW	Fidalgo	Shoreline Wells	Waterway	1st Ave	EMW	Fidalgo	Shoreline Wells
1	15	25	40	40	50	55	55	20	35	45	50
2	15	25	40	40	50	50	50	20	35	45	45
3	10	20	30	40	50	50	50	15	35	45	45
4	10	20	30	40	50	50	50	15	35	45	45
5	10	20	30	40	50	35	35	15	35	45	40
6	10	20	30	40	40	40	40	15	35	35	40
7	10	20	30	40	40	35	35	15	30	35	35
8	10	20	30	40	50	50	50	15	35	45	45
9	<5	20	20	35	40	30	30	10	25	30	30

Table 8-1 - Disproportionate Cost Analysis and Comparison to MTCA Criteria

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

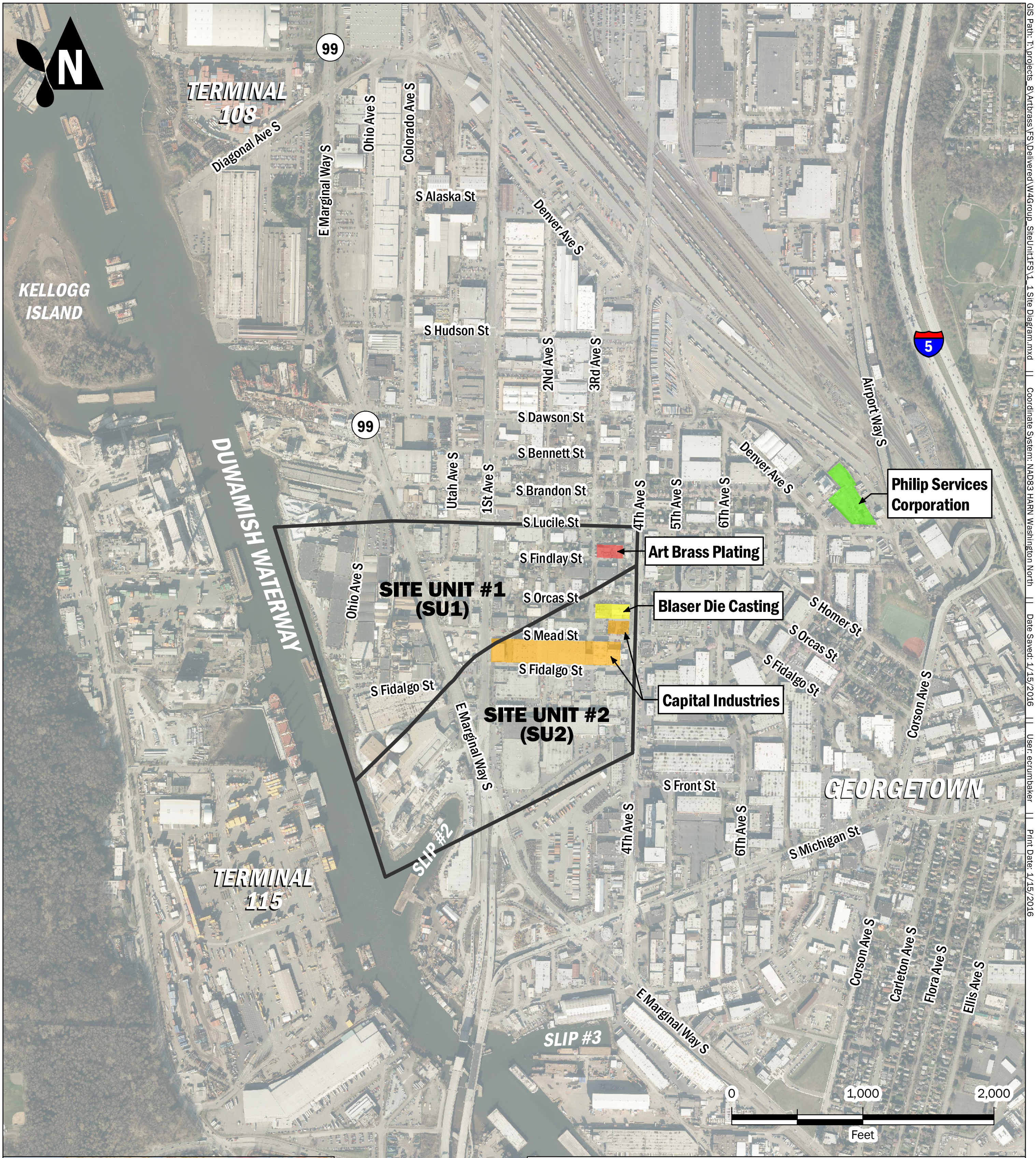
	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7	Alternative 8	Alternative 9
	Source pH neutralization, Monitored Natural Attenuation	**Source pH neutralization, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+EAnB, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient EAnB (PRB@Fidalgo)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo and EMW)**	**Source pH neutralization+ISCR, Downgradient ISCR (PRBs@Fidalgo, EMW, and 1st Ave)**	**Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB@Fidalgo)**	**Source Excavation+ISS, Downgradient ISCR (Areal Coverage)**
Threshold Criteria									
Protection of Human Health and the Environment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compliance with Cleanup Standards	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compliance with Applicable State and Federal Laws	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Provision for Compliance Monitoring	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Weighted Benefits Ranking for Disproportionate Cost Analysis (Score 1-10)									
Weighting Criteria									
30% Overall Protectiveness	4	5	6	6	8	7	7	6	9
20% Permanence	5	5	5	6	6	6	6	7	8
20% Long Term Effectiveness	3	4	5	6	7	7	7	5	8
10% Management of Short Term Risk	9	8	8	8	8	8	8	6	5
10% Implementability	8	7	6	6	4	4	4	5	2
10% Consideration of Public Concerns	3	4	5	5	6	5	5	5	3
MTCA Overall Benefit Score (1-10)	**4.8**	**5.2**	**5.7**	**6.1**	**6.8**	**6.4**	**6.4**	**5.8**	**6.9**
Disproportionate Cost Analysis									
Estimated Remedy Cost	$2,800,000	$4,600,000	$6,000,000	$5,200,000	$7,800,000	$8,000,000	$8,200,000	$6,800,000	$18,100,000
Estimated Remedy Cost	$1,000,000	$2,300,000	$3,700,000	$2,900,000	$3,000,000	$5,900,000	$6,100,000	$4,500,000	$16,300,000
Sparge Curtain Cost[1]	--	--	--	--	$2,500,000	--	--	--	--
Estimated Vapor Mitigation Cost	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$300,000	$200,000
Estimated Compliance Monitoring Cost[2]	$1,500,000	$2,000,000	$2,000,000	$2,000,000	$2,000,000	$1,800,000	$1,800,000	$2,000,000	$1,600,000
Relative Benefit to Cost Ratio (multiplied by 1,000,000)	1.7	1.1	1.0	1.2	0.9	0.8	0.8	0.9	0.4
Estimated Contingency Cost	$1,800,000	$1,800,000	$1,300,000	$1,300,000	$0	$1,300,000	$1,300,000	$1,300,000	$0
Evaluation of Restoration Time Frame									
Time to Achieve RAOs	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	>1000 Years	1000 Years
Estimated Time to Achieve VI CULs	25 Years	25 Years	20 Years	20 Years	20 Years	20 Years	20 Years	20 Years	20 Years
Estimated Time to Achieve cVOC SW CULs at Waterway	55 Years	50 Years	50 Years	50 Years	35 Years	40 Years	35 Years	50 Years	30 Years
Estimated Time to Achieve cVOC SW CULs	55 Years	50 Years	50 Years	50 Years	50 Years	40 Years	40 Years	50 Years	40 Years
Estimated Time to Achieve metals SW CULs	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	280 Years	>1000 Years	1000 Years
Provides for a Reasonable Restoration Time Frame	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

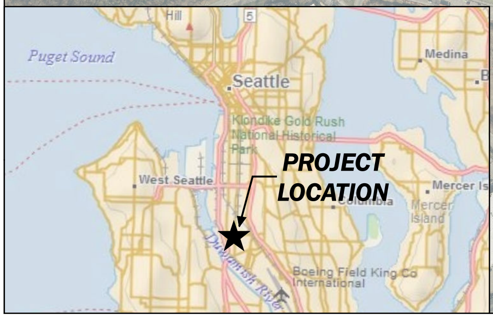
Notes:

Remedial Alternative cost details in Appendix E.

