APPENDIX A

Post-Remedial Investigation Data Collection

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Attachment

This appendix provides a summary of the supplemental Remedial Investigation (RI) data collected following Agreed Order No. DE10402. In their conditional acceptance of the Art Brass Plating (ABP) RI Report (Aspect Consulting, 2012), Washington State Department of Ecology (Ecology) provided comments that identified data gaps to be addressed prior to completing the Feasibility Study (FS) (Ecology, 2012). Aspect prepared a memo, *Revised Remedial Investigation Data Gaps and Supplemental Work Plan for Site Unit 1* (Work Plan, 2014), the purpose of which was to summarize how these Ecology comments were to be addressed, define RI data gaps, and provide a work plan describing how the data gaps were to be addressed. Ecology provided comments on the work plan and work was completed in accordance with the work plan and t

Summary of Data Collection

This section provides a discussion of the environmental investigations completed in accordance with the Work Plan and Ecology's associated comments. Sampling locations are illustrated on Figure A-1.

Groundwater Sampling and Analyses

To support metals fate and transport analyses discussed in Appendix B of this FS Report, additional groundwater monitoring was completed in selected Site Unit 1 wells. As outlined in the Work Plan, additional groundwater data were collected in 2014 during the third quarter sampling event (September 2014).

The following wells were selected to represent water quality from the indicated areas for use in the modeling:

- Upgradient wells: MW-12, MW-6, MW-6-30;
- Source area wells: MW-1, MW-3, MW-3-30;
- Downgradient wells: MW-8, MW-8-30, MW-16-40; and
- Downgradient wells near the Duwamish Waterway: MW-24, MW-22-30.

The suite of analytes required for the modeling included:

- Field parameters: oxidation-reduction potential (ORP), pH, dissolved oxygen (DO), specific conductance, temperature;
- Plating metals, dissolved: cadmium, copper, nickel, zinc (EPA 200.8);
- Major cations, dissolved: calcium, magnesium, potassium, sodium (EPA 6010);
- Major anions, dissolved: sulfate, nitrate, and chloride (EPA 300) and alkalinity (SM 2320B); and
- Attenuation indicators:
  - Dissolved Sulfide (EPA 376.2);
  - Dissolved Iron, manganese, aluminum, silicon (or silica) (EPA 6010);

- Dissolved Ortho-phosphorous (EPA 300);
- Total organic carbon (EPA 415.1).

The above mentioned laboratory analyses were completed by Analytical Resources, Inc. (ARI) of Tukwila. Validated data were reported in the Third Quarter Progress Report for 2014 dated December 19, 2014. No data were qualified for any reason. All data, as reported, were deemed acceptable for use. Results are provided in Tables A-1 through A-3 of this appendix. Anchor QEA used this data set for their fate and transport analyses and natural attenuation discussions in Appendix B of this FS Report.

Soil Sampling and Analyses

In October 2014, Aspect completed three geoprobe borings (SPO-53 through SPO-55), at and downgradient of the ABP facility (Figure 1). Direct-push borings SPO-53 and -54 were advanced to a depth of 30 feet and boring SPO-55 to a depth of 39 feet. Soil sample cores were cut into 1-foot sections, sealed with caps and taped on both ends. Samples were stored in cooler with dry ice and delivered to Anchor QEA in Portland, Oregon for processing.

Anchor QEA processed the samples consistent with the Work Plan. Cores were sectioned at three foot intervals and homogenized. Anchor QEA measured pH by EPA Method 9045D and submitted a subsample from each homogenized section to ARI for laboratory analysis of total metals (cadmium, copper, iron, manganese, nickel, and zinc by EPA Methods 200.7/6010C) and total acid insoluble sulfide (SM 4500). Validated results are provided in Tables A-4 of this appendix. No data were qualified for any reason. All data, as reported, were deemed acceptable for use. The validation report is provided in Attachment A of this appendix.

Based on these preliminary soil results, the following six soil samples were selected for sequential extraction and x-ray diffraction:

- **SPO-53, 6-9 feet and 9-12 feet:** The soil sample 6-9 feet below ground surface (bgs) had the highest nickel and copper concentrations in soil near source area. This interval straddles water table but is within seasonal saturated zone for this location. The sample from 9-12 feet bgs had high concentration of nickel and copper within saturated zone soil. The peak metals concentration intervals in SPO-53 (6-9 and 9-12 feet bgs) represent soils near with the release zone with the greatest accumulation of metals (nickel, copper, cadmium, zinc) on the soil matrix. Mineralogy and sequential extraction data were used to demonstrate metals attenuation by precipitation of iron oxy-hydroxides and/or sulfides.
- **SPO-54, 15-18 feet and 21-24 feet:** The sample from 15-18 feet bgs had the highest nickel concentration in saturated zone soil downgradient of source area. The sample from 21-24 feet bgs had a lower nickel concentration and represents the lower edge of the low pH soil zone. A comparison of changes between the shallower and lower interval at SPO-54 provides an assessment of the capacity of aquifer minerals to sustain metals attenuation by neutralizing/buffering acidic groundwater.
- **SPO-55, 15-18 feet and 27-30 feet:** The sample from 15-18 feet bgs has a low nickel concentration and is located above the low pH soil zone. The sample from

27-30 feet bgs has a low nickel concentration and is located within the low pH soil zone. A comparison of changes between the shallower and lower interval at SPO-55 provides and assessment of the capacity of aquifer minerals to sustain metals attenuation by neutralizing/buffering acidic groundwater.

The preliminary data and the above rationale were submitted to Ecology via email and Ecology approved the selection on December 10, 2014. Refer Appendix B for a detailed discussion of the results.

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TABLES

Table A-1 - Validated September 2014 Groundwater Quality Data – Water Table Interval

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

Chemical Name	Groundwater Cleanup Level Protective of Surface Water	MW-1 09/23/14	MW-3 09/22/14	MW-5 09/25/14	MW-6 09/22/14	MW-7 09/25/14	MW-7 09/25/14 FD	MW-8 09/22/14	MW-12 09/22/14
Metals									
Dissolved Cadmium in ug/L	8.8	0.2	0.4		0.1 U			0.1 U	0.1 U
Dissolved Calcium in ug/L		38,900	30,600		46,800			62,800	34,800
Dissolved Copper in ug/L	2.4	12.8	27.6	22.7	4.1	42.1	41.5	0.5 U	1.5
Dissolved Iron in ug/L		50	50 U		50 U			18,900	7,460
Dissolved Magnesium in ug/L		13,200	9,390		14,800			21,100	14,800
Dissolved Manganese in ug/L	100	916	527		7			1,470	418
Dissolved Nickel in ug/L	8.2	26,300	13,600	81.3	3.4	69.7	66	5,930	7.7
Dissolved Potassium in ug/L		10,500	7,610		18,200			18,000	8,770
Dissolved Silicon in ug/L		45,000	47,900		26,600			49,300	30,600
Dissolved Sodium in ug/L		40,500	28,800		25,500			48,800	25,700
Dissolved Zinc in ug/L	81	57	63	69	4 U	62	62	4	9
Total Arsenic in ug/L	0.14							1.1	
Total Barium in ug/L	4							19.8	
Total Cadmium in ug/L	8.8	0.2	0.3		0.1 U			0.1 U	
Total Copper in ug/L	2.4	15.8	27.8	22.2	4.3	42.5	41.7	0.8	4
Total Iron in ug/L									
Total Manganese in ug/L	100								
Total Nickel in ug/L	8.2	25,400	69,500	85.9	4.2	69	68.2	5,860	10.2
Total Zinc in ug/L	81	59 J	59 J	65	4 UJ	60	56	5 J	9 J
Conventional Chemistry Parameters									
Alkalinity (Total) in mg/L as CaCO3		1 U	1 U		127			15	64.1
Bicarbonate in mg/L as CaCO3		1 U	1 U		127			15	64.1
Carbonate in mg/L as CaCO3		1 U	1 U		1 U			1 U	1 U
Chloride in mg/L		45	21.2		19.9			34.3	40.6
Dissolved Calcium in ug/L		38,900	30,600		46,800			62,800	34,800
Dissolved Potassium in ug/L		10,500	7,610		18,200			18,000	8,770
Dissolved Sodium in ug/L		40,500	28,800		25,500			48,800	25,700
Hydroxide in mg/L as CaCO3		1 U	1 U		1 U			1 U	1 U
Nitrate as Nitrogen in mg-N/L		0.3	0.6		10.4			0.1 U	0.1 U
ortho-Phosphorus in mg/L		0.1 U	0.1 U		0.1			0.1 U	0.1 U
Sulfate in mg/L		238	186		61.3			341	99
Sulfide in mg/L		0.05 U	0.05 U		0.05 U			0.05 U	0.05 U
Total Organic Carbon in mg/L		1.5 U	1.5 U		3.93			1.5 U	3.95
Volatile Organic Compounds (VOC)									
1,1,1-Trichloroethane in ug/L		1 U	1 U	1 U	0.2 U	0.2 U	1 U	1 U	0.2 U
1,1-Dichloroethane in ug/L		1 U	1 U	0.89 J	0.2 U	3.8	3.5	0.9 J	1.6
1,1-Dichloroethene in ug/L	7,100	1 U	1 U	1 U	0.2 U	0.18 J	0.15 J	1 U	0.17 J
1,2-Dichloroethane (EDC) in ug/L		1 U	1 U	1 U	0.2 U	0.2 U	1 U	1 U	0.2 U
Chloroethane in ug/L		1 U	1 U	1 U	0.2 U	0.2 U	1 U	1 U	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L		14	0.75 J	0.36 J	0.2 U	5.4	5.1	8.7	1.8
Tetrachloroethene (PCE) in ug/L	3.3	1 U	1 U	1 U	0.2 U	0.2 U	1 U	1 U	0.2 U
trans-1,2-Dichloroethene in ug/L	10,000	1 U	1 U	1 U	0.2 U	0.28	0.28 J	1 U	0.2 U
Trichloroethene (TCE) in ug/L	18	27	14	2.2	0.2 U	35	32	51	13
Vinyl chloride in ug/L	2.4	1 U	1 U	1 U	0.2 U	0.2 U	1 U	1 U	0.2 U
Field Parameters									
Dissolved Oxygen in mg/L		7.86	4.06	7.27	0.18	0.38		0.01	0.11
ORP in mVolts		431.6	353.1	471.7	51.9	332.2		23.3	52.5
pH in pH Units		3.93	4.64	3.92	6.52	4.29		6.18	6.02
Specific Conductance in us/cm		737	518.4	742	541.7	6.17		866	485.1
Temperature in deg C		18.1	18.8	17.9	16.4	17.3		17.4	16.8
Turbidity in NTU		16.8	4.07	2.99		2.90		3.02	12.7

Notes

Concentrations in shaded cells indicate value exceeds Groundwater Cleanup Level Protective of Surface Water

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

Q - Indicates a detected analyte with an initial or continuing calibration that does not meet established acceptance criteria (<20% RSD, <20% Drift or minimum RRF).

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

UJ - Analyte was not detected at or above the reported estimate

Table A-2 - Validated September 2014 Groundwater Quality Data – Shallow Interval

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

Chemical Name	Groundwater Cleanup Level Protective of Surface Water	MW-3-30 09/22/14	MW-6-30 09/22/14	MW-8-30 09/22/14	MW-16-40 09/23/14	MW-22-30 09/23/14
Metals						
Dissolved Cadmium in ug/L	8.8	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
Dissolved Calcium in ug/L		21,100	20,900	65,300	78,000	63,200
Dissolved Copper in ug/L	2.4	0.5 U	0.5 U	0.8	0.7	0.5
Dissolved Iron in ug/L		13,600	16,600	48,600	53,300	2,850
Dissolved Magnesium in ug/L		33,500	12,500	34,400	35,700	43,500
Dissolved Manganese in ug/L	100	744	391	2,010	836	256
Dissolved Nickel in ug/L	8.2	1.4	1.3	2,020	2.5	1.8
Dissolved Potassium in ug/L		9,110	5,320	11,300	8,740	16,100
Dissolved Silicon in ug/L		29,500	30,000	47,100	32,800	28,200
Dissolved Sodium in ug/L		37,200	19,400	40,200	35,100	291,000
Dissolved Zinc in ug/L	81	4 U	4 U	15	4 U	4 U
Total Arsenic in ug/L	0.14	0.6		0.3		
Total Barium in ug/L	4	11		27		
Total Copper in ug/L	2.4	1.4		2.6	2	
Total Iron in ug/L		29,300		45,700	51,800	
Total Manganese in ug/L	100	746		1,860	804	
Total Nickel in ug/L	8.2	2.7		1,890	2.6	
Total Zinc in ug/L	81	4 UJ		17 J	9 J	
Conventional Chemistry Parameters						
Alkalinity (Total) in mg/L as CaCO3		241	117	47.4	26.8	308
Bicarbonate in mg/L as CaCO3		241	117	47.4	26.8	308
Carbonate in mg/L as CaCO3		1 U	1 U	1 U	1 U	1 U
Chloride in mg/L		26.2	11.1	25.5	19.7	446
Dissolved Calcium in ug/L		21,100	20,900	65,300	78,000	63,200
Dissolved Potassium in ug/L		9,110	5,320	11,300	8,740	16,100
Dissolved Sodium in ug/L		37,200	19,400	40,200	35,100	291,000
Hydroxide in mg/L as CaCO3		1 U	1 U	1 U	1 U	1 U
Nitrate as Nitrogen in mg-N/L		0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
ortho-Phosphorus in mg/L		0.1 U	0.1 U	0.1 U	0.1 U	0.4
Sulfate in mg/L		4.1	32	391	445	98.5
Sulfide in mg/L		0.05 U	0.05 U	0.05 U	0.05 U	0.412
Total Organic Carbon in mg/L		5.36	5.23	1.98	1.99	12.8
Volatile Organic Compounds (VOC)						
1,1,1-Trichloroethane in ug/L		0.2 U	0.2 U	1 U	20 U	0.2 U
1,1-Dichloroethane in ug/L		7.3	16	1.2	20 U	3.6
1,1-Dichloroethene in ug/L	7,100	0.2 U	0.2 U	1 U	20 U	0.87
1,2-Dichloroethane (EDC) in ug/L		0.3	0.32	1 U	20 U	0.2 U
Chloroethane in ug/L		0.82	0.44	1 U	20 U	0.2 U
cis-1,2-Dichloroethene (DCE) in ug/L		1.4	14	5.2	100	400
Tetrachloroethene (PCE) in ug/L	3.3	0.2 U	0.2 U	1 U	20 U	0.2 U
trans-1,2-Dichloroethene in ug/L	10,000	0.2 U	0.2 U	1 U	20 U	2.2
Trichloroethene (TCE) in ug/L	18	0.28	4.1	24	630	5.4
Vinyl chloride in ug/L	2.4	3.7 Q	0.98	1 U	20 U	44 Q
Field Parameters						
Dissolved Oxygen in mg/L		0.01	0.02	0.01	0.02	0.10
ORP in mVolts		-46.9	-38.9	-08.0	-039.0	-49.6
pH in pH Units		6.85	6.59	6.32	6.23	6.69
Specific Conductance in us/cm		586.6	353.0	935	1,027	2,263
Temperature in deg C		17.1	16.1	15.9	15.0	17.0
Turbidity in NTU		25.9	1.26	6.30	3.18	6.44

Notes

Concentrations in shaded cells indicate value exceeds Groundwater Cleanup Level Protective of Surface Water

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

Q - Indicates a detected analyte with an initial or continuing calibration that does not meet established acceptance criteria (<20% RSD, <20% Drift or minimum RRF).

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

UJ - Analyte was not detected at or above the reported estimate

Table A-3 - Validated September 2014 Groundwater Quality Data – Intermediate Interval

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

Chemical Name	Groundwater Cleanup Level Protective of Surface Water	MW-16-75 09/23/14
Metals		
Dissolved Calcium in ug/L		2,930
Dissolved Copper in ug/L	2.4	0.6
Dissolved Iron in ug/L		290
Dissolved Magnesium in ug/L		4,410
Dissolved Manganese in ug/L	100	56
Dissolved Nickel in ug/L	8.2	0.5 U
Dissolved Potassium in ug/L		8,000
Dissolved Silicon in ug/L		16,900
Dissolved Sodium in ug/L		74,400
Dissolved Zinc in ug/L	81	4 U
Total Arsenic in ug/L	0.14	1.2
Total Barium in ug/L	4	4.6
Total Copper in ug/L	2.4	9.5
Total Iron in ug/L		720
Total Manganese in ug/L	100	57
Total Nickel in ug/L	8.2	0.7
Total Zinc in ug/L	81	4 UJ
Conventional Chemistry Parameters		
Dissolved Calcium in ug/L		2,930
Dissolved Potassium in ug/L		8,000
Dissolved Sodium in ug/L		74,400
Volatile Organic Compounds (VOC)		
1,1,1-Trichloroethane in ug/L		
1,1-Dichloroethane in ug/L		
1,1-Dichloroethene in ug/L	7,100	
1,2-Dichloroethane (EDC) in ug/L		
Chloroethane in ug/L		
cis-1,2-Dichloroethene (DCE) in ug/L		
Tetrachloroethene (PCE) in ug/L	3.3	
trans-1,2-Dichloroethene in ug/L	10,000	
Trichloroethene (TCE) in ug/L	18	
Vinyl chloride in ug/L	2.4	
Field Parameters		
Dissolved Oxygen in mg/L		0.03
ORP in mVolts		.160.9
pH in pH Units		7.94
Specific Conductance in us/cm		389.1
Temperature in deg C		15.0
Turbidity in NTU		

Notes

Concentrations in shaded cells indicate value exceeds Groundwater Cleanup Level Protective of Surface Water.

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

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

UJ - Analyte was not detected at or above the reported estimate.

Table A-4 - Total Metals and Insoluble Sulfide Results from All Soil Samples

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

Chemical Name	SPO-53 10/15/2014 (0-3 ft.)	SPO-53 10/15/2014 (3-6 ft.)	SPO-53 10/15/2014 (6-9 ft.)	SPO-53 10/15/2014 (9-12 ft.)	SPO-53 10/15/2014 (12-15 ft.)	SPO-53 10/15/2014 (15-18 ft.)	SPO-53 10/15/2014 (18-21 ft.)	SPO-53 10/15/2014 (21-24 ft.)	SPO-53 10/15/2014 (24-27 ft.)	SPO-53 10/15/2014 (27-30 ft.)	SPO-53 FD 10/15/2014 (27-30 ft.)	SPO-54 10/20/2014 (0-3 ft.)	SPO-54 10/20/2014 (3-6 ft.)
Metals													
Cadmium in mg/kg	0.3	0.2 U	0.2 U	0.3 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.5	0.2 U
Copper in mg/kg	21.8	21.5	74.1	21.9	8.4	5.6	8.7	8.2	6.8	7	7.5	25.2 J	15.4 J
Iron in mg/kg	17,100	12,200	11,900	12,100	9,980	8,560	9,910	10,700	10,500	8,540	8,830	18,600 J	12,800 J
Manganese in mg/kg	243	96.3	102	90.6	72	65.6	79.8	81	74.1	67.5	68.4	174	90.1
Nickel in mg/kg	20	55	684	440	32	16	6	6	5	5	6	13	8
Zinc in mg/kg	59	23	34	24	19	15	19	19	16	15	16	148 J	28 J
Other Parameters													
Total Sulfur in Percent (Acid Insoluble)	1.69	0.01	0.03	0.14	0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.04	0.02
Sulfide in mg/kg	1.22 UJ	1.19 UJ	1.26 UJ	2.96 J	2.1 J	1.2 UJ	1.24 UJ	1.52 J	1.26 UJ	1.3 UJ	1.28 UJ	1.07 UJ	1.2 UJ
pH in pH Units	4	5	5	5	4	4	6	5	4	5	5	5	5
Total Solids in Percent	81.47	83.78	77.83	76.66	77.93	82.57	79.09	80.03	77.62	76.88	76.96	89.95	81.17

Table A-4 - Total Metals and Insoluble Sulfide Results from All Soil Samples

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

Chemical Name	SPO-54 10/20/2014 (6-9 ft.)	SPO-54 10/20/2014 (9-12 ft.)	SPO-54 10/20/2014 (12-15 ft.)	SPO-54 10/20/2014 (15-18 ft.)	SPO-54 10/20/2014 (18-21 ft.)	SPO-54 10/20/2014 (21-24 ft.)	SPO-54 10/20/2014 (24-27 ft.)	SPO-54 10/20/2014 (27-30 ft.)	SPO-54 FD 10/20/2014 (27-30 ft.)	SPO-55 10/17/2014 (0-3 ft.)	SPO-55 10/17/2014 (3-6 ft.)	SPO-55 10/17/2014 (6-9 ft.)	SPO-55 10/17/2014 (9-12 ft.)
Metals													
Cadmium in mg/kg	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.4	0.2 U	0.2 U	0.2 U
Copper in mg/kg	15 J	13.2 J	7 J	10.9 J	8.1 J	12.5 J	7.2 J	17.8 J	20.2 J	21	17.1	13.4	14.5
Iron in mg/kg	10,900 J	14,600 J	9,180 J	12,700 J	10,100 J	11,300 J	8,940 J	10,900 J	11,100 J	15,200	15,000	11,100	10,400
Manganese in mg/kg	81	131	77	103	88.5	94.2	75.4	82.7	84.4	295	132	92.4	78.7
Nickel in mg/kg	9	25	182	585	206	82	32	19	16	40	12	7	10
Zinc in mg/kg	25 J	30 J	19 J	21 J	18 J	19 J	16 J	18 J	18 J	74	27	21	25
Other Parameters													
Total Sulfur in Percent (Acid Insoluble)	0.09	0.03	0.02	0.09	0.04	0.12	0.06	0.16	0.14	0.11	0.02	0.03	0.08
Sulfide in mg/kg	3.48 J	2.74 J	2.53 J	1.23 UJ	2.84 J	1.3 UJ	1.26 UJ	2.12 J	2.17 J	1.11 UJ	1.2 UJ	1.24 UJ	2.6 J
pH in pH Units	5	4	4	4	4	4	4	5	5	4	5	5	5
Total Solids in Percent	77.1	80.52	78.87	78.64	80.1	75.82	76.78	78.71	77.94	89.03	80.89	79	78.18

Table A-4 - Total Metals and Insoluble Sulfide Results from All Soil Samples

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

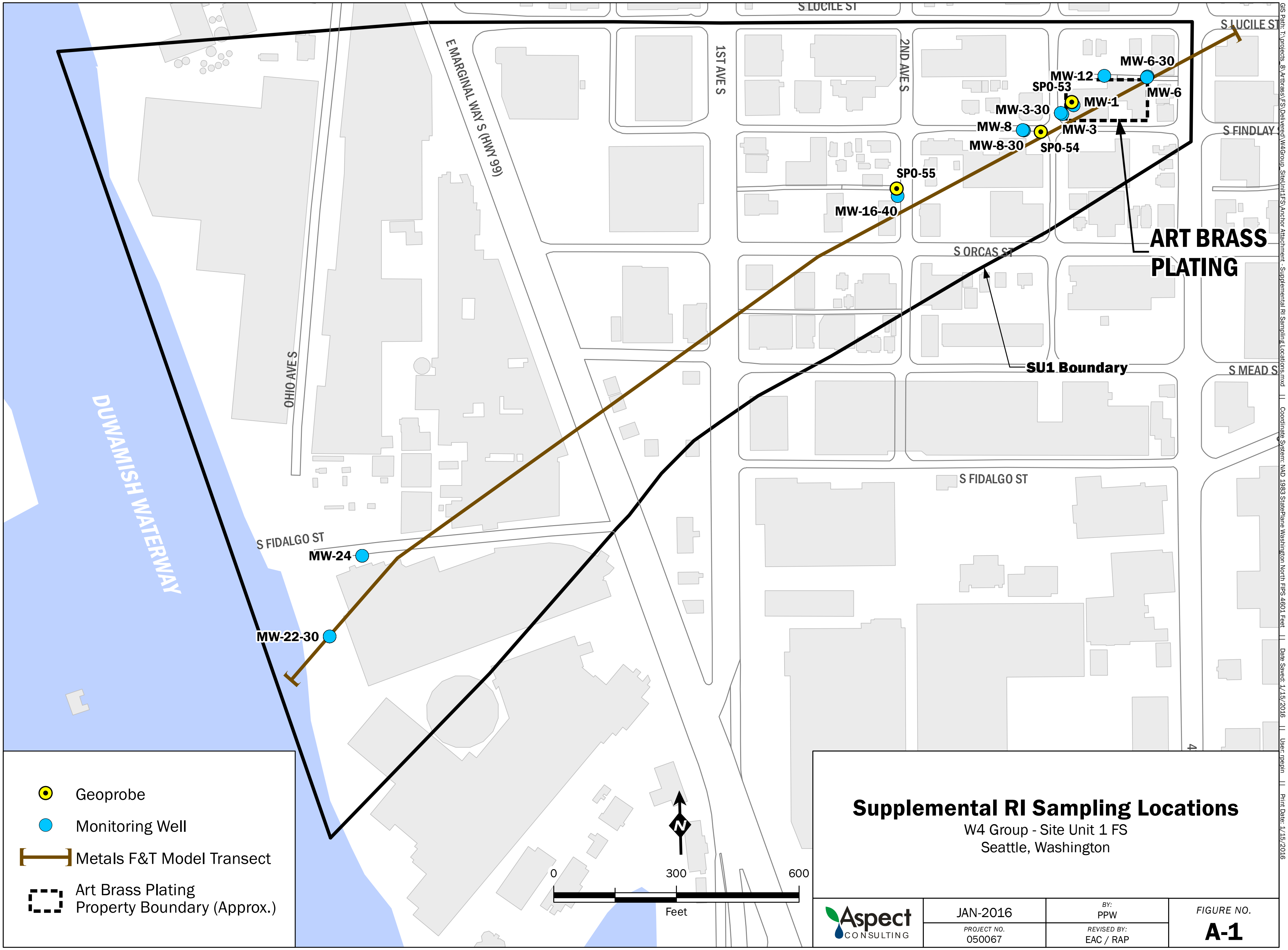
Chemical Name	SPO-55 10/17/2014 (12-15 ft.)	SPO-55 10/17/2014 (15-18 ft.)	SPO-55 10/17/2014 (18-21 ft.)	SPO-55 10/17/2014 (21-24 ft.)	SPO-55 10/17/2014 (24-27 ft.)	SPO-55 10/17/2014 (27-30 ft.)	SPO-55 10/17/2014 (30-33 ft.)	SPO-55 10/17/2014 (33-36 ft.)	SPO-55 10/17/2014 (36-39 ft.)
Metals									
Cadmium in mg/kg	0.2 U	0.2 U	0.3 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Copper in mg/kg	11.5	11.1	10.5	9.6	7.5	7.1	7.4	8.3	7.3
Iron in mg/kg	10,200	10,900	10,700	10,500	10,300	9,710	9,960	9,230	8,610
Manganese in mg/kg	78.7	85.9	81.5	87.1	88.2	83	88	74.4	68.6
Nickel in mg/kg	8	8	8	6	7	6	7	6	5
Zinc in mg/kg	22	23	20	20	19	18	18	17	16
Other Parameters									
Total Sulfur in Percent (Acid Insoluble)	0.04	0.02	0.05	0.03	0.02	0.03	0.01	0.02	0.02
Sulfide in mg/kg	1.22 UJ	1.61 J	1.81 J	2.33 J	1.46 J	1.27 UJ	1.22 UJ	1.76 J	1.24 UJ
pH in pH Units	5	5	4	4	5	4	4	4	4
Total Solids in Percent	80.96	79.48	77.69	77.79	80.2	78.73	81.68	79.76	80.24

Notes

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

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

FIGURE



Supplemental RI Sampling Locations

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

JAN-2016	BY: PPW	FIGURE NO.
PROJECT NO. 050067	REVISED BY: EAC / RAP	**A-1**

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\Anchor Attachment - Supplemental RI Sampling Locations.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/15/2016 || User: rpepin || Print Date: 1/15/2016

ATTACHMENT A

Validation and Laboratory Reports

ECOCHEM
Data Quality

DATA VALIDATION REPORT

Art Brass Plating - October 2014 Soil Sampling

Prepared for:

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350 Madison Avenue North
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Prepared by:

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EcoChem Project: C22802-28

January 7, 2015

Approved for Release:

Chris Ransom
Project Manager
EcoChem, Inc.

PROJECT NARRATIVE

Basis for Data Validation

This report summarizes the results of compliance review (EPA Stage 2A) performed on soil and laboratory quality control (QC) data for the Art Brass Plating October 2014 Soil Sampling. A complete list of samples is provided in the **Sample Index**.

Samples were analyzed by Analytical Resources, Inc. (ARI), Tukwila, Washington. The analytical methods and EcoChem project chemists are listed below.

Analysis	Method	Primary Review	Secondary Review
Metals	6010C	R. Hedelund	A. Bodkin
Conventional Parameters (sulfide, total solids)	EPA 376.2, SM2540G		

The data were reviewed using guidance and quality control criteria documented in the analytical methods; the *Quality Assurance Project Plan (QAPP) for Art Brass Plating* (Sept. 25, 2008) and *National Functional Guidelines for Inorganic Data Review* (USEPA 1994, 2010).

EcoChem's goal in assigning data validation qualifiers is to assist in proper data interpretation. If values are estimated (assigned a J), data may be used for site evaluation purposes; but reasons for data qualification should be taken into consideration when interpreting sample concentrations. Data that have been labeled as do-not-report (DNR) should not be used for any purpose. Values with no data qualifier meet all data measurement quality objectives and are acceptable for use.

Data qualifier definitions, reason codes, and validation criteria are included as **Appendix A**. A Qualified Data Summary Table is included in **Appendix B**. Data Validation Worksheets will be kept on file at EcoChem, Inc. A qualified laboratory electronic data deliverable (EDD) is also submitted with this report.