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

FIGURES





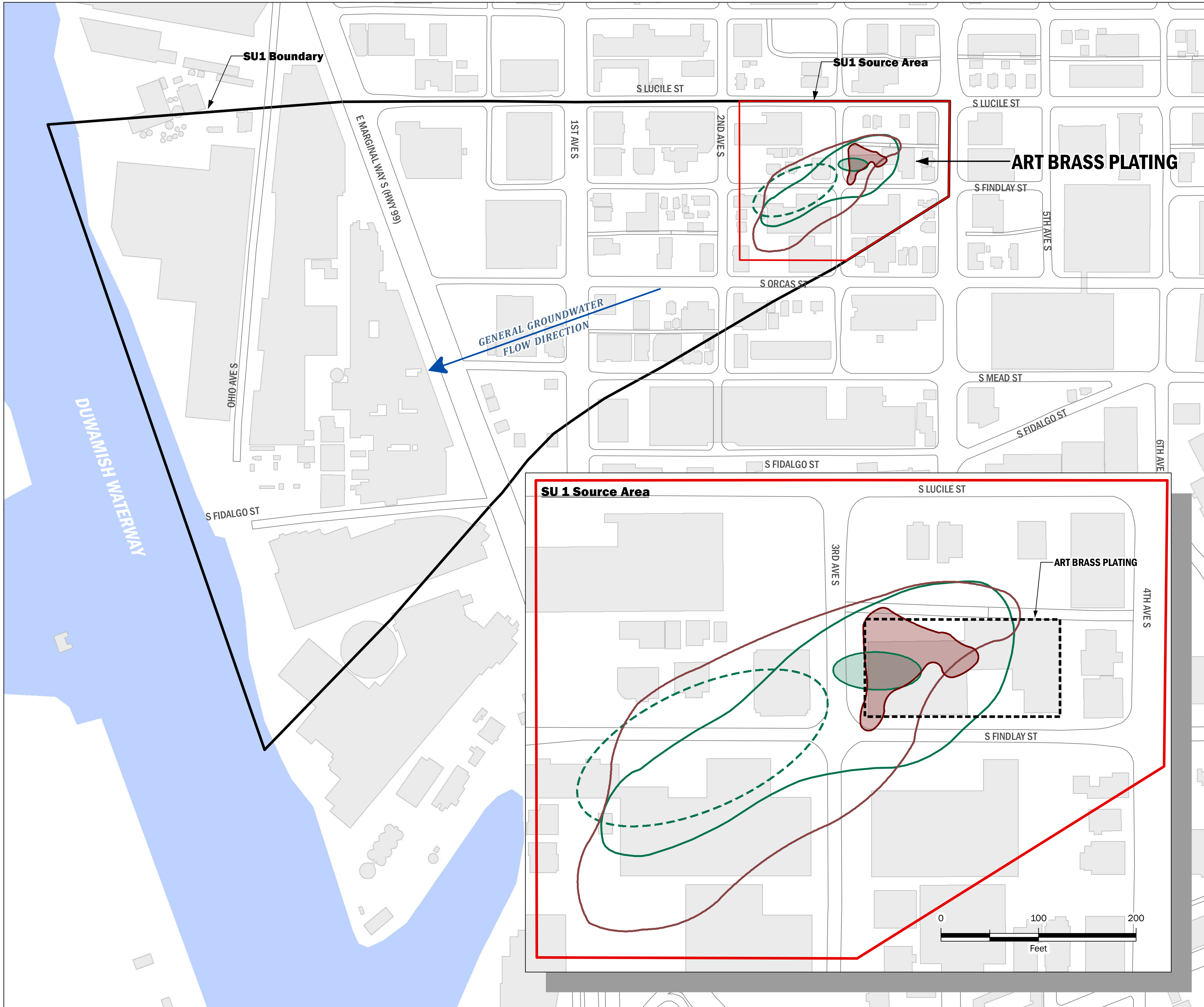
Site Diagram

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JAN-2016	BY: PPW	FIGURE: 1-1
PROJECT NO. 050067	REVISED BY: EAC	

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\1_1 Site Diagram.mxd || Coordinate System: NAD83 HARN Washington North || Date Saved: 1/15/2016 || User: ecrumbaker || Print Date: 1/15/2016



TCE Isoconcentration Line at 0.03 mg/kg Cleanup Level in Soil (for Protection of Air Quality)

Nickel Isoconcentration Line at 48 mg/kg Cleanup Level in Soil (for Protection of Surface Water)

TCE Isoconcentration Line at 6.9 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Water Table Groundwater (for Protection of Surface Water)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

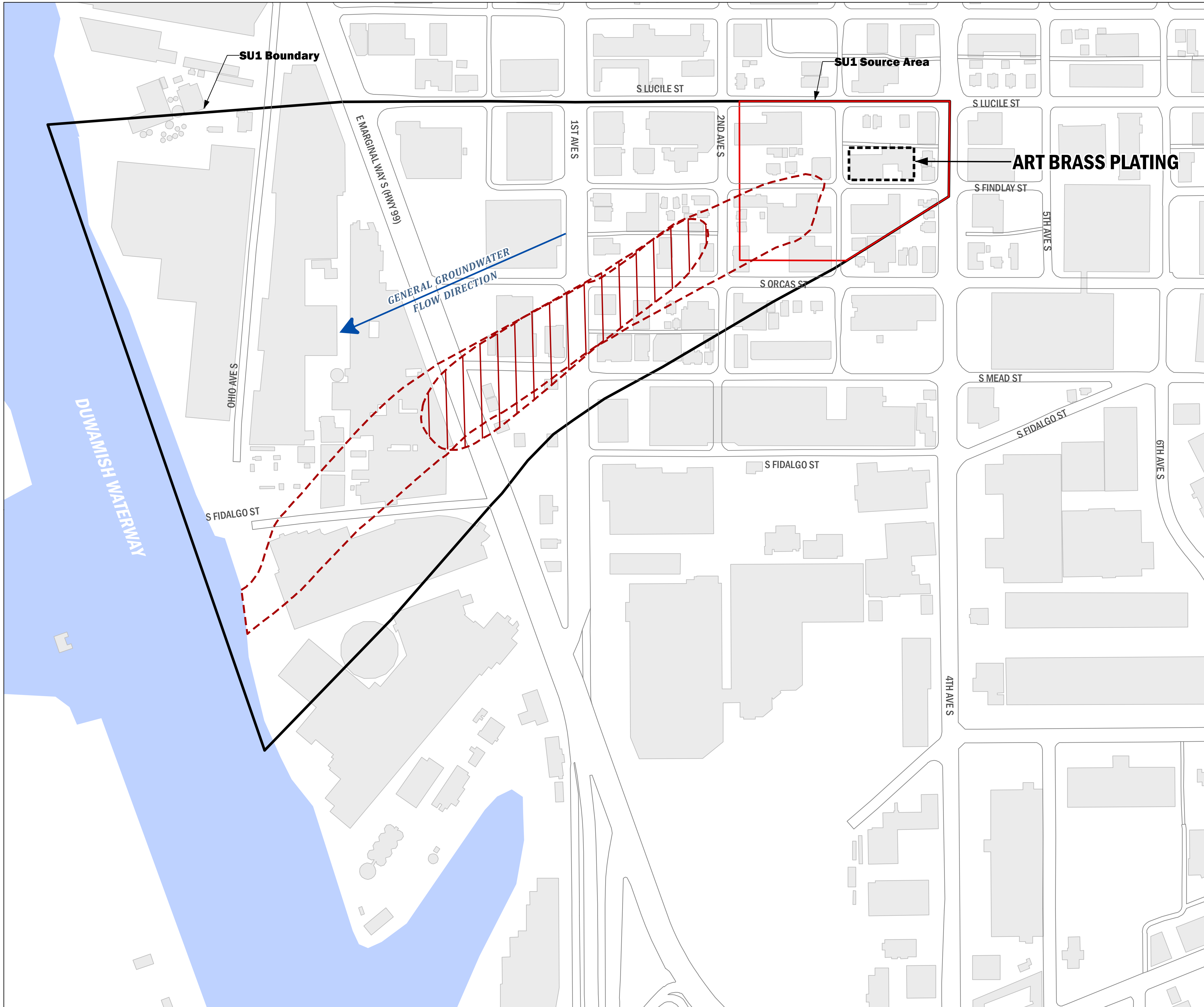
0 300 600
Feet

TCE and Nickel in Source Area Soil and Groundwater

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JAN-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	5-1

GIS Path: T:\projects_8\ArtBrass\FS\Delivered\W4Group_SiteUnit1FS\5_1 TCE and Nickel in Soil and GW.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/15/2016 || User: ecrumbaker || Print Date: 1/15/2016



TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

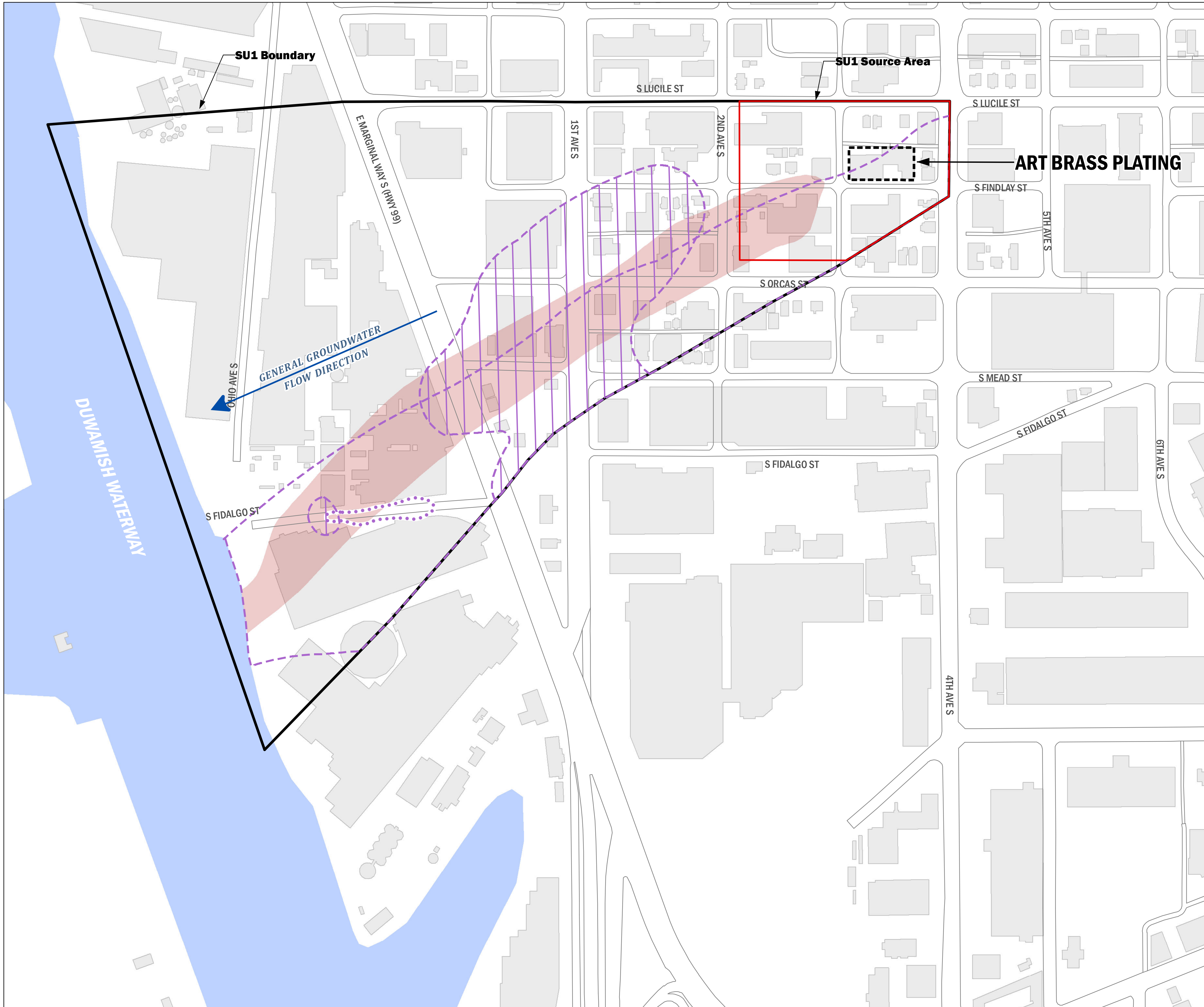
0 300 600
Feet

Downgradient TCE Plume in Shallow and Intermediate Groundwater

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JAN-2016	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REVISED BY: EAC	5-2



Vinyl Chloride Isoconcentration Line at 1.6 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Vinyl Chloride Isoconcentration Line at 1.6 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Vinyl Chloride Isoconcentration Line at 1.3 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Downgradient TCE Plumes (Refer to Figure 6.2)

Art Brass Plating Property Boundary (Approx.)

Vinyl Chloride Plumes
W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JAN-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	**5-3**

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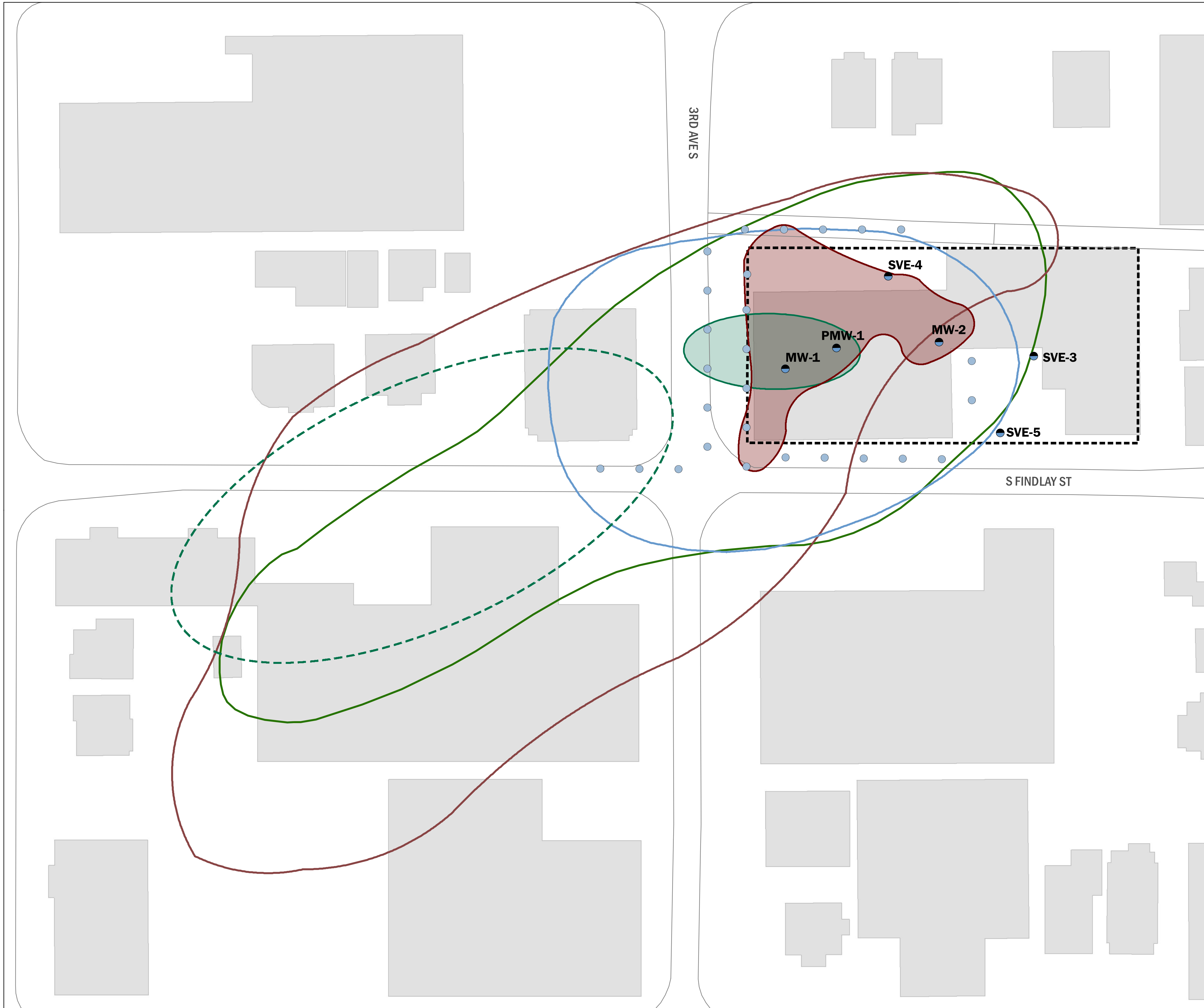


TCE Isoconcentration Line at 0.03 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Air Quality)

TCE Isoconcentration Line at 6.9 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Nickel Isoconcentration Line at 48 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Surface Water)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Water Table Groundwater (for Protection of Surface Water)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Water Table Groundwater pH < 6

Proposed pH Neutralization Solution Injection Well

Existing pH Neutralization Solution Injection Well

Art Brass Plating Property Boundary (Approx.)