SAMPLE INDEX
Art Brass Plating - October 2014 Soil Sampling

SDG	Sample ID	Laboratory ID	Metals	Conv
ZG61	O-09_s053_0003	14-22765-ZG61A	✓	✓
ZG61	O-09_s053_0306	14-22766-ZG61B	✓	✓
ZG61	O-09_s053_0609	14-22767-ZG61C	✓	✓
ZG61	O-09_s053_0912	14-22768-ZG61D	✓	✓
ZG61	O-09_s053_1215	14-22769-ZG61E	✓	✓
ZG61	O-09_s053_1821	14-22770-ZG61F	✓	✓
ZG61	O-09_s053_2124	14-22771-ZG61G	✓	✓
ZG61	O-09_s053_2427	14-22772-ZG61H	✓	✓
ZG61	O-09_s053_2730	14-22773-ZG61I	✓	✓
ZG61	O-09_s153_2730	14-22774-ZG61J	✓	✓
ZG61	O-09_s053_1518	14-22775-ZG61K	✓	✓
ZG64	O-09_s054_0003	14-22776-ZG64A	✓	✓
ZG64	O-09_s054_0306	14-22777-ZG64B	✓	✓
ZG64	O-09_s054_0609	14-22778-ZG64C	✓	✓
ZG64	O-09_s054_0912	14-22779-ZG64D	✓	✓
ZG64	O-09_s054_1215	14-22780-ZG64E	✓	✓
ZG64	O-09_s054_1518	14-22781-ZG64F	✓	✓
ZG64	O-09_s054_1821	14-22782-ZG64G	✓	✓
ZG64	O-09_s054_2124	14-22783-ZG64H	✓	✓
ZG64	O-09_s054_2427	14-22784-ZG64I	✓	✓
ZG64	O-09_s054_2730	14-22785-ZG64J	✓	✓
ZG64	O-09_s154_2730	14-22786-ZG64K	✓	✓
ZG65	O-09_s055_0003	14-22787-ZG65A	✓	✓
ZG65	O-09_s055_0306	14-22788-ZG65B	✓	✓
ZG65	O-09_s055_0609	14-22789-ZG65C	✓	✓
ZG65	O-09_s055_0912	14-22790-ZG65D	✓	✓
ZG65	O-09_s055_1215	14-22791-ZG65E	✓	✓
ZG65	O-09_s055_1518	14-22792-ZG65F	✓	✓
ZG65	O-09_s055_1821	14-22793-ZG65G	✓	✓
ZG65	O-09_s055_2124	14-22794-ZG65H	✓	✓
ZG65	O-09_s055_2427	14-22795-ZG65I	✓	✓
ZG65	O-09_s055_2730	14-22796-ZG65J	✓	✓
ZG65	O-09_s055_3033	14-22797-ZG65K	✓	✓
ZG65	O-09_s055_3336	14-22798-ZG65L	✓	✓
ZG65	O-09_s055_3639	14-22799-ZG65M	✓	✓

DATA VALIDATION REPORT
Art Brass Plating - October 2014 Soil Sampling
Metals by Method 6010C

This report documents the review of analytical data from the analysis of soil samples and the associated laboratory and field quality control (QC) samples. Analytical Resources, Inc., Tukwila, Washington, analyzed the samples. Refer to the **Sample Index** for a list of the individual samples.

SDG	Number of Samples	Validation Level
ZG61	11 Soil	EPA Stage 2A
ZG64	11 Soil	EPA Stage 2A
ZG65	13 Soil	EPA Stage 2A

I. DATA PACKAGE COMPLETENESS

The laboratory submitted all required deliverables. The laboratory followed adequate corrective action processes and all anomalies were discussed in the case narrative.

II. TECHNICAL DATA VALIDATION

The QC requirements for review are listed below.

√	Sample Receipt, Preservation, and Holding Times	**2**	Laboratory Duplicates
√	Method Blanks	**1**	Field Duplicates
√	Laboratory Control Samples (LCS)	√	Reported Results
2	Matrix Spikes (MS)	√	Reporting Limits

✓***Method quality objectives (MQO) and QC criteria have been met. No outliers are noted or discussed.***
[1] ***Quality control results are discussed below, but no data were qualified.***
[2] ***Quality control outliers that impact the reported data were noted. Data qualifiers were issued as discussed below.***

Matrix Spikes

SDG ZG64: The matrix spike analysis was performed using Sample O_09_s054_0003. The percent recovery value for zinc was less than the lower control limit of 75%. The zinc results for all associated samples were estimated (J-8L) to indicate a potential low bias.

Laboratory Duplicates

SDG ZG64: Sample O_09_s054_0003 was analyzed in duplicate. The relative percent difference (RPD) values for copper and iron were greater than the control limit of 20%. The copper and iron results for all associated samples were estimated (J-9).

Field Duplicates

The RPD control limit is 35% for results greater than 5x the reporting limit (RL). For results less than five times the RL, the difference between the sample and duplicate must be less than two times the RL.

SDG ZG61: The data for one set of field duplicates was submitted: O-09_s053_2730 and O-09_s153_2730. All field precision criteria were met.

SDG ZG64: The data for one set of field duplicates was submitted: O-09_s054_2730 and O-09_s154_2730. All field precision criteria were met.

IV. OVERALL ASSESSMENT

As was determined by this evaluation, the laboratory followed the specified analytical method. With the exceptions noted above, accuracy was acceptable as demonstrated by the laboratory control sample and matrix spike recoveries and precision was acceptable as demonstrated by the laboratory and field duplicate RPD values.

Results were estimated due to a matrix spike recovery outlier and laboratory duplicate precision outliers.

All data, as qualified, are acceptable for use.

DATA VALIDATION REPORT
Art Brass Plating - October 2014 Soil Sampling
Sulfide by EPA 376.2 and Total Solids by SM2540G

This report documents the review of analytical data from the analysis of soil samples and the associated laboratory and field quality control (QC) samples. Analytical Resources, Inc., Tukwila, Washington, analyzed the samples. Refer to the **Sample Index** for a list of the individual samples.

SDG	Number of Samples	Validation Level
ZG61	11 Soil	EPA Stage 2A
ZG64	11 Soil	EPA Stage 2A
ZG65	13 Soil	EPA Stage 2A

I. DATA PACKAGE COMPLETENESS

The laboratory submitted all required deliverables. The laboratory followed adequate corrective action processes and all anomalies were discussed in the case narrative.

II. TECHNICAL DATA VALIDATION

The QC requirements for review are listed below.

√	Sample Receipt, Preservation, and Holding Times	**1**	Field Duplicates
√	Method Blanks	√	Laboratory Replicates
√	Laboratory Control Samples (LCS)	√	Reported Results
2	Matrix Spikes (MS)	√	Reporting Limits

✓Method quality objectives (MQO) and QC criteria have been met. No outliers are noted or discussed.
[1] Quality control results are discussed below, but no data were qualified.
[2] Quality control outliers that impact the reported data were noted. Data qualifiers were issued as discussed below.

Matrix Spikes

SDG ZG61: The sulfide matrix spike analysis was performed using Sample O_09_s053_0003. The percent recovery (%R) value was less than the lower control limit. The sulfide results for all associated samples were estimated (J/UJ-8L) to indicate a potential low bias.

SDGs ZG64, ZG65: The sulfide MS analysis was performed using Sample O_09_s054_2730. The %R value was less than the lower control limit. The sulfide results for all associated samples were estimated (J/UJ-8L) to indicate a potential low bias.

Field Duplicates

The relative percent difference (RPD) control limit is 35% for results greater than the reporting limit (RL). For results less than five times the RL, the difference between the sample and duplicate must be less than two times the RL.

SDG ZG61: The data for one set of field duplicates was submitted: O-09_s053_2730 and O-09_s153_2730. All field precision criteria were met.

SDG ZG64: The data for one set of field duplicates was submitted: O-09_s054_2730 and O-09_s154_2730. All field precision criteria were met.

IV. OVERALL ASSESSMENT

As was determined by this evaluation, the laboratory followed the specified analytical method. With the exceptions noted above, accuracy was acceptable as demonstrated by the laboratory control sample and matrix spike recoveries. Precision was acceptable as demonstrated by the field duplicate and laboratory duplicate RPD values.

Sulfide results were estimated due to matrix spike recovery outliers.

All data, as qualified, are acceptable for use.

ECOCHEM
Data Quality

APPENDIX A

DATA QUALIFIER DEFINITIONS
REASON CODES
AND CRITERIA TABLES

DATA VALIDATION QUALIFIER CODES
Based on National Functional Guidelines

The following definitions provide brief explanations of the qualifiers assigned to results in the data review process.

U	The analyte was analyzed for, but was not detected above the reported sample quantitation limit.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
NJ	The analysis indicates the presence of an analyte that has been "tentatively identified" and the associated numerical value represents the approximate concentration.
UJ	The analyte was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.
R	The sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.

The following is an EcoChem qualifier that may also be assigned during the data review process:

DNR	Do not report; a more appropriate result is reported from another analysis or dilution.

DATA QUALIFIER REASON CODES

Group	Code	Reason for Qualification
Sample Handling	1	Improper Sample Handling or Sample Preservation (i.e., headspace, cooler temperature, pH, summa canister pressure); Exceeded Holding Times
Instrument Performance	24	Instrument Performance (i.e., tune, resolution, retention time window, endrin breakdown, lock-mass)
	5A	Initial Calibration (RF, %RSD, r^2)
	5B	Calibration Verification (ICV, CCV, CCAL; RF, %D, %R) Use bias flags (H,L)[1] where appropriate
Blank Contamination	6	Field Blank Contamination (Equipment Rinsate, Trip Blank, etc.)
	7	Lab Blank Contamination (i.e., method blank, instrument blank, etc.) Use low bias flag (L)[1] for negative instrument blanks
Precision and Accuracy	8	Matrix Spike (MS &/or MSD) Recoveries Use bias flags (H,L)[1] where appropriate
	9	Precision (all replicates: LCS/LCSD, MS/MSD, Lab Replicate, Field Replicate)
	10	Laboratory Control Sample Recoveries (a.k.a. Blank Spikes) Use bias flags (H,L)[1] where appropriate
	12	Reference Material Use bias flags (H,L)[1] where appropriate
	13	Surrogate Spike Recoveries (a.k.a. labeled compounds, recovery standards) Use bias flags (H,L)[1] where appropriate
Interferences	16	ICP/ICP-MS Serial Dilution Percent Difference
	17	ICP/ICP-MS Interference Check Standard Recovery Use bias flags (H,L)[1] where appropriate
	19	Internal Standard Performance (i.e., area, retention time, recovery)
	22	Elevated Detection Limit due to Interference (i.e., chemical and/or matrix)
	23	Bias from Matrix Interference (i.e. diphenyl ether, PCB/pesticides)
Identification and Quantitation	2	Chromatographic pattern in sample does not match pattern of calibration standard
	3	2nd column confirmation (RPD or %D)
	4	Tentatively Identified Compound (TIC) (associated with NJ only)
	20	Calibration Range or Linear Range Exceeded
	25	Compound Identification (i.e., ion ratio, retention time, relative abundance, etc.)
Miscellaneous	11	A more appropriate result is reported (multiple reported analyses i.e., dilutions, re-extractions, etc. Associated with “R” and “DNR” only)
	14	Other (See DV report for details)
	26	Method QC information not provided

[1] H = high bias indicated
L = low bias indicated

EcoChem Validation Guidelines for Metals Analysis by ICP
(Based on Inorganic NFG 1994 & 2004)

VALIDATION QC ELEMENT	ACCEPTANCE CRITERIA	ACTION	REASON CODE
Cooler Temperature and Preservation	Cooler temperature: 4°C ±2° Waters: Nitric Acid to pH < 2 For Dissolved Metals: 0.45um filter & preserve after filtration Tissues: Frozen	EcoChem Professional Judgment - no qualification based on cooler temperature outliers J(+)/UJ(-) if pH preservation requirements are not met	1
Holding Time	180 days from date sampled Frozen tissues - HT extended to 2 years	J(+)/UJ(-) if holding time exceeded	1
Initial Calibration	Blank + minimum 1 standard If more than 1 standard, r > 0.995	J(+)/UJ(-) if r < 0.995 (multi point cal)	5A
Initial Calibration Verification (ICV)	Independent source analyzed immediately after calibration %R within ±10% of true value	J(+)/UJ(-) if %R 75-89% J(+) if %R = 111-125% R(+) if %R > 125% R(+/-) if %R < 75%	5A
Continuing Calibration Verification (CCV)	Every ten samples, immediately following ICV/ICB and at end of run %R within ±10% of true value	J(+)/UJ(-) if %R = 75-89% J(+) if %R 111-125% R(+) if %R > 125% R(+/-) if %R < 75%	5B

Initial and Continuing Calibration Blank (ICB/CCB)	After each ICV and CCV
	every ten samples and end of run
	| blank | < IDL (MDL)
		Action level is 5x absolute value of blank conc.
		For (+) blanks, U(+) results < action level
		For (-) blanks, J(+)/UJ(-) results < action level
		(Refer to TM-02 for additional information)
			7

Reporting Limit Standard	2x RL analyzed beginning of run Not required for Al, Ba, Ca, Fe, Mg, Na, K %R = 70%-130% (50%-150% Sb, Pb, Tl)	R(-)/J(+) < 2x RL if %R <50% (< 30% Sb, Pb, Tl) J(+) < 2x RL, UJ(-) if %R 50-69% (30-49% Sb, Pb,Tl) J(+) < 2x RL if %R 130-180% (150-200% Sb, Pb, Tl) R(+) < 2x RL if %R > 180% (200% Sb, Pb, Tl)	14
Interference Check Samples (ICSA/ICSAB)	ICSAB %R 80 - 120% for all spiked elements | ICSA | < MDL for all unspiked elements except: K, Na	For samples with Al, Ca, Fe, or Mg > ICS levels R(+/-) if %R < 50% J(+) if %R >120% J(+)/UJ(-) if %R= 50 to 79% Use Professional Judgment for ICSA to determine if bias is present see **TM-09** for additional details	17
Method Blank	One per matrix per batch (batch not to exceed 20 samples) blank < MDL	Action level is 5x blank concentration U(+) results < action level	7
Laboratory Control Sample (LCS)	One per matrix per batch		10
	Blank Spike: %R within 80-120%	R(+/-) if %R < 50% J(+)/UJ(-) if %R = 50-79% J(+) if %R >120%	
	CRM: Result within manufacturer's certified acceptance range or project guidelines	J(+)/UJ(-) if < LCL, J(+) if > UCL	

EcoChem Validation Guidelines for Metals Analysis by ICP
(Based on Inorganic NFG 1994 & 2004)

VALIDATION QC ELEMENT	ACCEPTANCE CRITERIA	ACTION	REASON CODE
Matrix Spikes	One per matrix per batch 75-125% for samples less than 4x spike level	J(+) if %R > 125% J(+)/UJ(-) if %R < 75% J(+)/R(-) if %R < 30% **or** J(+)/UJ(-) if Post Spike %R 75-125% Qualify all samples in batch	8
Post-digestion Spike	If Matrix Spike is outside 75-125%, spike at twice the sample conc.	No qualifiers assigned based on this element	
Laboratory Duplicate (or MS/MSD)	One per matrix per batch RPD < 20% for samples > 5x RL Diff ≤ RL for samples >RL and < 5x RL (Diff ≤ 2x RL for solids)	J(+)/UJ(-) if RPD > 20% or diff > RL (2x RL for solids) qualify all samples in batch	9
Serial Dilution	5x dilution one per matrix %D < 10% for original sample conc. > 50x MDL	J(+)/UJ(-) if %D >10% qualify all samples in batch	16
Field Blank	Blank < MDL	Action level is 5x blank conc. U(+) sample values < action level in associated field samples only	6
Field Duplicate	For results > 5x RL: Water: RPD < 35% Solid: RPD < 50% For results < 5 x RL: Water: Diff < RL Solid: Diff < 2x RL	J(+)/UJ(-) in parent samples only	9
Linear Range	Sample concentrations must fall within range	J values over range	20

EcoChem Validation Guidelines for Conventional Chemistry Analysis
(Based on EPA Standard Methods)

VALIDATION QC ELEMENT	ACCEPTANCE CRITERIA	ACTION	REASON CODE
Cooler Temperature and Preservation	Cooler Temperature 4°C ±2°C Preservation: Method Specific	Use Professional Judgment to qualify based to qualify for coole temp outliers J(+)/UJ(-) if preservation requirements not met	1
Holding Time	Method Specific	Professional Judgment J(+)/UJ(-) if holding time exceeded J(+)/R(-) if HT exceeded by > 3X	1
Initial Calibration	Method specific r>0.995	Use professional judgment J(+)/UJ(-) for r < 0.995	5A
Initial Calibration Verification (ICV)	Where applicable to method Independent source analyzed immediately after calibration %R method specific, usually 90% - 110%	R(+/-) if %R significantly < LCL J(+)/UJ(-) if %R < LCL J(+) if %R > UCL R(+) if %R significantly > UCL	5A
Continuing Cal Verification (CCV)	Where applicable to method Every ten samples, immed. following ICV/ICB and end of run %R method specific, usually 90% - 110%	R(+/-) if %R significantly < LCL J(+)/UJ(-) if %R < LCL J(+) if %R > UCL R(+) if %R significantly > UCL	5B

Initial and Continuing Cal Blanks (ICB/CCB)	Where applicable to method
	After each ICV and CCV every ten samples and end of run
	| blank| < MDL
		Action level is 5x absolute value of blank conc.
		For (+) blanks, U(+) results < action level
		For (-) blanks, J(+)/UJ(-) results < action level
		refer to TM-02 for additional details
			7

Method Blank	One per matrix per batch
	(not to exceed 20 samples)
	blank < MDL
		Action level is 5x absolute value of blank conc.
		For (+) blk value, U(+) results < action level
		For (-) blk value, J(+)/UJ(-) results < action level
			7

Laboratory Control Sample	Waters: One per matrix per batch %R (80-120%)	R(+/-) if %R < 50% J(+)/UJ(-) if %R = 50-79% J(+) if %R >120%	10
	Soils: One per matrix per batch Result within manufacturer's certified acceptance range	J(+)/UJ(-) if < LCL, J(+) if > UCL	10
Matrix Spike	One per matrix per batch; 5% frequency 75-125% for samples less than 4 x spike level	J(+) if %R > 125% or < 75% UJ(-) if %R = 30-74% R(+/-) results < IDL if %R < 30%	8
Laboratory Duplicate	One per matrix per batch RPD <20% for samples > 5x RL Diff <RL for samples >RL and <5 x RL (may use RPD < 35%, Diff < 2X RL for solids)	J(+)/UJ(-) if RPD > 20% or diff > RL all samples in batch	9

EcoChem Validation Guidelines for Conventional Chemistry Analysis
(Based on EPA Standard Methods)

VALIDATION QC ELEMENT	ACCEPTANCE CRITERIA	ACTION	REASON CODE
Field Blank	blank < MDL	Action level is 5x blank conc. U(+) sample values < action level in associated field samples only	6
Field Duplicate	For results > 5X RL: Water: RPD < 35% Solid: RPD < 50% For results < 5 x RL: Water: Diff<RL Solid: Diff < 2X RL	J(+)/UJ(-) in parent samples only	9

ECOCHEM
Data Quality

APPENDIX B

QUALIFIED DATA SUMMARY TABLE

QUALIFIED DATA SUMMARY TABLE
Art Brass Plating - October 2014 Soil Sampling

SDG	Sample ID	Laboratory ID	Method	Analyte	Result	Units	Lab Flag	DV Qual	Reason Code
ZG61	O-09_s053_0003	14-22765-ZG61A	EPA376.2	Sulfide	1.22	mg/kg	U	UJ	8L
ZG61	O-09_s053_0306	14-22766-ZG61B	EPA376.2	Sulfide	1.19	mg/kg	U	UJ	8L
ZG61	O-09_s053_0609	14-22767-ZG61C	EPA376.2	Sulfide	1.26	mg/kg	U	UJ	8L
ZG61	O-09_s053_0912	14-22768-ZG61D	EPA376.2	Sulfide	2.96	mg/kg		J	8L
ZG61	O-09_s053_1215	14-22769-ZG61E	EPA376.2	Sulfide	2.1	mg/kg		J	8L
ZG61	O-09_s053_1821	14-22770-ZG61F	EPA376.2	Sulfide	1.24	mg/kg	U	UJ	8L
ZG61	O-09_s053_2124	14-22771-ZG61G	EPA376.2	Sulfide	1.52	mg/kg		J	8L
ZG61	O-09_s053_2427	14-22772-ZG61H	EPA376.2	Sulfide	1.26	mg/kg	U	UJ	8L
ZG61	O-09_s053_2730	14-22773-ZG61I	EPA376.2	Sulfide	1.3	mg/kg	U	UJ	8L
ZG61	O-09_s153_2730	14-22774-ZG61J	EPA376.2	Sulfide	1.28	mg/kg	U	UJ	8L
ZG61	O-09_s053_1518	14-22775-ZG61K	EPA376.2	Sulfide	1.2	mg/kg	U	UJ	8L
ZG64	O-09_s054_0003	14-22776-ZG64A	EPA376.2	Sulfide	1.07	mg/kg	U	UJ	8L
ZG64	O-09_s054_0003	14-22776-ZG64A	SW6010C	Iron	18,600	mg/kg		J	9
ZG64	O-09_s054_0003	14-22776-ZG64A	SW6010C	Copper	25.2	mg/kg		J	9
ZG64	O-09_s054_0003	14-22776-ZG64A	SW6010C	Zinc	148	mg/kg		J	8L
ZG64	O-09_s054_0306	14-22777-ZG64B	EPA376.2	Sulfide	1.2	mg/kg	U	UJ	8L
ZG64	O-09_s054_0306	14-22777-ZG64B	SW6010C	Iron	12,800	mg/kg		J	9
ZG64	O-09_s054_0306	14-22777-ZG64B	SW6010C	Copper	15.4	mg/kg		J	9
ZG64	O-09_s054_0306	14-22777-ZG64B	SW6010C	Zinc	28	mg/kg		J	8L
ZG64	O-09_s054_0609	14-22778-ZG64C	EPA376.2	Sulfide	3.48	mg/kg		J	8L
ZG64	O-09_s054_0609	14-22778-ZG64C	SW6010C	Iron	10,900	mg/kg		J	9
ZG64	O-09_s054_0609	14-22778-ZG64C	SW6010C	Copper	15	mg/kg		J	9
ZG64	O-09_s054_0609	14-22778-ZG64C	SW6010C	Zinc	25	mg/kg		J	8L
ZG64	O-09_s054_0912	14-22779-ZG64D	EPA376.2	Sulfide	2.74	mg/kg		J	8L
ZG64	O-09_s054_0912	14-22779-ZG64D	SW6010C	Iron	14,600	mg/kg		J	9
ZG64	O-09_s054_0912	14-22779-ZG64D	SW6010C	Copper	13.2	mg/kg		J	9
ZG64	O-09_s054_0912	14-22779-ZG64D	SW6010C	Zinc	30	mg/kg		J	8L
ZG64	O-09_s054_1215	14-22780-ZG64E	EPA376.2	Sulfide	2.53	mg/kg		J	8L
ZG64	O-09_s054_1215	14-22780-ZG64E	SW6010C	Iron	9,180	mg/kg		J	9
ZG64	O-09_s054_1215	14-22780-ZG64E	SW6010C	Copper	7	mg/kg		J	9
ZG64	O-09_s054_1215	14-22780-ZG64E	SW6010C	Zinc	19	mg/kg		J	8L
ZG64	O-09_s054_1518	14-22781-ZG64F	EPA376.2	Sulfide	1.23	mg/kg	U	UJ	8L
ZG64	O-09_s054_1518	14-22781-ZG64F	SW6010C	Iron	12,700	mg/kg		J	9
ZG64	O-09_s054_1518	14-22781-ZG64F	SW6010C	Copper	10.9	mg/kg		J	9
ZG64	O-09_s054_1518	14-22781-ZG64F	SW6010C	Zinc	21	mg/kg		J	8L
ZG64	O-09_s054_1821	14-22782-ZG64G	EPA376.2	Sulfide	2.84	mg/kg		J	8L
ZG64	O-09_s054_1821	14-22782-ZG64G	SW6010C	Iron	10,100	mg/kg		J	9
ZG64	O-09_s054_1821	14-22782-ZG64G	SW6010C	Copper	8.1	mg/kg		J	9
ZG64	O-09_s054_1821	14-22782-ZG64G	SW6010C	Zinc	18	mg/kg		J	8L
ZG64	O-09_s054_2124	14-22783-ZG64H	EPA376.2	Sulfide	1.3	mg/kg	U	UJ	8L
ZG64	O-09_s054_2124	14-22783-ZG64H	SW6010C	Iron	11,300	mg/kg		J	9
ZG64	O-09_s054_2124	14-22783-ZG64H	SW6010C	Copper	12.5	mg/kg		J	9
ZG64	O-09_s054_2124	14-22783-ZG64H	SW6010C	Zinc	19	mg/kg		J	8L
ZG64	O-09_s054_2427	14-22784-ZG64I	EPA376.2	Sulfide	1.26	mg/kg	U	UJ	8L
ZG64	O-09_s054_2427	14-22784-ZG64I	SW6010C	Iron	8,940	mg/kg		J	9
ZG64	O-09_s054_2427	14-22784-ZG64I	SW6010C	Copper	7.2	mg/kg		J	9
ZG64	O-09_s054_2427	14-22784-ZG64I	SW6010C	Zinc	16	mg/kg		J	8L
ZG64	O-09_s054_2730	14-22785-ZG64J	EPA376.2	Sulfide	2.12	mg/kg		J	8L
ZG64	O-09_s054_2730	14-22785-ZG64J	SW6010C	Iron	10,900	mg/kg		J	9

QUALIFIED DATA SUMMARY TABLE
Art Brass Plating - October 2014 Soil Sampling

SDG	Sample ID	Laboratory ID	Method	Analyte	Result	Units	Lab Flag	DV Qual	Reason Code
ZG64	O-09_s054_2730	14-22785-ZG64J	SW6010C	Copper	17.8	mg/kg		J	9
ZG64	O-09_s054_2730	14-22785-ZG64J	SW6010C	Zinc	18	mg/kg		J	8L
ZG64	O-09_s154_2730	14-22786-ZG64K	EPA376.2	Sulfide	2.17	mg/kg		J	8L
ZG64	O-09_s154_2730	14-22786-ZG64K	SW6010C	Iron	11,100	mg/kg		J	9
ZG64	O-09_s154_2730	14-22786-ZG64K	SW6010C	Copper	20.2	mg/kg		J	9
ZG64	O-09_s154_2730	14-22786-ZG64K	SW6010C	Zinc	18	mg/kg		J	8L
ZG65	O-09_s055_0003	14-22787-ZG65A	EPA376.2	Sulfide	1.11	mg/kg	U	UJ	8L
ZG65	O-09_s055_0306	14-22788-ZG65B	EPA376.2	Sulfide	1.2	mg/kg	U	UJ	8L
ZG65	O-09_s055_0609	14-22789-ZG65C	EPA376.2	Sulfide	1.24	mg/kg	U	UJ	8L
ZG65	O-09_s055_0912	14-22790-ZG65D	EPA376.2	Sulfide	2.6	mg/kg		J	8L
ZG65	O-09_s055_1215	14-22791-ZG65E	EPA376.2	Sulfide	1.22	mg/kg	U	UJ	8L
ZG65	O-09_s055_1518	14-22792-ZG65F	EPA376.2	Sulfide	1.61	mg/kg		J	8L
ZG65	O-09_s055_1821	14-22793-ZG65G	EPA376.2	Sulfide	1.81	mg/kg		J	8L
ZG65	O-09_s055_2124	14-22794-ZG65H	EPA376.2	Sulfide	2.33	mg/kg		J	8L
ZG65	O-09_s055_2427	14-22795-ZG65I	EPA376.2	Sulfide	1.46	mg/kg		J	8L
ZG65	O-09_s055_2730	14-22796-ZG65J	EPA376.2	Sulfide	1.27	mg/kg	U	UJ	8L
ZG65	O-09_s055_3033	14-22797-ZG65K	EPA376.2	Sulfide	1.22	mg/kg	U	UJ	8L
ZG65	O-09_s055_3336	14-22798-ZG65L	EPA376.2	Sulfide	1.76	mg/kg		J	8L
ZG65	O-09_s055_3639	14-22799-ZG65M	EPA376.2	Sulfide	1.24	mg/kg	U	UJ	8L

Analytical Resources, Incorporated
Analytical Chemists and Consultants

12 November 2014

Dana Cannon
Aspect Consulting
401 Second Avenue, Suite 201
Seattle, WA 98104

RE: Client Project: 050067, Art Brass Plating
ARI Jobs: ZG61, ZG64, ZG65

Dear Dana:

Please find enclosed the original chain of custody records and the final results for samples from the project referenced above.

Analytical Resources, Inc. accepted thirty-five soil samples in good condition on October 22, 2014. The samples were analyzed for sulfide, sulfur and total metals as requested. The analysis for sulfur was sub-contracted to Horizon Labs in Price, UT.

A matrix spike (MS) was prepared and analyzed for sulfide in conjunction with sample O-09_s053_003. The percent recovery was low following the analysis of the MS. Since the percent recovery for sulfide was within acceptable QC limits for the corresponding LCS, it was concluded that the sample matrix was the cause of the low MS recovery. No corrective actions were taken.

A matrix duplicate (MD) was prepared and analyzed for total metals in conjunction with sample O-09_s053_0003. The RPD for cadmium was high following the analysis of the MD. Since the percent recovery for cadmium was within acceptable QC limits for the corresponding LCS, it was concluded that a lack of sample homogeneity was the cause of the high RPD. No corrective actions were taken.

An MS was prepared and analyzed for total metals in conjunction with sample O-09_s053_0003. The percent recoveries for iron and manganese were not within control limits following the analysis of the MS. Since the percent recoveries for all elements were within acceptable QC limits for the corresponding LCS, it was concluded that the sample matrix was the cause of the poor MS recoveries. No corrective actions were taken.

An MS was prepared and analyzed for sulfide in conjunction with sample O-09_s054_2730. The percent recovery was low following the analysis of the MS. Since the percent recovery for sulfide was within acceptable QC limits for the corresponding LCS, it was concluded that the sample matrix was the cause of the low MS recovery. No corrective actions were taken.

Cannon, Aspect Consulting
Art Brass Plating
Soil
ZG61, ZG64, ZG65

12 November 2014

An MD was prepared and analyzed for total metals in conjunction with sample O-09_s054_0003. The RPDs for copper and iron were high following the analysis of the MD. Since the percent recoveries for all elements were within acceptable QC limits for the corresponding LCS, it was concluded that a lack of sample homogeneity was the cause of the high RPDs. No corrective actions were taken.

An MS was prepared and analyzed for total metals in conjunction with sample O-09_s054_0003. The percent recoveries for iron and zinc were not within control limits following the analysis of the MS. Since the percent recoveries for all elements were within acceptable QC limits for the corresponding LCS, it was concluded that the sample matrix was the cause of the poor MS recoveries. No corrective actions were taken.

An MS was prepared and analyzed for total metals in conjunction with sample O-09_s055_0003. The percent recoveries for iron and manganese were not within control limits following the analysis of the MS. Since the percent recoveries for all elements were within acceptable QC limits for the corresponding LCS, it was concluded that the sample matrix was the cause of the poor MS recoveries. No corrective actions were taken.

There were no other incidents of note associated with these analyses.

Copies of these reports and all raw data will be kept on file at ARI. If you have questions or require additional information, please feel free to contact me at your convenience.

Sincerely,

ANALYTICAL RESOURCES, INC.