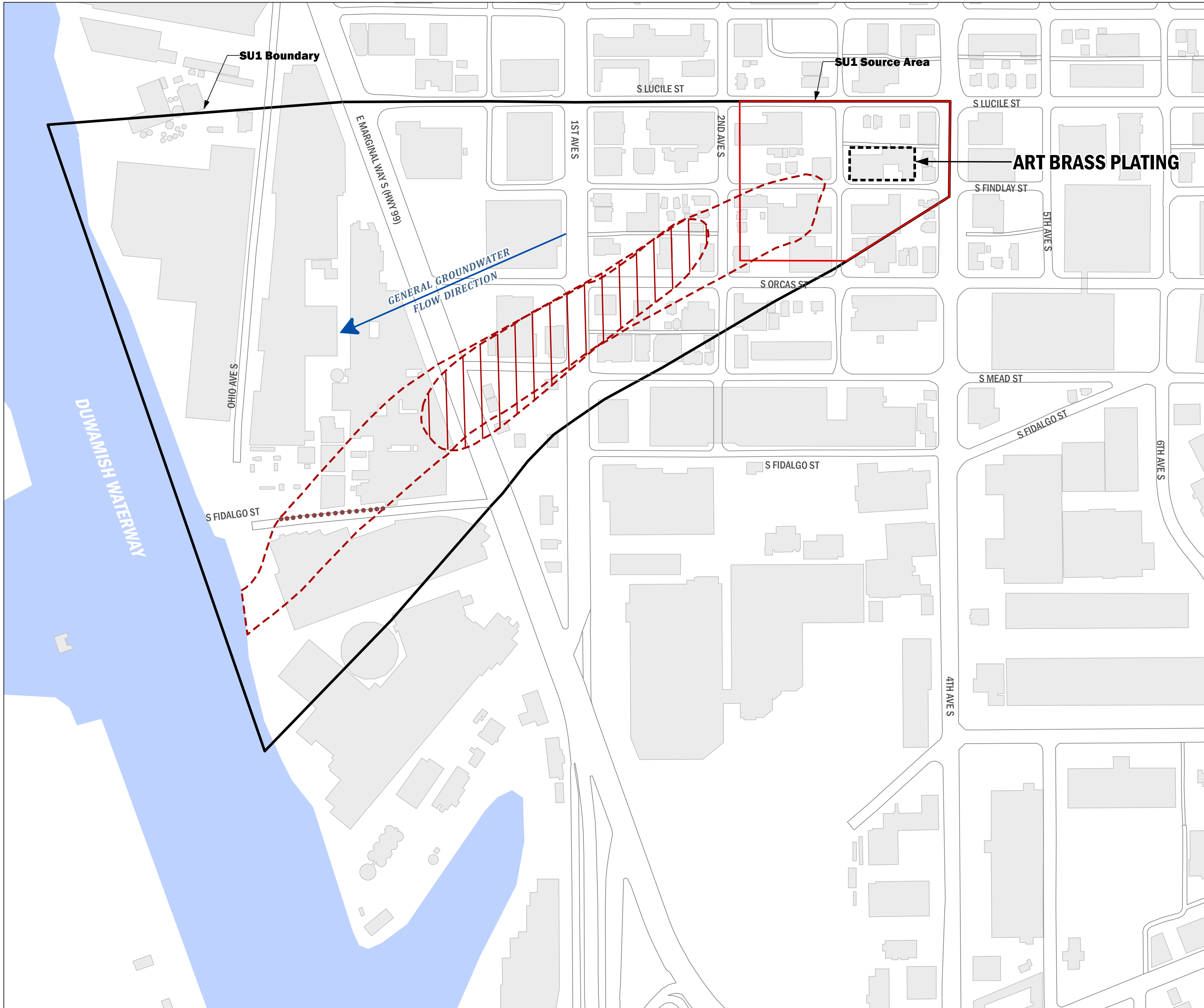
0 50 100
Feet

Remedial Design Concept in Source Area Alternatives 1 and 2

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	7-1

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_1 Alternative 1 and 2.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016



Permeable Reactive Barrier

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

0 300 600
Feet

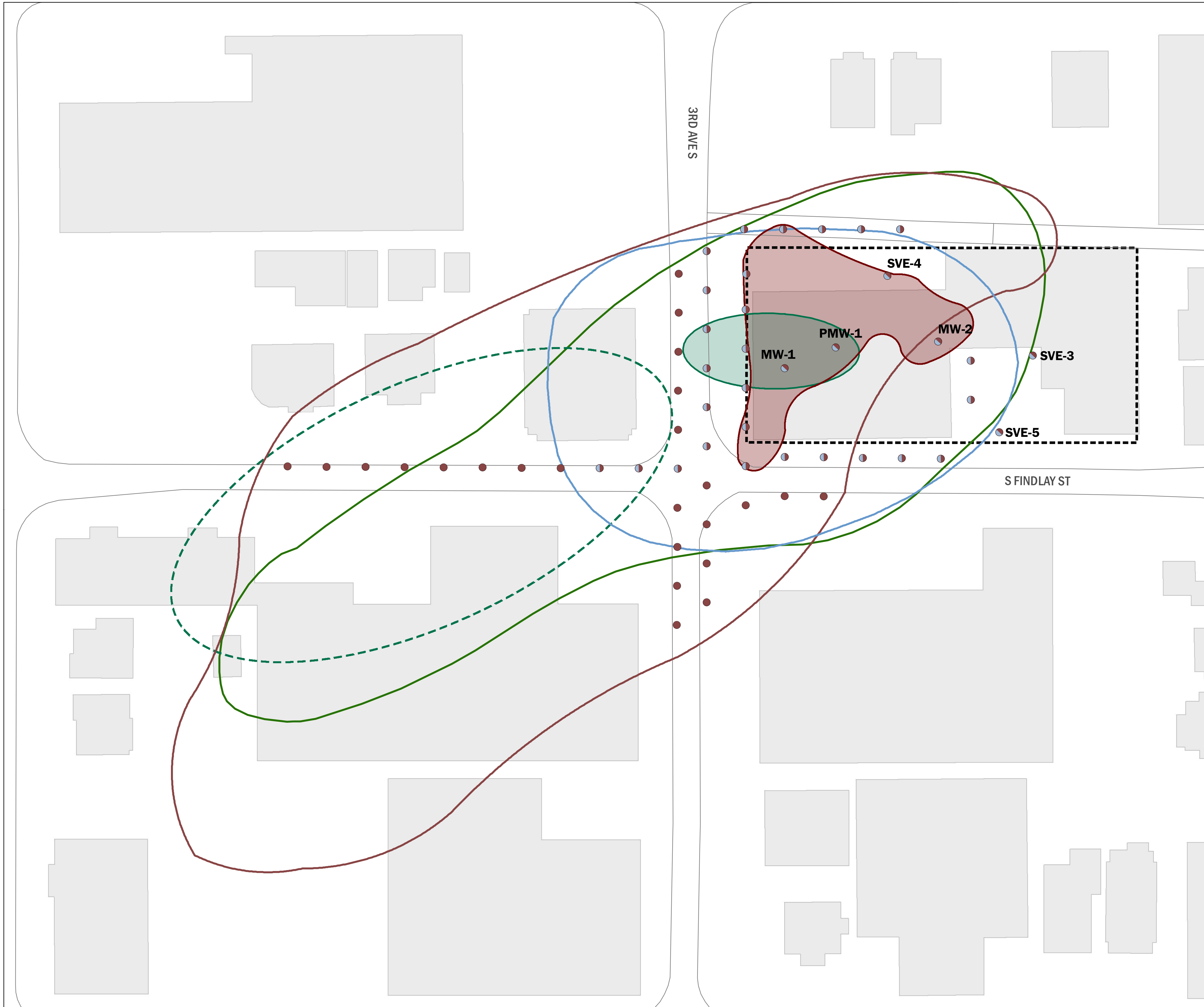
Remedial Design Concept in Downgradient Area Alternatives 2, 3, 4, and 8

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JUL-2016	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REVISED BY: EAC	7-2

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_2 Remedial Design Concept - 2 3 4 8.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016



TCE Isoconcentration Line at 0.03 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Surface Water)

Nickel Isoconcentration Line at 48 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Surface Water)

TCE Isoconcentration Line at 6.9 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Water Table Groundwater (for Protection of Surface Water)

Water Table Groundwater pH < 6

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Existing Combination pH Neutralization Solution Injection/Enhanced Anerobic Biodegradation Well

Proposed Combination pH Neutralization Solution Injection/Enhanced Anerobic Biodegradation Well

Proposed Enhanced Anerobic Biodegradation Well

Art Brass Plating Property Boundary (Approx.)

0 50 100

Feet

Remedial Design Concept in Source Area Alternative 3

W4 Group - Site Unit 1 FS

Seattle, Washington

Aspect CONSULTING

JUL-2016	BY: PPW	FIGURE NO.	
PROJECT NO. 050067	REVISED BY: EAC	7-3	

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_3 Remedial Design Concept - Alternative 3.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016

In-situ Chemical Reduction Treatment Area

TCE Isoconcentration Line at 0.03 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Surface Water)

Nickel Isoconcentration Line at 48 mg/kg Cleanup Level in Soil Vadose Zone (for Protection of Surface Water)

TCE Isoconcentration Line at 6.9 µg/L Cleanup Level in Water Table Groundwater (for Protection of Air Quality)

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Water Table Groundwater (for Protection of Surface Water)

Water Table Groundwater pH < 6

Nickel Isoconcentration Line at 8.2 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

Proposed pH Neutralization Solution Injection Well

Existing pH Neutralization Solution Injection Well

Art Brass Plating Property Boundary (Approx.)