Mark D. Harris
Project Manager
206/695-6210
markh@arilabs.com

Enclosures

cc: Files ZG61, ZG64, ZG65

MDH/mdh

11K7 DIC-1155

JESSICA C. GOIN, PH.D.
Geomicrobiologist

ANCHOR QEA

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ANCHOR QEA

Jessica Goin
Suite 750
421 SW 6th Ave
Portland OR 97204

Line	Field Sample ID	Collection Date/Time	Matrix	No. of Containers	Test Parameters: TOTAL SULFUR	BY COMB	TOTAL METALS	(Cd, Cu, Fe,	Mn, Ni, Zn)	Comments/Preservation
1	O-09_s053_0003	10/15	S	1	✓		✓			
2	O-09_s053_0306			1	✓		✓			
3	O-09_s053_0609			1	✓		✓			
4	O-09_s053_0912			1	✓		✓			
5	O-09_s053_1215			1	✓		✓			
6	O-09_s053_1518			1	✓		✓			
7	O-09_s053_1821			1	✓		✓			
8	O-09_s053_2124			1	✓		✓			
9	O-09_s053_2427			1	✓		✓			
10	O-09_s053_2730			2	✓		✓			PLEASE COMPOSITE
11	O-09_s153_2730			2	✓		✓			PLEASE COMPOSITE
12										
13										
14										
15										

Notes:
LOG UNDER ASPECT PROJECT # 050067 (ART BRASS)
PLEASE COMPOSITE SAMPLES REC. IN MULTIPLE JARS

Relinquished By: J GOIN
Company: Anchor QEA
Signature/Printed Name
Date/Time: 10/21

Received By: Taylor Streeter
Company: ARI
Signature/Printed Name: 10-22-14 1030
Date/Time

Relinquished By:
Company:
Signature/Printed Name
Date/Time

Received By:
Company:
Signature/Printed Name
Date/Time

Distribution: A copy will be made for the laboratory and client. The Project file will retain the original.

Analytical Resources, Incorporated
Analytical Chemists and Consultants

Cooler Receipt Form

ARI Client: Aspect

Project Name: Art Brass

COC No(s): ________ NA

Delivered by: [✓ Fed-Ex] UPS Courier Hand Delivered Other: ________

Assigned ARI Job No: ZG61

Tracking No: 7715 70094699 NA

Preliminary Examination Phase:

Were intact, properly signed and dated custody seals attached to the outside of to cooler?	YES	[✓ NO]
Were custody papers included with the cooler?	[✓ YES]	NO
Were custody papers properly filled out (ink, signed, etc.)	[✓ YES]	NO

Temperature of Cooler(s) (°C) (recommended 2.0-6.0 °C for chemistry) 13 5.4

Time: ________

If cooler temperature is out of compliance fill out form 00070F

Temp Gun ID#: 90877952

Cooler Accepted by: TS Date: 10-22-14 Time: 1030

Complete custody forms and attach all shipping documents

Log-In Phase:

Was a temperature blank included in the cooler?		YES	[✓ NO]
Was sufficient ice used (if appropriate)?	NA	[✓ YES]	NO
Were all bottles sealed in individual plastic bags?		YES	[✓ NO]
Did all bottles arrive in good condition (unbroken)?		[✓ YES]	NO
Were all bottle labels complete and legible?		[✓ YES]	NO
Did the number of containers listed on COC match with the number of containers received?		[✓ YES]	NO
Did all bottle labels and tags agree with custody papers?		[✓ YES]	NO
Were all bottles used correct for the requested analyses?		[✓ YES]	NO
Do any of the analyses (bottles) require preservation? (attach preservation sheet, excluding VOCs)	[✓ NA]	YES	NO
Were all VOC vials free of air bubbles?	[✓ NA]	YES	NO
Was sufficient amount of sample sent in each bottle?		[✓ YES]	NO
Date VOC Trip Blank was made at ARI	[✓ NA]	________	

What kind of packing material was used? [✓ Bubble Wrap] Wet Ice [✓ Gel Packs] Baggies Foam Block Paper Other: ________

Was Sample Split by ARI: [✓ NA] YES Date/Time: ________ Equipment: ________ Split by: ________

Samples Logged by: TS Date: 10-22-14 Time: 1559

***** Notify Project Manager of discrepancies or concerns *****

Sample ID on Bottle	Sample ID on COC	Sample ID on Bottle	Sample ID on COC

Additional Notes, Discrepancies, & Resolutions:

By: Date:

Small Air Bubbles ~2mm • • • •	Small → "sm" (< 2 mm)
Peabubbles' 2-4 mm ● ● ● ● ●	Peabubbles → "pb" (2 to < 4 mm)
LARGE Air Bubbles > 4 mm ● ● ●	Large → "lg" (4 to < 6 mm)
	Headspace → "hs" (> 6 mm)

Analytical Resources,
Incorporated
Analytical Chemists and
Consultants

Data Reporting Qualifiers

Effective 12/31/13

Inorganic Data

U	Indicates that the target analyte was not detected at the reported concentration
*	Duplicate RPD is not within established control limits
B	Reported value is less than the CRDL but ≥ the Reporting Limit
N	Matrix Spike recovery not within established control limits
NA	Not Applicable, analyte not spiked
H	The natural concentration of the spiked element is so much greater than the concentration spiked that an accurate determination of spike recovery is not possible
L	Analyte concentration is ≤5 times the Reporting Limit and the replicate control limit defaults to ±1 RL instead of the normal 20% RPD

Organic Data

U	Indicates that the target analyte was not detected at the reported concentration
*	Flagged value is not within established control limits
B	Analyte detected in an associated Method Blank at a concentration greater than one-half of ARI's Reporting Limit or 5% of the regulatory limit or 5% of the analyte concentration in the sample.
J	Estimated concentration when the value is less than ARI's established reporting limits
D	The spiked compound was not detected due to sample extract dilution
E	Estimated concentration calculated for an analyte response above the valid instrument calibration range. A dilution is required to obtain an accurate quantification of the analyte.

Q	Indicates a detected analyte with an initial or continuing calibration that does not meet established acceptance criteria (<20%RSD, <20%Drift or minimum RRF).
S	Indicates an analyte response that has saturated the detector. The calculated concentration is not valid; a dilution is required to obtain valid quantification of the analyte
NA	The flagged analyte was not analyzed for
NR	Spiked compound recovery is not reported due to chromatographic interference
NS	The flagged analyte was not spiked into the sample
M	Estimated value for an analyte detected and confirmed by an analyst but with low spectral match parameters. This flag is used only for GC-MS analyses
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a “tentative identification”
Y	The analyte is not detected at or above the reported concentration. The reporting limit is raised due to chromatographic interference. The Y flag is equivalent to the U flag with a raised reporting limit.
EMPC	Estimated Maximum Possible Concentration (EMPC) defined in EPA Statement of Work DLM02.2 as a value “calculated for 2,3,7,8-substituted isomers for which the quantitation and /or confirmation ion(s) has signal to noise in excess of 2.5, but does not meet identification criteria” **(Dioxin/Furan analysis only)**
C	The analyte was positively identified on only one of two chromatographic columns. Chromatographic interference prevented a positive identification on the second column
P	The analyte was detected on both chromatographic columns but the quantified values differ by ≥40% RPD with no obvious chromatographic interference
X	Analyte signal includes interference from polychlorinated diphenyl ethers. **(Dioxin/Furan analysis only)**
Z	Analyte signal includes interference from the sample matrix or perfluorokerosene ions. **(Dioxin/Furan analysis only)**

Geotechnical Data

A	The total of all fines fractions. This flag is used to report total fines when only sieve analysis is requested and balances total grain size with sample weight.
F	Samples were frozen prior to particle size determination
SM	Sample matrix was not appropriate for the requested analysis. This normally refers to samples contaminated with an organic product that interferes with the sieving process and/or moisture content, porosity and saturation calculations
SS	Sample did not contain the proportion of “fines” required to perform the pipette portion of the grain size analysis
W	Weight of sample in some pipette aliquots was below the level required for accurate weighting

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_0003
ARI ID: 14-22765 ZG61A

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	81.47	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.22	< 1.22	U

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

**ANALYTICAL
RESOURCES
INCORPORATED**

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_0306
ARI ID: 14-22766 ZG61B

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	83.78	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.19	< 1.19	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_0609
ARI ID: 14-22767 ZG61C

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.83	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.26	< 1.26	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: 0-09_s053_0912
ARI ID: 14-22768 ZG61D

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	76.66
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.29	2.96

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_1215
ARI ID: 14-22769 ZG61E

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.93
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.26	2.10

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_1821
ARI ID: 14-22770 ZG61F

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	79.09	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.24	< 1.24	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_2124
ARI ID: 14-22771 ZG61G

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.03
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.24	1.52

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_2427
ARI ID: 14-22772 ZG61H

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.62
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.26	< 1.26 U

RL	Analytical reporting limit
U	Undetected at reported detection limit

ANALYTICAL RESOURCES INCORPORATED

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_2730
ARI ID: 14-22773 ZG61I

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	76.88	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.30	< 1.30	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

ANALYTICAL RESOURCES INCORPORATED

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s153_2730
ARI ID: 14-22774 ZG61J

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	76.96	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.28	< 1.28	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Client ID: O-09_s053_1518
ARI ID: 14-22775 ZG61K

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	82.57	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.20	< 1.20	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

METHOD BLANK RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: NA
Date Received: NA

Analyte	Date	Units	Blank	QC ID
Preserved Total Solids	10/28/14	Percent	< 0.01 U	ICB
Sulfide	10/27/14	mg/kg	< 0.05 U	PREP

LAB CONTROL RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: NA
Date Received: NA

Analyte/Method	QC ID	Date	Units	LCS	Spike Added	Recovery
Sulfide SM4500-S2D	PREP	10/27/14	mg/kg	7.92	7.25	109.2%

REPLICATE RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Analyte	Date	Units	Sample	Replicate(s)	RPD/RSD
ARI ID: ZG61A Client ID: O-09_s053_0003					
Preserved Total Solids	10/28/14	Percent	81.47	82.37	1.1%
Sulfide	10/27/14	mg/kg	< 1.22	3.70	NA

MS/MSD RESULTS-CONVENTIONALS
ZG61-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Analyte	Date	Units	Sample	Spike	Spike Added	Recovery
ARI ID: ZG61A Client ID: O-09_s053_0003						
Sulfide	10/27/14	mg/kg	< 1.22	50.6	178	28.4%

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s053_0003
SAMPLE

Lab Sample ID: ZG61A
LIMS ID: 14-22765
Matrix: Soil
Data Release Authorized
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 85.9%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	**7440-43-9**	**Cadmium**	0.2	**0.3**	
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**21.8**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**17,100**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**243**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**20**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**59**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s053_0003
DUPLICATE

Lab Sample ID: ZG61A
LIMS ID: 14-22765
Matrix: Soil
Data Release Authorized
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

MATRIX DUPLICATE QUALITY CONTROL REPORT

Analyte	**Analysis Method**	**Sample**	**Duplicate**	**RPD**	**Control Limit**	**Q**
Cadmium	6010C	0.3	0.4	28.6%	+/- 0.2	L
Copper	6010C	21.8	23.3	6.7%	+/- 20%	
Iron	6010C	17,100	18,400	7.3%	+/- 20%	
Manganese	6010C	243	235	3.3%	+/- 20%	
Nickel	6010C	20	19	5.1%	+/- 20%	
Zinc	6010C	59	70	17.1%	+/- 20%	

Reported in mg/kg-dry

*-Control Limit Not Met
L-RPD Invalid, Limit = Detection Limit

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INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s053_0003
MATRIX SPIKE

Lab Sample ID: ZG61A
LIMS ID: 14-22765
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

MATRIX SPIKE QUALITY CONTROL REPORT

Analyte	Analysis Method	Sample	Spike	Spike Added	% Recovery	Q
Cadmium	6010C	0.3	59.9	58.1	103%	
Copper	6010C	21.8	78.1	58.1	96.9%	
Iron	6010C	17,100	15,600	232	-647%	H
Manganese	6010C	243	264	58.1	36.1%	H
Nickel	6010C	20	74	58.1	92.9%	
Zinc	6010C	59	111	58.1	89.5%	

Reported in mg/kg-dry

N-Control Limit Not Met
H-% Recovery Not Applicable, Sample Concentration Too High
NA-Not Applicable, Analyte Not Spiked

Percent Recovery Limits: 75-125%

ANALYTICAL
RESOURCES
INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s053_0306
SAMPLE

Lab Sample ID: ZG61B
LIMS ID: 14-22766
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 85.1%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**21.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**12,200**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**96.3**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**55**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**23**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s053_0609
SAMPLE

Lab Sample ID: ZG61C
LIMS ID: 14-22767
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 78.0%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**74.1**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**11,900**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**102**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**684**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**34**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s053_0912
SAMPLE

Lab Sample ID: ZG61D
LIMS ID: 14-22768
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 76.7%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.3	0.3	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.3	**21.9**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**12,100**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**90.6**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**440**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**24**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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INORGANICS ANALYSIS DATA SHEET
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Sample ID: O-09_s053_1215
SAMPLE

Lab Sample ID: ZG61E
LIMS ID: 14-22769
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 79.1%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**8.4**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**9,980**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**72.0**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**32**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**19**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
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Sample ID: O-09_s053_1821
SAMPLE

Lab Sample ID: ZG61F
LIMS ID: 14-22770
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 81.1%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**8.7**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**9,910**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**79.8**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**6**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**19**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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TOTAL METALS
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Sample ID: O-09_s053_2124
SAMPLE

Lab Sample ID: ZG61G
LIMS ID: 14-22771
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 79.7%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**8.2**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,700**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**81.0**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**6**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**19**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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TOTAL METALS
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Sample ID: 0-09_s053_2427
SAMPLE

Lab Sample ID: ZG61H
LIMS ID: 14-22772
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 79.8%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**6.8**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,500**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**74.1**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**5**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**16**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s053_2730
SAMPLE

Lab Sample ID: ZG61I
LIMS ID: 14-22773
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 79.9%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.0**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**8,540**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**67.5**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**5**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**15**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: 0-09_s153_2730
SAMPLE

Lab Sample ID: ZG61J
LIMS ID: 14-22774
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 78.8%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**8,830**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**68.4**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**6**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**16**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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INORGANICS ANALYSIS DATA SHEET
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Sample ID: O-09_s053_1518
SAMPLE

Lab Sample ID: ZG61K
LIMS ID: 14-22775
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/15/14
Date Received: 10/22/14

Percent Total Solids: 84.3%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**5.6**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**8,560**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**65.6**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**16**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**15**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
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Sample ID: METHOD BLANK

Lab Sample ID: ZG61MB
LIMS ID: 14-22766
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: NA
Date Received: NA

Percent Total Solids: NA

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	7440-50-8	Copper	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	7439-89-6	Iron	5	5	U
3050B	10/29/14	6010C	10/30/14	7439-96-5	Manganese	0.1	0.1	U
3050B	10/29/14	6010C	10/30/14	7440-02-0	Nickel	1	1	U
3050B	10/29/14	6010C	10/30/14	7440-66-6	Zinc	1	1	U

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
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Sample ID: LAB CONTROL

Lab Sample ID: ZG61LCS
LIMS ID: 14-22766
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG61-Aspect Consulting
Project: Art Brass
050067
Date Sampled: NA
Date Received: NA

BLANK SPIKE QUALITY CONTROL REPORT

Analyte	Analysis Method	Spike Found	Spike Added	% Recovery	Q
Cadmium	6010C	52.7	50.0	105%	
Copper	6010C	50.1	50.0	100%	
Iron	6010C	203	200	102%	
Manganese	6010C	50.3	50.0	101%	
Nickel	6010C	51	50	102%	
Zinc	6010C	50	50	100%	

Reported in mg/kg-dry

N-Control limit not met
NA-Not Applicable, Analyte Not Spiked
Control Limits: 80-120%

HORIZON LABORATORIES

General Offices: P.O. Box 995 Price, Utah 84501 435-637-4343
Laboratory: 545 East 100 North Price, Utah 84501

Submitted to:
Analytical Resources Inc.
Mark Harris
4611 S. 134th Place
Suite 100
Tukwila, WA 98168-3240

November 10, 2014

Date Sampled: 10/15/2014
Date Received: 10/29/2014

Sampled By: ARI
Identification By: ARI

Analysis Report #: See Below

Sample Identification:
Set ZG61
See Below

CERTIFICATE OF ANALYSIS

Analysis #	ARI ID	Sulfur (Acid Insoluble) %
89738	14-22765- ZG61A	1.69
89739	14-22766- ZG61B	0.01
89740	14-22767- ZG61C	0.03
89741	14-22768- ZG61D	0.14
89742	14-22769- ZG61E	0.04
89743	14-22770- ZG61F	0.01
89744	14-22771- ZG61G	0.01
89745	14-22772- ZG61H	0.01
89746	14-22773- ZG61I	0.01
89747	14-22774- ZG61J	0.01
89748	14-22775- ZG61K	0.01

Respectfully Submitted,
HORIZON LABORATORIES

Laboratory Manager

JESSICA C. GOIN, PH.D.
Geomicrobiologist

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ANCHOR QEA
Jessica Goin
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Line	Field Sample ID	Collection Date/Time	Matrix	No. of Containers	Test Parameters	Comments/Preservation
1	O-09_s054_0003	10/20	S	1		
2	O-09_s054_0306			1		
3	O-09_s054_0609			1		
4	O-09_s054_0912			1		
5	O-09_s054_1215			1		
6	O-09_s054_1518			1		
7	O-09_s054_1821			1		
8	O-09_s054_2124			1		
9	O-09_s054_2427			1		
10	O-09_s054_2730			2		PLEASE COMPOSITE
11	O-09_s154_2730			2		PLEASE COMPOSITE
12						
13						
14						
15						

Notes:
LOG UNDER ASPECT PROJECT # 050067 (ART BRASS)
PLEASE COMPOSITE SAMPLES REC. IN MULTIPLE JARS

Relinquished By: J. GOIN Company: ANCHOR QEA Signature/Printed Name Date/Time 10/21	Received By Tyler Streeter Company: ART Signature/Printed Name Tyler Streeter Date/Time 10-22-14 1030
Relinquished By: Company: Signature/Printed Name Date/Time	Received By: Company: Signature/Printed Name Date/Time

Distribution: A copy will be made for the laboratory and client. The Project file will retain the original.

Analytical Resources, Incorporated
Analytical Chemists and Consultants

Cooler Receipt Form

ARI Client: Aspect

COC No(s). ______ NA

Assigned ARI Job No: ZG64

Project Name: Art Grass

Delivered by: [✓ Fed-Ex] UPS Courier Hand Delivered Other. ______

Tracking No 7715 [illegible]49 NA

Preliminary Examination Phase:

Were intact, properly signed and dated custody seals attached to the outside of to cooler?	YES	[✓ NO]
Were custody papers included with the cooler?	[✓ YES]	NO
Were custody papers properly filled out (ink, signed, etc.)	[✓ YES]	NO

Temperature of Cooler(s) (°C) (recommended 2.0-6 0 °C for chemistry) 13 5.4
Time. ______

If cooler temperature is out of compliance fill out form 00070F

Temp Gun ID#: 0c37795

Cooler Accepted by: ______ Date: 10-22-11 Time: 1032

Complete custody forms and attach all shipping documents

Log-In Phase:

Was a temperature blank included in the cooler?		YES	[✓ NO]
Was sufficient ice used (if appropriate)?	NA	[✓ YES]	NO
Were all bottles sealed in individual plastic bags?		YES	[✓ NO]
Did all bottles arrive in good condition (unbroken)?		[✓ YES]	NO
Were all bottle labels complete and legible?		[✓ YES]	NO
Did the number of containers listed on COC match with the number of containers received?		[✓ YES]	NO
Did all bottle labels and tags agree with custody papers?		[✓ YES]	NO
Were all bottles used correct for the requested analyses?		[✓ YES]	NO
Do any of the analyses (bottles) require preservation? (attach preservation sheet, excluding VOCs)...	[✓ NA]	YES	NO
Were all VOC vials free of air bubbles?	[✓ NA]	YES	NO
Was sufficient amount of sample sent in each bottle?		[✓ YES]	NO
Date VOC Trip Blank was made at ARI	[✓ NA]		

What kind of packing material was used? [✓ Bubble Wrap] Wet Ice [✓ Gel Packs] Baggies Foam Block Paper Other: ______

Was Sample Split by ARI : [✓ NA] YES Date/Time: ______ Equipment ______ Split by: ______

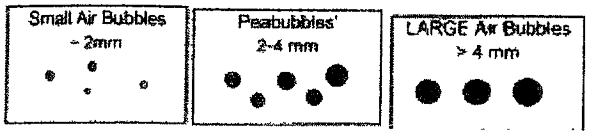
Samples Logged by: ______ Date. 10-22-11 Time: 1559

*** Notify Project Manager of discrepancies or concerns ***

Sample ID on Bottle	Sample ID on COC	Sample ID on Bottle	Sample ID on COC

Additional Notes, Discrepancies, & Resolutions:

By: ______ Date: ______



Small → "sm" (< 2 mm)
Peabubbles → "pb" (2 to < 4 mm)
Large → "lg" (4 to < 6 mm)
Headspace → "hs" (> 6 mm)

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_0003
ARI ID: 14-22776 ZG64A

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	89.95	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.07	< 1.07	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_0306
ARI ID: 14-22777 ZG64B

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	81.17	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.20	< 1.20	U

RL Analytical reporting limit
U Undetected at reported detection limit

ANALYTICAL RESOURCES INCORPORATED

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_0609
ARI ID: 14-22778 ZG64C

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.10
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.26	3.48

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

ANALYTICAL
RESOURCES
INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_0912
ARI ID: 14-22779 ZG64D

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.52
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.23	2.74

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_1215
ARI ID: 14-22780 ZG64E

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	78.87
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.27	2.53

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_1518
ARI ID: 14-22781 ZG64F

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	78.64	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.23	< 1.23	U

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_1821
ARI ID: 14-22782 ZG64G

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.10
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.20	2.84

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_2124
ARI ID: 14-22783 ZG64H

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	75.82	
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.30	< 1.30	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

ANALYTICAL RESOURCES INCORPORATED

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_2427
ARI ID: 14-22784 ZG64I

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	76.78
Sulfide	10/27/14 102714#1	SM4500-S2D	mg/kg	1.26	< 1.26 U

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s054_2730
ARI ID: 14-22785 ZG64J

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	78.71
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.25	2.12

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Client ID: O-09_s154_2730
ARI ID: 14-22786 ZG64K

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.94
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.26	2.17

RL	Analytical reporting limit
U	Undetected at reported detection limit

METHOD BLANK RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: NA
Date Received: NA

Analyte	Date	Units	Blank	QC ID
Preserved Total Solids	10/28/14	Percent	< 0.01 U	ICB
Sulfide	10/27/14	mg/kg	< 0.05 U	PREP
	10/28/14		< 0.05 U	PREP

LAB CONTROL RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

**ANALYTICAL
RESOURCES
INCORPORATED**

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: NA
Date Received: NA

Analyte/Method	QC ID	Date	Units	LCS	Spike Added	Recovery
Sulfide	PREP	10/27/14	mg/kg	7.92	7.25	109.2%
SM4500-S2D	PREP	10/28/14		7.67	7.25	105.8%

REPLICATE RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Analyte	**Date**	**Units**	**Sample**	**Replicate(s)**	**RPD/RSD**
ARI ID: ZG64A Client ID: O-09_s054_0003					
Preserved Total Solids	10/28/14	Percent	89.95	88.91	1.2%
ARI ID: ZG64J Client ID: O-09_s054_2730					
Sulfide	10/28/14	mg/kg	2.12	2.46	14.8%

MS/MSD RESULTS-CONVENTIONALS
ZG64-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Analyte	**Date**	**Units**	**Sample**	**Spike**	**Spike Added**	**Recovery**
ARI ID: ZG64J Client ID: O-09_s054_2730						
Sulfide	10/28/14	mg/kg	2.12	111	182	59.8%

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s054_0003
SAMPLE

Lab Sample ID: ZG64A
LIMS ID: 14-22776
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 92.2%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	**7440-43-9**	**Cadmium**	0.2	**0.5**	
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**25.2**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	5	**18,600**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**174**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**13**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**148**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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ANALYTICAL RESOURCES INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: 0-09_s054_0003
DUPLICATE

Lab Sample ID: ZG64A
LIMS ID: 14-22776
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

MATRIX DUPLICATE QUALITY CONTROL REPORT

Analyte	Analysis Method	Sample	Duplicate	RPD	Control Limit	Q
Cadmium	6010C	0.5	0.5	0.0%	+/- 0.2	L
Copper	6010C	25.2	149	142%	+/- 20%	*
Iron	6010C	18,600	12,400	40.0%	+/- 20%	*
Manganese	6010C	174	148	16.1%	+/- 20%	
Nickel	6010C	13	14	7.4%	+/- 20%	
Zinc	6010C	148	134	9.9%	+/- 20%	

Reported in mg/kg-dry

*-Control Limit Not Met
L-RPD Invalid, Limit = Detection Limit

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INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s054_0003
MATRIX SPIKE

Lab Sample ID: ZG64A
LIMS ID: 14-22776
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

MATRIX SPIKE QUALITY CONTROL REPORT

Analyte	Analysis Method	Sample	Spike	Spike Added	% Recovery	Q
Cadmium	6010C	0.5	53.0	53.6	97.9%	
Copper	6010C	25.2	77.0	53.6	96.6%	
Iron	6010C	18,600	13,100	215	-2560%	H
Manganese	6010C	174	220	53.6	85.8%	
Nickel	6010C	13	65	53.6	97.0%	
Zinc	6010C	148	183	53.6	65.3%	N

Reported in mg/kg-dry

N-Control Limit Not Met
H-% Recovery Not Applicable, Sample Concentration Too High
NA-Not Applicable, Analyte Not Spiked

Percent Recovery Limits: 75-125%

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s054_0306
SAMPLE

Lab Sample ID: ZG64B
LIMS ID: 14-22777
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 82.3%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**15.4**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**12,800**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**90.1**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**8**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**28**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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TOTAL METALS
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Sample ID: O-09_s054_0609
SAMPLE

Lab Sample ID: ZG64C
LIMS ID: 14-22778
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 79.5%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**15.0**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,900**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**81.0**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**9**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**25**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s054_0912
SAMPLE

Lab Sample ID: ZG64D
LIMS ID: 14-22779
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 81.7%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**13.2**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**14,600**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**131**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**25**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**30**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s054_1215
SAMPLE

Lab Sample ID: ZG64E
LIMS ID: 14-22780
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 81.3%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.0**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**9,180**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**77.0**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**182**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**19**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
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Sample ID: O-09_s054_1518
SAMPLE

Lab Sample ID: ZG64F
LIMS ID: 14-22781
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 76.8%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**10.9**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**12,700**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**103**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**585**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**21**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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TOTAL METALS

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Sample ID: O-09_s054_1821
SAMPLE

Lab Sample ID: ZG64G
LIMS ID: 14-22782
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 80.7%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**8.1**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,100**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**88.5**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**206**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**18**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s054_2124
SAMPLE

Lab Sample ID: ZG64H
LIMS ID: 14-22783
Matrix: Soil
Data Release Authorized
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 78.7%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**12.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**11,300**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**94.2**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**82**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**19**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
Page 1 of 1

Sample ID: O-09_s054_2427
SAMPLE

Lab Sample ID: ZG64I
LIMS ID: 14-22784
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 78.3%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.2**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**8,940**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**75.4**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**32**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**16**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

FORM-I

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
Page 1 of 1

Sample ID: O-09_s054_2730
SAMPLE

Lab Sample ID: ZG64J
LIMS ID: 14-22785
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 79.9%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**17.8**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,900**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**82.7**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**19**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**18**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
Page 1 of 1

Sample ID: 0-09_s154_2730
SAMPLE

Lab Sample ID: ZG64K
LIMS ID: 14-22786
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/20/14
Date Received: 10/22/14

Percent Total Solids: 78.9%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**20.2**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**11,100**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**84.4**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**16**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**18**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
Page 1 of 1

Sample ID: METHOD BLANK

Lab Sample ID: ZG64MB
LIMS ID: 14-22777
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: NA
Date Received: NA

Percent Total Solids: NA

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	7440-50-8	Copper	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	7439-89-6	Iron	5	5	U
3050B	10/29/14	6010C	10/30/14	7439-96-5	Manganese	0.1	0.1	U
3050B	10/29/14	6010C	10/30/14	7440-02-0	Nickel	1	1	U
3050B	10/29/14	6010C	10/30/14	7440-66-6	Zinc	1	1	U

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
Page 1 of 1

Sample ID: LAB CONTROL

Lab Sample ID: ZG64LCS
LIMS ID: 14-22777
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG64-Aspect Consulting
Project: Art Brass
050067
Date Sampled: NA
Date Received: NA

BLANK SPIKE QUALITY CONTROL REPORT

Analyte	Analysis Method	Spike Found	Spike Added	% Recovery	Q
Cadmium	6010C	52.9	50.0	106%	
Copper	6010C	50.0	50.0	100%	
Iron	6010C	202	200	101%	
Manganese	6010C	50.1	50.0	100%	
Nickel	6010C	50	50	100%	
Zinc	6010C	50	50	100%	

Reported in mg/kg-dry

N-Control limit not met
NA-Not Applicable, Analyte Not Spiked
Control Limits: 80-120%

HORIZON
LABORATORIES

General Offices: P.O. Box 995 Price, Utah 84501 435-637-4343
Laboratory: 545 East 100 North Price, Utah 84501

Submitted to:

Analytical Resources Inc.
Mark Harris
4611 S. 134th Place
Suite 100
Tukwila, WA 98168-3240

November 10, 2014

Date Sampled: 10/20/2014
Date Received: 10/29/2014

Sample Identification:
Set ZG64
See Below

Sampled By: ARI
Identification By: ARI

Analysis Report #: See Below

CERTIFICATE OF ANALYSIS

Analysis #	ARI ID	Sulfur (Acid Insoluble)
89749	14-22776- ZG64A	0.04
89750	14-22777- ZG64B	0.02
89751	14-22778- ZG64C	0.09
89752	14-22779- ZG64D	0.03
89753	14-22780- ZG64E	0.02
89754	14-22781- ZG64F	0.09
89755	14-22782- ZG64G	0.04
89756	14-22783- ZG64H	0.12
89757	14-22784- ZG64I	0.06
89758	14-22785- ZG64J	0.16
89759	14-22786- ZG64K	0.14

Respectfully Submitted,
HORIZON LABORATORIES
Laboratory Manager

JESSICA C. GOIN, PH.D.
Geomicrobiologist

ANCHOR QEA

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ANCHOR QEA

Jessica Goin
Suite 750
421 SW 6th Ave
Portland OR 97204

Line	Field Sample ID	Collection Date/Time	Matrix	No. of Containers	Test Parameters	Comments/Preservation
1	O-09_s055_0003	10/17	S	1		
2	O-09_s055_0306			1		
3	O-09_s055_0609			2		
4	O-09_s055_0912			2		
5	O-09_s055_1215			2		
6	O-09_s055_1518			2		
7	O-09_s055_1821			2		PLEASE COMPOSITE EACH SAMPLE
8	O-09_s055_2124			2		
9	O-09_s055_2427			2		
10	O-09_s055_2730			2		
11	O-09_s055_3033			2		
12	O-09_s055_3336			2		
13	O-09_s055_3639			2		
14						
15						

Notes: LOG UNDER ASPECT PROJECT # 050067 (ART BRASS)

PLEASE COMPOSITE THE SAMPLES REC AS 2 JARS INTO A SINGLE COMPOSITE FOR EACH SAMPLE

Relinquished By: J GOIN	Company: ANCHOR QEA
Signature/Printed Name	Date/Time 10/21
Received By: Taylor Streeter	Company: ART
Signature/Printed Name 10.22-14 1020	Date/Time
Relinquished By:	Company:
Signature/Printed Name	Date/Time
Received By:	Company:
Signature/Printed Name	Date/Time

Distribution: A copy will be made for the laboratory and client The Project file will retain the original.