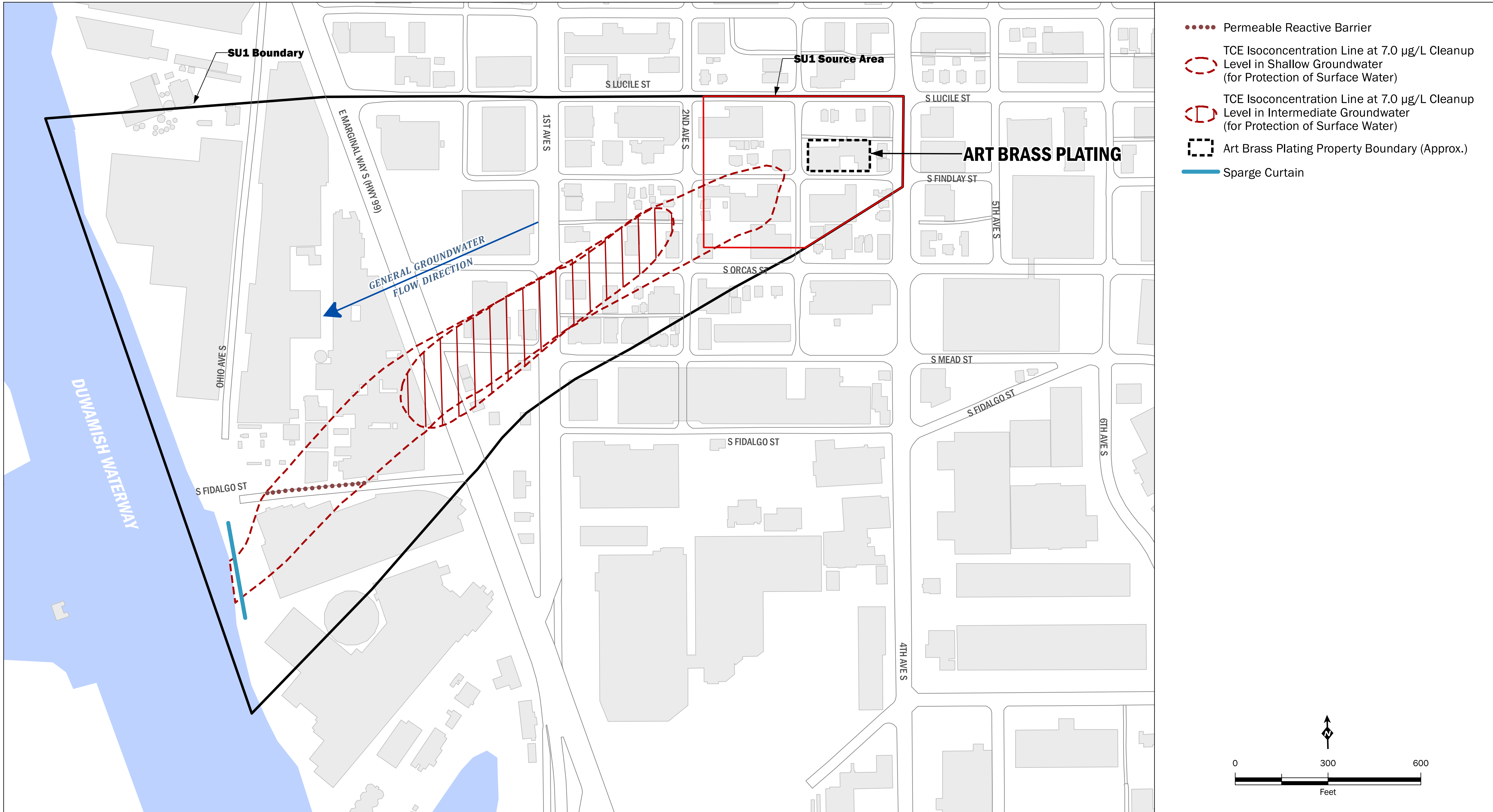
0 50 100

Feet

Remedial Design Concept in Source Area Alternatives 4, 5, 6, and 7

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	7-4

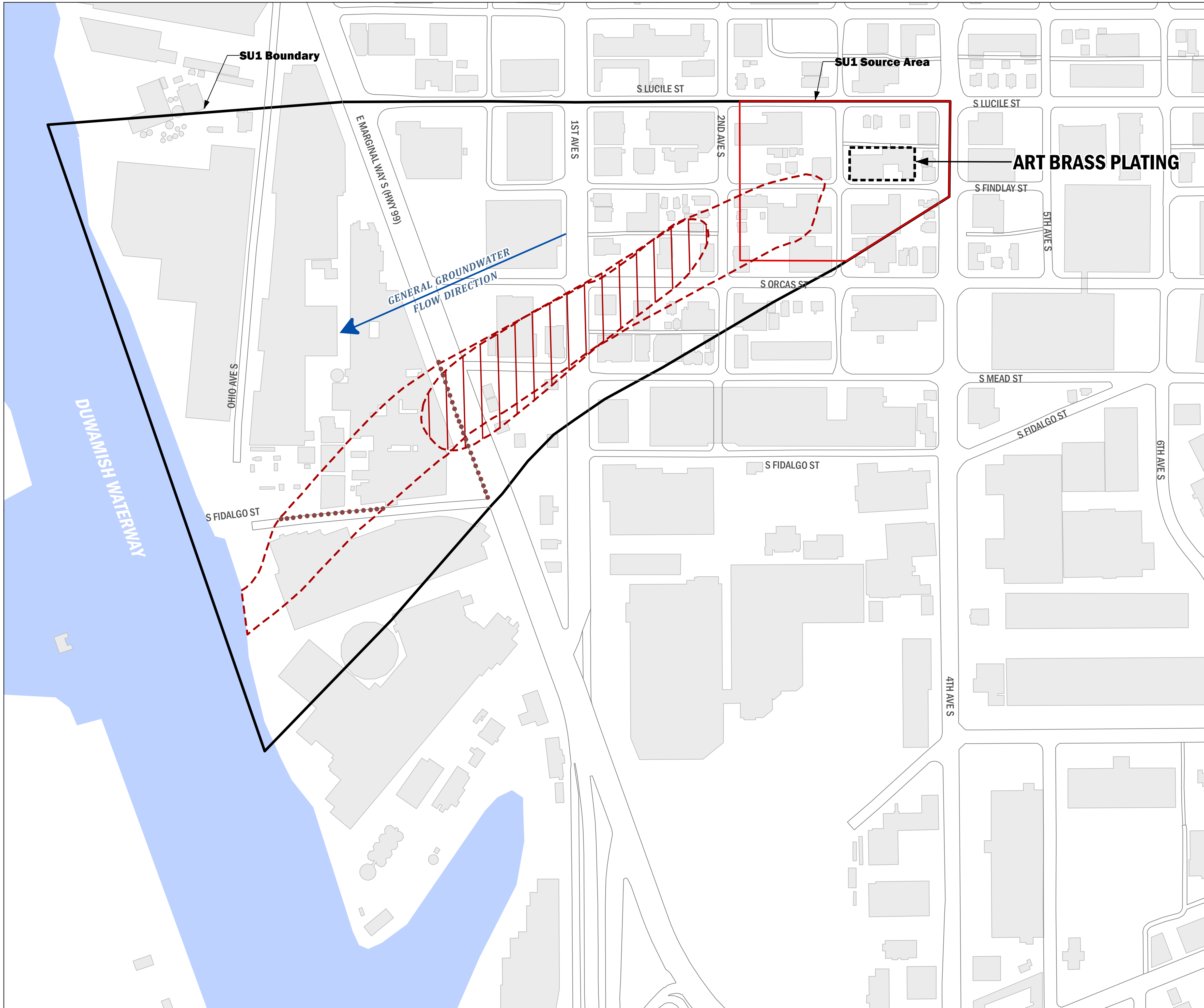


Remedial Design Concept in Downgradient Area Alternative 5

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	7-5

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_5 Remedial Design Concept - Alternative 5.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016