Page 3 of 3

Analytical Resources, Incorporated
Analytical Chemists and Consultants

Cooler Receipt Form

ARI Client: ______________________

COC No(s). ______________________ NA

Assigned ARI Job No: ZG65

Project Name: ______________________

Delivered by: Fed-Ex UPS Courier Hand Delivered Other: ________

Tracking No. ______________________ NA

Preliminary Examination Phase:

Were intact, properly signed and dated custody seals attached to the outside of to cooler?	YES	[✓ NO]
Were custody papers included with the cooler?	[✓ YES]	NO
Were custody papers properly filled out (ink, signed, etc.)	[✓ YES]	NO

Temperature of Cooler(s) (°C) (recommended 2.0-6.0 °C for chemistry)
Time ______________

If cooler temperature is out of compliance fill out form 00070F

Temp Gun ID#: ______________

Cooler Accepted by. ______________________ Date: ______________ Time: ______________

Complete custody forms and attach all shipping documents

Log-In Phase:

Was a temperature blank included in the cooler?		YES	[✓ NO]
What kind of packing material was used? ... Bubble Wrap Wet Ice Gel Packs Baggies Foam Block Paper Other: ______			
Was sufficient ice used (if appropriate)?	NA	[✓ YES]	NO
Were all bottles sealed in individual plastic bags?		YES	[✓ NO]
Did all bottles arrive in good condition (unbroken)?		[✓ YES]	NO
Were all bottle labels complete and legible?		[✓ YES]	NO
Did the number of containers listed on COC match with the number of containers received?		[✓ YES]	NO
Did all bottle labels and tags agree with custody papers?		[✓ YES]	NO
Were all bottles used correct for the requested analyses?		[✓ YES]	NO
Do any of the analyses (bottles) require preservation? (attach preservation sheet, excluding VOCs)..	[✓ NA]	YES	NO
Were all VOC vials free of air bubbles?	[✓ NA]	YES	NO
Was sufficient amount of sample sent in each bottle?		[✓ YES]	NO
Date VOC Trip Blank was made at ARI	[✓ NA]	______	

Was Sample Split by ARI : [✓ NA] YES Date/Time: ________ Equipment: ________ Split by: ________

Samples Logged by: ______________________ Date: 10-22-11 Time: 1059

***** Notify Project Manager of discrepancies or concerns *****

Sample ID on Bottle	Sample ID on COC	Sample ID on Bottle	Sample ID on COC

Additional Notes, Discrepancies, & Resolutions:

By: Date:

Small Air Bubbles ~2mm ○ ○ ○ ○	**Small → "sm" (< 2 mm)**
Peabubbles 2-4 mm ● ● ● ● ●	**Peabubbles → "pb" (2 to < 4 mm)**
LARGE Air Bubbles > 4 mm ● ● ●	**Large → "lg" (4 to < 6 mm)**
	Headspace → "hs" (> 6 mm)

Sample ID Cross Reference Report

ANALYTICAL RESOURCES INCORPORATED

ARI Job No: ZG65
Client: Aspect Consulting
Project Event: 050067
Project Name: Art Brass

	Sample ID	ARI Lab ID	ARI LIMS ID	Matrix	Sample Date/Time	VTSR
1.	O-09_s055_0003	ZG65A	14-22787	Soil	10/17/14	10/22/14 10:30
2.	O-09_s055_0306	ZG65B	14-22788	Soil	10/17/14	10/22/14 10:30
3.	O-09_s055_0609	ZG65C	14-22789	Soil	10/17/14	10/22/14 10:30
4.	O-09_s055_0912	ZG65D	14-22790	Soil	10/17/14	10/22/14 10:30
5.	O-09_s055_1215	ZG65E	14-22791	Soil	10/17/14	10/22/14 10:30
6.	O-09_s055_1518	ZG65F	14-22792	Soil	10/17/14	10/22/14 10:30
7.	O-09_s055_1821	ZG65G	14-22793	Soil	10/17/14	10/22/14 10:30
8.	O-09_s055_2124	ZG65H	14-22794	Soil	10/17/14	10/22/14 10:30
9.	O-09_s055_2427	ZG65I	14-22795	Soil	10/17/14	10/22/14 10:30
10.	O-09_s055_2730	ZG65J	14-22796	Soil	10/17/14	10/22/14 10:30
11.	O-09_s055_3033	ZG65K	14-22797	Soil	10/17/14	10/22/14 10:30
12.	O-09_s055_3336	ZG65L	14-22798	Soil	10/17/14	10/22/14 10:30
13.	O-09_s055_3639	ZG65M	14-22799	Soil	10/17/14	10/22/14 10:30

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_0003
ARI ID: 14-22787 ZG65A

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	89.03
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.11	< 1.11 U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_0306
ARI ID: 14-22788 ZG65B

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.89
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.20	< 1.20 U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_0609
ARI ID: 14-22789 ZG65C

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	79.00	
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.24	< 1.24	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_0912
ARI ID: 14-22790 ZG65D

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	78.18
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.28	2.60

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_1215
ARI ID: 14-22791 ZG65E

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.96	
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.22	< 1.22	U

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_1518
ARI ID: 14-22792 ZG65F

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	79.48
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.24	1.61

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_1821
ARI ID: 14-22793 ZG65G

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.69
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.27	1.81

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_2124
ARI ID: 14-22794 ZG65H

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	77.79
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.28	2.33

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_2427
ARI ID: 14-22795 ZG65I

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.20
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.24	1.46

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_2730
ARI ID: 14-22796 ZG65J

Analyte	Date	Method	Units	RL	Sample	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	78.73	
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.27	< 1.27	U

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_3033
ARI ID: 14-22797 ZG65K

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**	
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	81.68	
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.22	< 1.22	U

RL Analytical reporting limit
U Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_3336
ARI ID: 14-22798 ZG65L

Analyte	**Date**	**Method**	**Units**	**RL**	**Sample**
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	79.76
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.21	1.76

RL	Analytical reporting limit
U	Undetected at reported detection limit

SAMPLE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Client ID: O-09_s055_3639
ARI ID: 14-22799 ZG65M

Analyte	Date	Method	Units	RL	Sample
Preserved Total Solids	10/28/14 102814#1	SM2540G	Percent	0.01	80.24
Sulfide	10/28/14 102814#1	SM4500-S2D	mg/kg	1.24	< 1.24 U

RL	Analytical reporting limit
U	Undetected at reported detection limit

METHOD BLANK RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

ANALYTICAL RESOURCES INCORPORATED

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: NA
Date Received: NA

Analyte	Date	Units	Blank	QC ID
Preserved Total Solids	10/28/14	Percent	< 0.01 U	ICB
Sulfide	10/28/14	mg/kg	< 0.05 U	PREP

LAB CONTROL RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: NA
Date Received: NA

Analyte/Method	QC ID	Date	Units	LCS	Spike Added	Recovery
Sulfide SM4500-S2D	PREP	10/28/14	mg/kg	7.67	7.25	105.8%

REPLICATE RESULTS-CONVENTIONALS
ZG65-Aspect Consulting

Matrix: Soil
Data Release Authorized:
Reported: 11/05/14

Project: Art Brass
Event: 050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Analyte	**Date**	**Units**	**Sample**	**Replicate(s)**	**RPD/RSD**
ARI ID: ZG65A Client ID: O-09_s055_0003					
Preserved Total Solids	10/28/14	Percent	89.03	90.04	1.1%

ANALYTICAL
RESOURCES
INCORPORATED

INORGANICS ANALYSIS DATA SHEET
TOTAL METALS
Page 1 of 1

Sample ID: O-09_s055_0003
SAMPLE

Lab Sample ID: ZG65A
LIMS ID: 14-22787
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 93.1%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	**7440-43-9**	**Cadmium**	0.2	**0.4**	
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**21.0**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	5	**15,200**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**295**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**40**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**74**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_0003
DUPLICATE

Lab Sample ID: ZG65A
LIMS ID: 14-22787
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

MATRIX DUPLICATE QUALITY CONTROL REPORT

Analyte	Analysis Method	Sample	Duplicate	RPD	Control Limit	Q
Cadmium	6010C	0.4	0.4	0.0%	+/- 0.2	L
Copper	6010C	21.0	21.5	2.4%	+/- 20%	
Iron	6010C	15,200	15,600	2.6%	+/- 20%	
Manganese	6010C	295	302	2.3%	+/- 20%	
Nickel	6010C	40	40	0.0%	+/- 20%	
Zinc	6010C	74	80	7.8%	+/- 20%	

Reported in mg/kg-dry

*-Control Limit Not Met
L-RPD Invalid, Limit = Detection Limit

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Sample ID: O-09_s055_0003
MATRIX SPIKE

Lab Sample ID: ZG65A
LIMS ID: 14-22787
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

MATRIX SPIKE QUALITY CONTROL REPORT

Analyte	Analysis Method	Sample	Spike	Spike Added	% Recovery	Q
Cadmium	6010C	0.4	53.1	53.2	99.1%	
Copper	6010C	21.0	72.6	53.2	97.0%	
Iron	6010C	15,200	15,800	213	282%	H
Manganese	6010C	295	386	53.2	171%	H
Nickel	6010C	40	92	53.2	97.7%	
Zinc	6010C	74	128	53.2	102%	

Reported in mg/kg-dry

N-Control Limit Not Met
H-% Recovery Not Applicable, Sample Concentration Too High
NA-Not Applicable, Analyte Not Spiked

Percent Recovery Limits: 75-125%

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Sample ID: 0-09_s055_0306
SAMPLE

Lab Sample ID: ZG65B
LIMS ID: 14-22788
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 83.2%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**17.1**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**15,000**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**132**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**12**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**27**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: 0-09_s055_0609
SAMPLE

Lab Sample ID: ZG65C
LIMS ID: 14-22789
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 81.1%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**13.4**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**11,100**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**92.4**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**7**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**21**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_0912
SAMPLE

Lab Sample ID: ZG65D
LIMS ID: 14-22790
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 78.8%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**14.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,400**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**78.7**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**10**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**25**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_1215
SAMPLE

Lab Sample ID: ZG65E
LIMS ID: 14-22791
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 83.0%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**11.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,200**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**78.7**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**8**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**22**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_1518
SAMPLE

Lab Sample ID: ZG65F
LIMS ID: 14-22792
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 82.0%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**11.1**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,900**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**85.9**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**8**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**23**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_1821
SAMPLE

Lab Sample ID: ZG65G
LIMS ID: 14-22793
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 79.2%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.3	0.3	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.3	**10.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,700**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**81.5**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**8**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**20**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_2124
SAMPLE

Lab Sample ID: ZG65H
LIMS ID: 14-22794
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 80.6%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**9.6**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,500**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**87.1**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**6**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**20**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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**Sample ID: O-09_s055_2427
SAMPLE**

Lab Sample ID: ZG65I
LIMS ID: 14-22795
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 81.3%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.5**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**10,300**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**88.2**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**7**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**19**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_2730
SAMPLE

Lab Sample ID: ZG65J
LIMS ID: 14-22796
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 81.2%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.1**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**9,710**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**83.0**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**6**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**18**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_3033
SAMPLE

Lab Sample ID: ZG65K
LIMS ID: 14-22797
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 81.9%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.4**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**9,960**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**88.0**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**7**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**18**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_3336
SAMPLE

Lab Sample ID: ZG65L
LIMS ID: 14-22798
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 80.4%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**8.3**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**9,230**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**74.4**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**6**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**17**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: O-09_s055_3639
SAMPLE

Lab Sample ID: ZG65M
LIMS ID: 14-22799
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: 10/17/14
Date Received: 10/22/14

Percent Total Solids: 80.7%

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	**7440-50-8**	**Copper**	0.2	**7.3**	
3050B	10/29/14	6010C	10/30/14	**7439-89-6**	**Iron**	6	**8,610**	
3050B	10/29/14	6010C	10/30/14	**7439-96-5**	**Manganese**	0.1	**68.6**	
3050B	10/29/14	6010C	10/30/14	**7440-02-0**	**Nickel**	1	**5**	
3050B	10/29/14	6010C	10/30/14	**7440-66-6**	**Zinc**	1	**16**	

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: METHOD BLANK

Lab Sample ID: ZG65MB
LIMS ID: 14-22788
Matrix: Soil
Data Release Authorized:
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: NA
Date Received: NA

Percent Total Solids: NA

Prep Meth	Prep Date	Analysis Method	Analysis Date	CAS Number	Analyte	LOQ	mg/kg-dry	Q
3050B	10/29/14	6010C	10/30/14	7440-43-9	Cadmium	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	7440-50-8	Copper	0.2	0.2	U
3050B	10/29/14	6010C	10/30/14	7439-89-6	Iron	5	5	U
3050B	10/29/14	6010C	10/30/14	7439-96-5	Manganese	0.1	0.1	U
3050B	10/29/14	6010C	10/30/14	7440-02-0	Nickel	1	1	U
3050B	10/29/14	6010C	10/30/14	7440-66-6	Zinc	1	1	U

U-Analyte undetected at given LOQ
LOQ-Limit of Quantitation

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Sample ID: LAB CONTROL

Lab Sample ID: ZG65LCS
LIMS ID: 14-22788
Matrix: Soil
Data Release Authorized
Reported: 10/31/14

QC Report No: ZG65-Aspect Consulting
Project: Art Brass
050067
Date Sampled: NA
Date Received: NA

BLANK SPIKE QUALITY CONTROL REPORT

Analyte	Analysis Method	Spike Found	Spike Added	% Recovery	Q
Cadmium	6010C	52.9	50.0	106%	
Copper	6010C	50.0	50.0	100%	
Iron	6010C	208	200	104%	
Manganese	6010C	51.2	50.0	102%	
Nickel	6010C	51	50	102%	
Zinc	6010C	50	50	100%	

Reported in mg/kg-dry

N-Control limit not met
NA-Not Applicable, Analyte Not Spiked
Control Limits: 80-120%

HORIZON LABORATORIES

General Offices: P.O. Box 995 Price, Utah 84501 435-637-4343
Laboratory: 545 East 100 North Price, Utah 84501

November 10, 2014

Submitted to:
Analytical Resources Inc.
Mark Harris
4611 S. 134th Place
Suite 100
Tukwila, WA 98168-3240

Date Sampled: 10/17/2014
Date Received: 10/29/2014

Sample Identification:
Set ZG64
See Below

Sampled By: ARI
Identification By: ARI

Analysis Report #: See Below

CERTIFICATE OF ANALYSIS

Analysis #	**ARI ID**	**Sulfur (Acid Insoluble) %**
89760	14-22787- ZG65A	0.11
89761	14-22788- ZG65B	0.02
89762	14-22789- ZG65C	0.03
89763	14-22790- ZG65D	0.08
89764	14-22791- ZG65E	0.04
89765	14-22792- ZG65F	0.02
89766	14-22793- ZG65G	0.05
89767	14-22794- ZG65H	0.03
89768	14-22795- ZG65I	0.02
89769	14-22796- ZG65J	0.03
89770	14-22797- ZG65K	0.01
89771	14-22798- ZG65L	0.02
89772	14-22799- ZG65M	0.02

Respectfully Submitted,
HORIZON LABORATORIES

Laboratory Manager

APPENDIX B

Fate and Transport Analysis of Metals

Contents – Appendix B

List of Figures

List of Attachments

The fate and transport evaluations for metals provided in this appendix follow the approach described in the *Revised Remedial Investigation Data Gaps and Supplemental Work Plan for Site Unit 1* (Work Plan; Aspect, 2014a) as conditionally approved by Washington State Department of Ecology (Ecology) on October 3 and 10, 2014. Refer to Appendix A of this Feasibility Study report for a summary of the data collection. Aspect submitted to Ecology a draft *Fate and Transport Summary Memorandum for SU1* in June 2015 (Aspect, 2015). This appendix focuses on the fate and transport analyses of metals, revised based on Ecology comments. Attachment A of this Appendix includes Anchor QEA's revised *Site Unit 1 Geochemical Fate and Transport Evaluation*. Monitoring well locations are illustrated on Figure B-1.