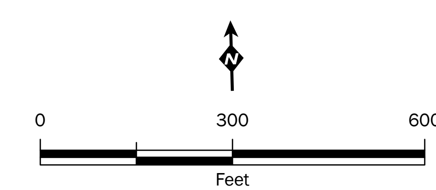


Permeable Reactive Barrier

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

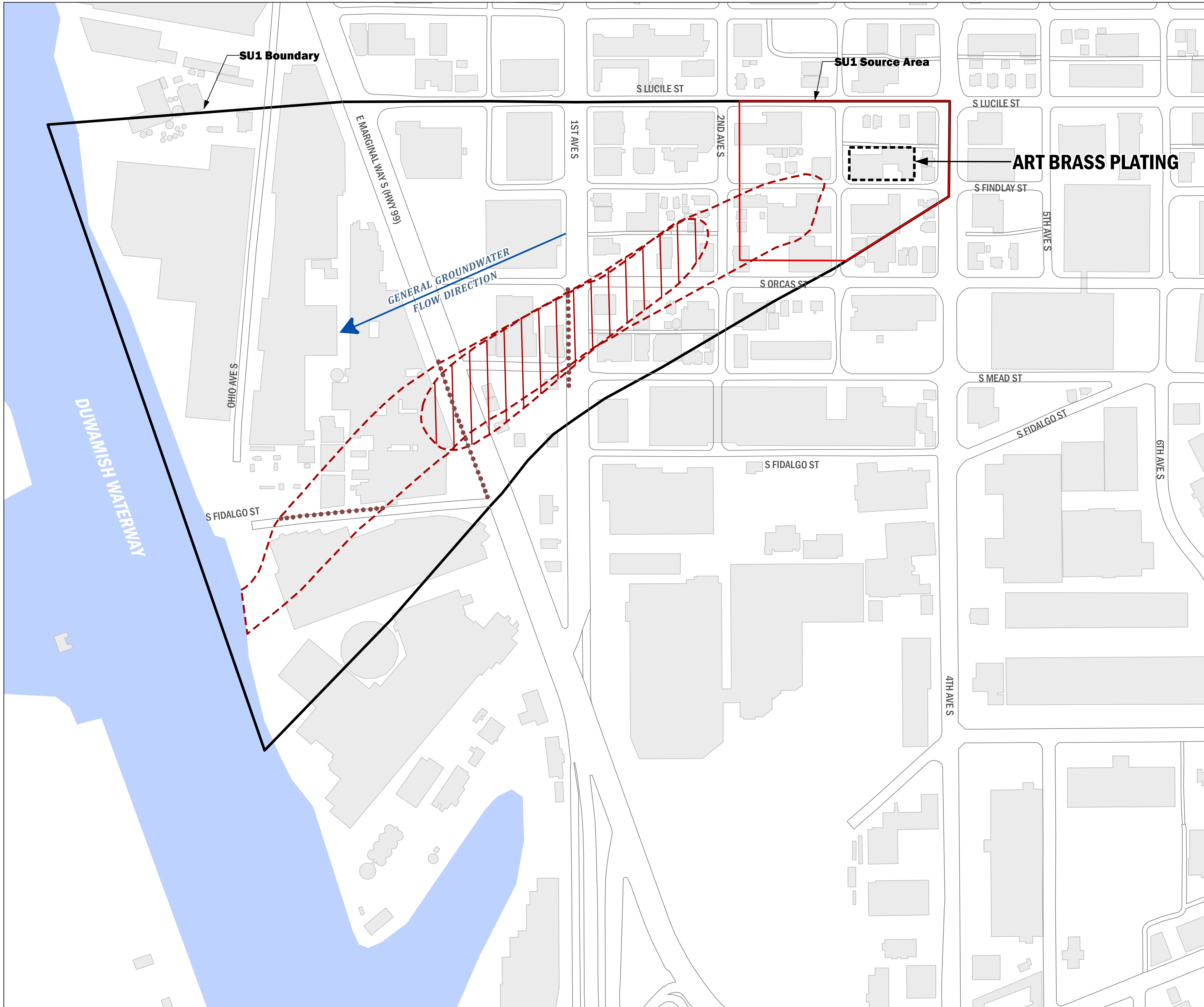


Remedial Design Concept in Downgradient Area Alternative 6

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016 PROJECT NO. 050067	BY: PPW REVISED BY: EAC	FIGURE NO. **7-6**

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_6 Remedial Design Concept - Alternative 6.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016



Permeable Reactive Barrier

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

TCE Isoconcentration Line at 7.0 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Art Brass Plating Property Boundary (Approx.)

0 300 600
Feet

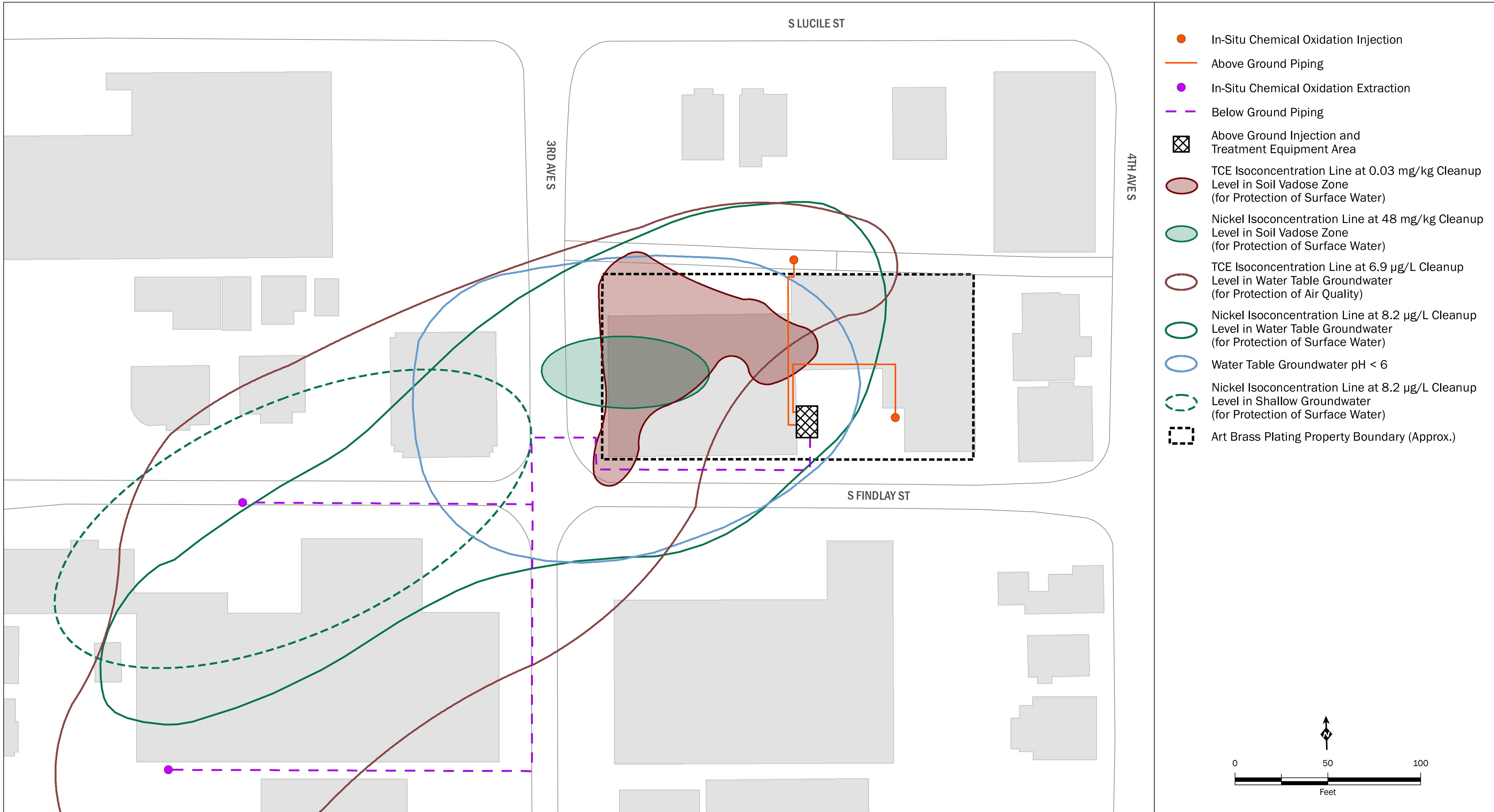
Remedial Design Concept in Downgradient Area Alternative 7

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JUL-2016	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REVISED BY: EAC	7-7

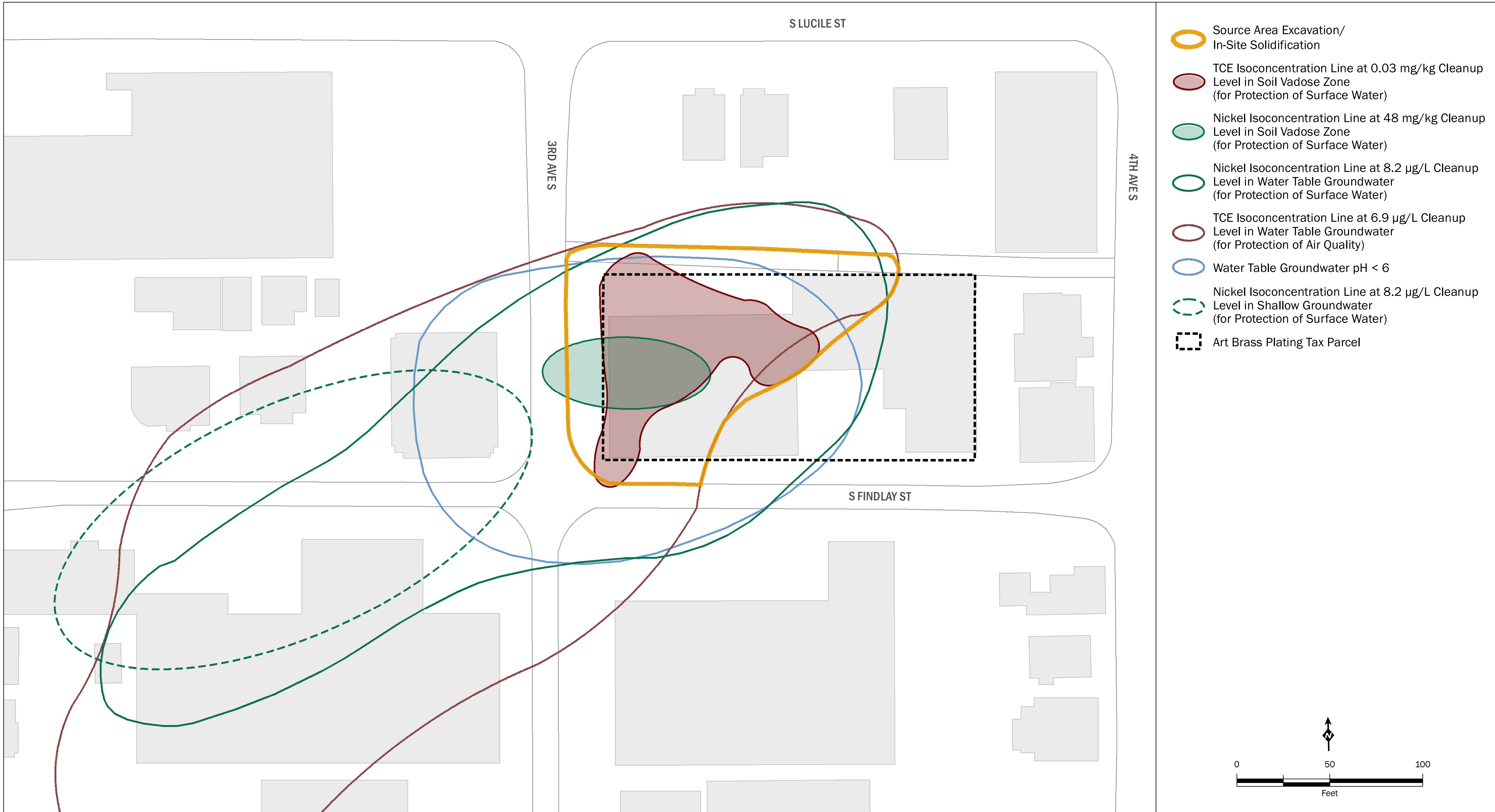
GIS Path: T:\projects_8\ArtBrass\FS\Delivered\W4Group_SiteUnit1FS\7_7 Remedial Design Concept - Alternative 7.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016



Remedial Design Concept in Source Area
Alternative 8
W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	7-8

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7_8 Remedial Design Concept - Alternative 8.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016

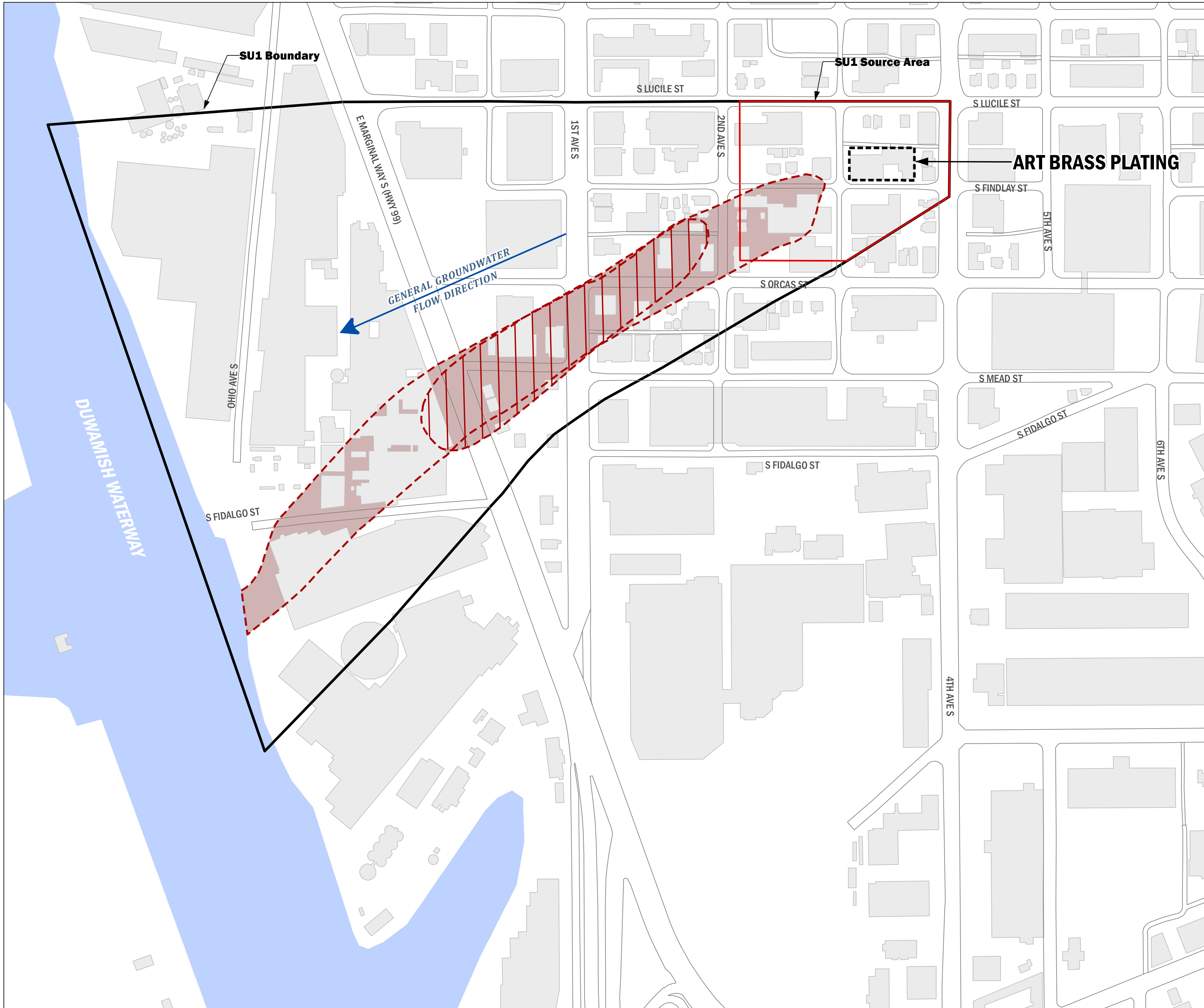


Remedial Design Concept in Source Area
Alternative 9
W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JUL-2016	BY: PPW	FIGURE NO.	
PROJECT NO. 050067	REVISED BY: EAC	7-9	

GIS Path: T:\projects_8\ArtbrassFS\Delivered\W4Group_SiteUnit1FS\7_9 Remedial Design Concept - Alternative 9.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016



TCE Isoconcentration Line at 7.0 μg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)

TCE Isoconcentration Line at 7.0 μg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)

Areal Treatment Area

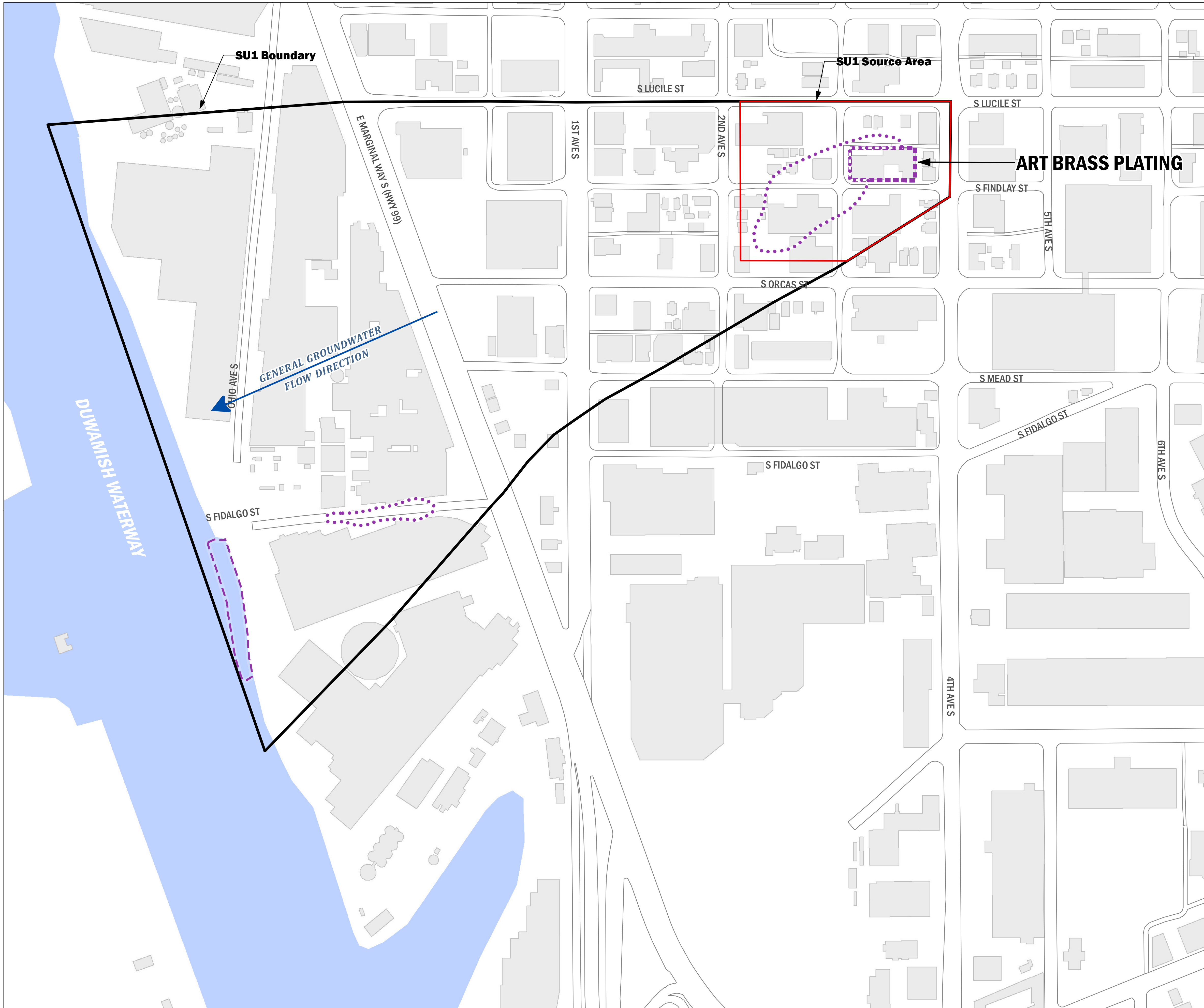
Art Brass Plating Property Boundary (Approx.)

Remedial Design Concept in Downgradient Area Alternative 9

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	7-10

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\7-10 Remedial Design Concept - Alternative 9.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/21/2016 || User: ecrumbaker || Print Date: 7/21/2016



Environmental Covenant for the Art Brass Plating Property that restricts or places requirements regarding underground activities and certain property uses that have the potential to present an exposure risk to contaminated material.[1]

Notifications to utility companies who may conduct subsurface trenching work.[2]

Restrictions (if needed) on shellfish harvesting in the area of contaminated groundwater discharges.[3]

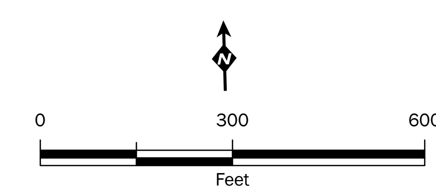
Notes:

1) The Environmental Covenant will be required indefinitely. Alternative 9 may require fewer restrictions on underground activities and/or property use. However, due to potential access issues, some contaminated materials (e.g. beneath building footings) will likely remain in place.

2) Notifications would be maintained until contamination in the vadose zone and Water Table Interval are below Site cleanup levels. Modeling results indicate that site cleanup levels will be achieved in the following time frames (years from completion of cleanup construction):

Alternative	SU1 Source Area	S. Fidalgo St.
1	25	50
2	25	50
3	20	50
4	20	50
5	20	50
6	20	40
7	20	40
8	20	50
9	20	40

3) A site-specific risk assessment presented in the RI did not identify a potential unacceptable risk from shellfish consumption under current conditions. This assessment may be updated in the future if conditions change.

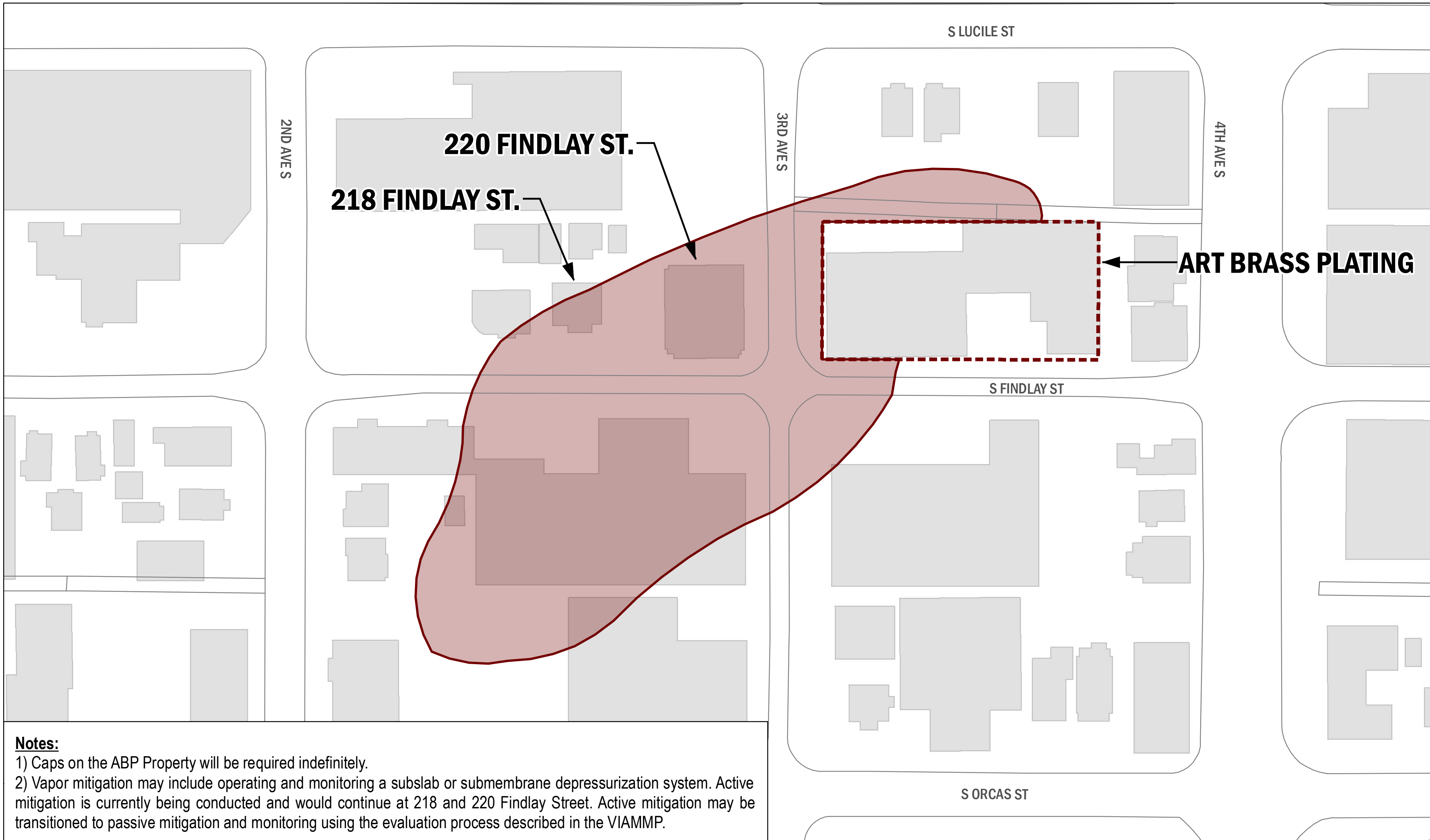


Areal Extent of Institutional Controls

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: PPW	FIGURE NO.
	PROJECT NO. 050067	REVISED BY: EAC	8-1

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\ECY_DraftReview_July2016\8_1 Areal Extent of Institutional Controls.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/25/2016 || User: ecrumbaker || Print Date: 7/25/2016



Notes:
1) Caps on the ABP Property will be required indefinitely.
2) Vapor mitigation may include operating and monitoring a subslab or submembrane depressurization system. Active mitigation is currently being conducted and would continue at 218 and 220 Findlay Street. Active mitigation may be transitioned to passive mitigation and monitoring using the evaluation process described in the VIAMMP.

Maintain existing caps (including building foundations and pavement) on the ABP Property to reduce migration of contaminant vapors into overlying structures.[1]

Implement vapor monitoring and/or mitigation in areas of shallow soil or groundwater exceeding levels potentially protective of the indoor pathway.[2]

N

0 100 200
Feet

Areal Extent of Engineering Controls

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING	JUL-2016	BY: EAC / DAH	FIGURE NO. 8-2
	PROJECT NO. 050067	REVISED BY: - - -	

GIS Path: T:\projects_8\ArtBrass\FS\Delivered\W4Group_SiteUnit1FS\ECY_DraftReview_July2016\8-2 Engineering Controls.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/22/2016 || User: ecrumbaker || Print Date: 7/22/2016