The Work Plan included an analysis of barium nature and extent. Barium concentrations in groundwater do not exceed preliminary screening levels in SU1, as illustrated in the *Site Conceptual Model Technical Memorandum* (Aspect, 2014b).

Secondary containment and other best management practices are used at the Art Brass Plating (ABP) facility to prevent a release from plating baths. The discussion below assumes no ongoing release from current operations at ABP facility. Please refer to Attachment B for a details about the plating baths, the facility's best management practices, and their King County sanitary sewer discharge permit.

Plating Metals

Concentration Trends

Figures B-2, B-3, and B-4 provide trends in groundwater concentrations for nickel, copper, and zinc, respectively. Data spans from 2008 through 2015 with the next plating metals monitoring event scheduled for September 2016. Wells located at and near to the Source Area with elevated plating metals concentrations have been selected for illustration (MW-1 through MW-5, MW-7, MW-8, and MW-8-30).

Operation of the air sparging system between late 2008 and 2015 has locally disturbed the ambient subsurface conditions near the Source Area by introducing oxygen and elevating water levels, which potentially have contributed to an increase in dissolved metals concentrations in groundwater. Since plating metals are attenuated by precipitation of sulfide minerals adjacent and downgradient of the Source Area, plating metals are potentially more mobile under oxygenated conditions than mildly reducing conditions. In addition, groundwater mounding into the contaminated vadose zone has the potential to leach metals into groundwater. In the future, as the sparging system is phased out, it is expected that subsurface conditions will again return to mildly to moderately reducing, maximum water table elevations will decrease, and leaching of metals from contaminated soils into groundwater will be reduced.

The highest nickel concentrations were recorded in late 2008 and early 2009 at MW-1, in the Source Area (see Figure B-2). Concentrations at wells MW-7, and MW-8-30 increased later in 2011, likely because these wells are located downgradient of the Source Area. Nickel concentrations at MW-8 have recently increased. However, based on metals concentrations trends observed at other wells, we do not expect this trend to continue long-term. This is supported by the fate-and-transport modeling, discussed in the next section. Furthermore, pH neutralization proposed in the area will increase nickel sorption to iron oxides and decrease the solubility of plating metal sulfides.

Concentrations at MW-8-30 increased prior to MW-8. Soils in the screen interval of MW-8-30 are fine to medium sand with occasional thin silt interbeds. Whereas, soils in the screen interval of MW-8 include 5 feet of silt sand then 5 feet of fine to medium sand. The greater percentage of silt beds at MW-8 screen interval may slow transport in the Water Table Interval compared to the Shallow Interval.

Fate-and-Transport Analyses

Attachment A provides a detailed discussion of the analyses completed by Anchor QEA to assess the fate and transport of plating metals (nickel, copper, zinc). The discussion focuses on nickel however the processes outlined in the attachment have the same effect on copper and zinc. Fate-and-transport analyses included multiple lines of evidence based on reactive transport modeling using PHAST code (Parkhurst et al., 2010), bulk chemistry, sequential extraction, and evaluation of mineral saturation indices, computed from groundwater chemistry using PHREEQC modeling code (Parkhurst and Appelo, 1999). A summary of Attachment A for the plating metals is provided below.

Metal Oxide/Hydroxide Precipitation

In the Work Plan, it was hypothesized that metal oxide/hydroxide precipitation reduces plating metal mobility via surface sorption and precipitation mechanisms. Aquifer geochemical conditions are favorable for the formation of iron oxyhydroxides; therefore, it is expected that adsorption on and coprecipitation of nickel and other plating metals in these phases plays an important role in their fate and transport at the Site. Sequential extraction results provide direct evidence for the presence of plating metals associated with iron oxides. Reactive transport modeling including only adsorption on iron oxides predicts that nickel concentrations will not exceed the preliminary cleanup level (PCUL) protective of surface water (8.2 micrograms per liter [µg/L]) at the Duwamish Waterway for over 500 years. Analysis of copper and zinc data indicate that these metals undergo similar attenuation mechanisms as that modeled for nickel.

Metal Sulfide Precipitation Reduces Metal Mobility

In the Work Plan, it was hypothesized that metal sulfide precipitation reduces plating metal mobility. Analyses indicate that metal sulfide precipitation is of comparable importance as adsorption on iron oxides as a natural attenuation mechanism for plating metals. Chemical analysis for total acid insoluble sulfur by combustion indicates that small quantities of metal sulfides are present in all Site soil samples analyzed. Sequential extraction data may indicate that nickel, copper, and zinc are associated with metals sulfides and organic matter. Reactive transport modeling that included both adsorption to iron oxides as well as sulfide precipitation predicts that nickel concentrations will not exceed the PCUL protective of surface water (8.2 µg/L) at the Duwamish Waterway for at least 1,000 years, the temporal extent of the model.

Buffering Capacity of the Aquifer

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.

Conclusions

Model simulations predict that, with all three processes operating (metal oxide/hydroxide precipitation, metal sulfide precipitation, and aquifer buffering capacity), 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 PCUL of 8.2 µg/L for at least 1,000 years, the temporal extent of the model.

Metals concentrations are not expected to increase at downgradient wells MW-10 and MW-16. An increase in metals concentrations are not expected to extend far beyond well cluster MW-8, and pH neutralization proposed in the area will increase nickel sorption to iron oxides and decrease the solubility of plating metal sulfides. Modeling indicates that the recent increase exhibited at MW-8 is due to changes in attenuation mechanisms from sorption to sorption plus sulfide precipitation. The increase is temporary, according to the model, and this is supported by monitoring data at upgradient wells where concentrations increased for a short-term before decreasing. Furthermore, the buffering capacity of the aquifer has been illustrated in that depressed pH has not been observed at the MW-8 well cluster. Metals are further attenuated by iron oxide adsorption and precipitation of sulfide solids.

Although the other plating metals were not modeled explicitly, cadmium, copper, and zinc are also attenuated by the same processes as nickel. These metals are all adsorbed on iron oxides and can form sulfide solids. These metals are more strongly sorbed on iron oxides at low to circumneutral pH. Since cadmium, copper, and zinc concentrations are lower than nickel concentrations in Source Area groundwater, they are also attenuated near the Source Area.

Iron and Manganese

Elevated concentrations of iron and manganese in SU1 groundwater are hypothesized to be 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. Based on the evaluation described Attachment A, we draw the following conclusions:

- Elevated iron concentrations are observed across SU1. The source of elevated iron concentrations appears to be dissolution of iron minerals from the aquifer matrix under reducing conditions. The data indicate that iron concentrations may be controlled by ferrihydrite (iron hydroxide) and siderite (iron carbonate) equilibria in upgradient areas, switch to ferrihydrite alone in the Source Area where conditions are more acidic and oxidizing, and gradually shift back to ferrihydrite and siderite downgradient as pH is attenuated.
- The source of elevated manganese concentrations appears to be dissolution of manganese minerals from the aquifer matrix under mildly reducing conditions

characteristic of SU1 groundwater. Conditions within the more acidic portion of the plume favor manganese in the dissolved phase.

Arsenic

Hypothesis: Elevated arsenic concentrations recorded at well MW-9 are not likely a result of an ABP release, either as a direct release of arsenic, or as mobilization due to changes in redox or pH caused by ABP releases. Arsenic may instead be elevated due to trace arsenic levels naturally occurring soil or fill debris near MW-9. Well MW-9 is located on the property west of the ABP facility, on the west side of 3rd Avenue South (Figure B-1).

Arsenic behavior in soil depends on redox, pH, and soil and groundwater chemistry. Dissolved arsenic concentrations in the subsurface can generally be controlled by either sulfide minerals, hydrous-ferric-oxide (HFO) mineral systems, or become mobile, depending on pH, redox, and groundwater composition. Changes in these conditions can happen on a small scale. Where present, sulfide and HFO minerals tend to sequester dissolved arsenic. Groundwater conditions conducive to HFO precipitation would likely immobilize dissolved arsenic with iron. Reducing conditions, in the presence of sulfur and iron or other metals would immobilize arsenic along with metal-sulfides.

Arsenic impacts are limited to MW-9 vicinity

In SU1, MW-9 is the only well out of 25 sampled locations and 85 total arsenic measurements where concentrations are above 4.6 µg/L. All other arsenic measurements in SU1 are below the Model Toxics Control Act (MTCA) Method A background concentration for arsenic of 5 µg/L. Arsenic concentrations at well MW-9 have ranged between 27 to 56 µg/L.

ABP Source Area wells and wells near MW-9 do not show anomalous concentrations of arsenic. ABP Source Area wells (MW-1 through MW-5) have arsenic concentrations between 0.2 and 2 µg/L Well MW-13, located 60 feet north of well MW-9, has arsenic concentrations between 0.1 and 2.6 µg/L. Well MW-8, which is 80 feet south of well MW-9, has arsenic concentrations between 0.5 and 1.1 µg/L.

Arsenic in MW-9 does not appear to be due to impacts from a plating metals release

The range of pH and oxygen-reduction potential (ORP) in MW-9 suggests arsenic in MW-9 is not part of a larger plume of arsenic, nor is it a direct result of changes to redox or pH conditions in the subsurface due to ABP releases. The pH and ORP at MW-9 are generally consistent with conditions in the SU1 vicinity, as illustrated in Figure B-5. The pH at MW-9 ranges from 5.8 to 6.9, generally within the wider range of Water Table Interval groundwater, but slightly more neutral (closer to 7). By comparison, the ABP wells near the Source Area have more acidic pHs (wells shown with pH below 4.5; MW-1 through MW-5, PMW-1).

Measured ORP conditions in MW-9 range from -458 millivolts (mV) to +13.1 mV. Dissolved oxygen (DO) ranges from 0.13 milligrams per liter (mg/L) to 1.54 mg/L and is typically below 0.5 mg/L. While MW-9 is on the lower end of redox conditions found within the Water Table Interval, it is generally consistent with the other near-neutral pH wells. In comparison, the Shallow and Intermediate Interval wells show relatively more alkaline and more reducing conditions, and slightly elevated arsenic relative to the Water Table Interval.

The slightly elevated pH in MW-9 may indicate that there is an anomalous mineral-groundwater interaction occurring in the vicinity of that well, such as dissolution of some alkaline material (e.g., arsenic-containing fly-ash cement debris). The alkalinity in MW-9 is generally low (65 to 82 mg/L), but elevated relative to the adjacent well MW-8 (in which alkalinity ranges from 7.7 to 68.5 mg/L).

Given the limited extent of arsenic impacts, it is not likely that arsenic was released or mobilized by ABP source area conditions. If we were to assume arsenic was mobilized in the subsurface due to conditions related to ABP releases, then we would expect to see more arsenic more centrally located within the plume of low pH impacts.

Arsenic mobility in MW-9 vicinity is controlled by iron oxide (HFO) minerals

Under mildly reducing, mildly acidic groundwater conditions, such as those found in well MW-9 and throughout much of SU1 Water Table Interval, arsenic is predicted to attenuate by mineral sorption and precipitation. The net mobility of arsenic should be limited by arsenic’s tendencies to sorb and precipitate in the presence of iron mineral surfaces and dissolved oxygen. Arsenic removal from groundwater occurs via a primarily sorption reaction to HFO (e.g., $Fe(OH)_3$), followed by a secondary conversion of HFO-sorbed arsenic to an insoluble ferric arsenate precipitate ($FeAsO_4*2H_2O$). This is the same two-step sorption-precipitation reaction sequence that occurs in iron-based arsenic filtration systems.

Geochemical modeling results indicate that iron is able to precipitate in the downgradient vicinity of MW-9, and that arsenic-iron-oxide minerals are stable under the Eh-pH groundwater conditions there. PHREEQC speciation of MW-9 data indicates that HFO minerals (including $Fe_3(OH)_8$, ferrihydrite, and goethite), each with the capacity to sorb arsenic, are thermodynamically stable in the MW-9 vicinity. Arsenic at MW-9 appears to be stable (at equilibrium) as a hydrous iron-arsenic-oxide ($FeAsO_4*2H_2O$, ferric arsenate) mineral phase. Taken together, these data indicate that HFO mineral formation is likely downgradient from MW-9. The mineral surfaces tend to sorb arsenic, and reprecipitate the arsenic as ferric arsenate.

An arsenic phase stability (Eh-pH) diagram for MW-9 is provided on Figure B-6. The speciation figure is derived from arsenic, iron, redox, pH, temperature, alkalinity, and sulfate data from MW-9 in 2013 and 2014. The ferric arsenate stability field (solid-phase arsenate) is generally under oxidizing to mildly reducing conditions in the pH range of 5 to 7 commonly seen in the Water Table Interval. Stability of the solid phase increases in more reducing groundwater conditions and increasing pHs. Model Eh, pH, saturation indices, and geochemical trends show that arsenic in the Water Table Interval is stable and controlled by the iron mineral systems.

There is abundant iron in the MW-9 vicinity to control arsenic mobility. There is approximately 600:1 mass ratio of iron to arsenic in solution at MW-9. Accounting for the difference in molecular weight between arsenic and iron, this results in an approximately 500:1 molar ratio of iron to arsenic. For comparison, in arsenic treatment studies, iron-to-arsenic ratios as low as 30:1 are ample for arsenic removal from groundwater.

Given the 500:1 molar ratio of iron to arsenic in MW-9, downgradient attenuation of both arsenic and iron, the modelled stability of iron-arsenic precipitates, and HFO minerals, our analysis is that iron is able to control the mobility of arsenic in the vicinity of MW-9 via ferric-arsenate precipitation reactions.

Groundwater data from MW-9 illustrate this relationship between arsenic and iron. Arsenic and iron concentration in MW-9 have decreased from 2010 to 2014. In 2010, arsenic ranged from 52.4 to 56.3 µg/L and iron ranged from 26 to 35.7 mg/L. In 2013, both arsenic (27.1 and 30.7 µg/L) and iron (16.3 mg/L) concentrations were about half as high, showing a proportional decrease.

Conclusions for Arsenic Analyses

Based on the evaluation described above, we draw the following conclusions:

- 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.

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Parkhurst, D.L., K.L. Kipp, and S.R. Charlton, 2010, PHAST Version 2—A Program for Simulating Groundwater Flow, Solute Transport, and Multicomponent Geochemical Reactions: U.S. Geological Survey Techniques and Methods 6–A35, p. 235.

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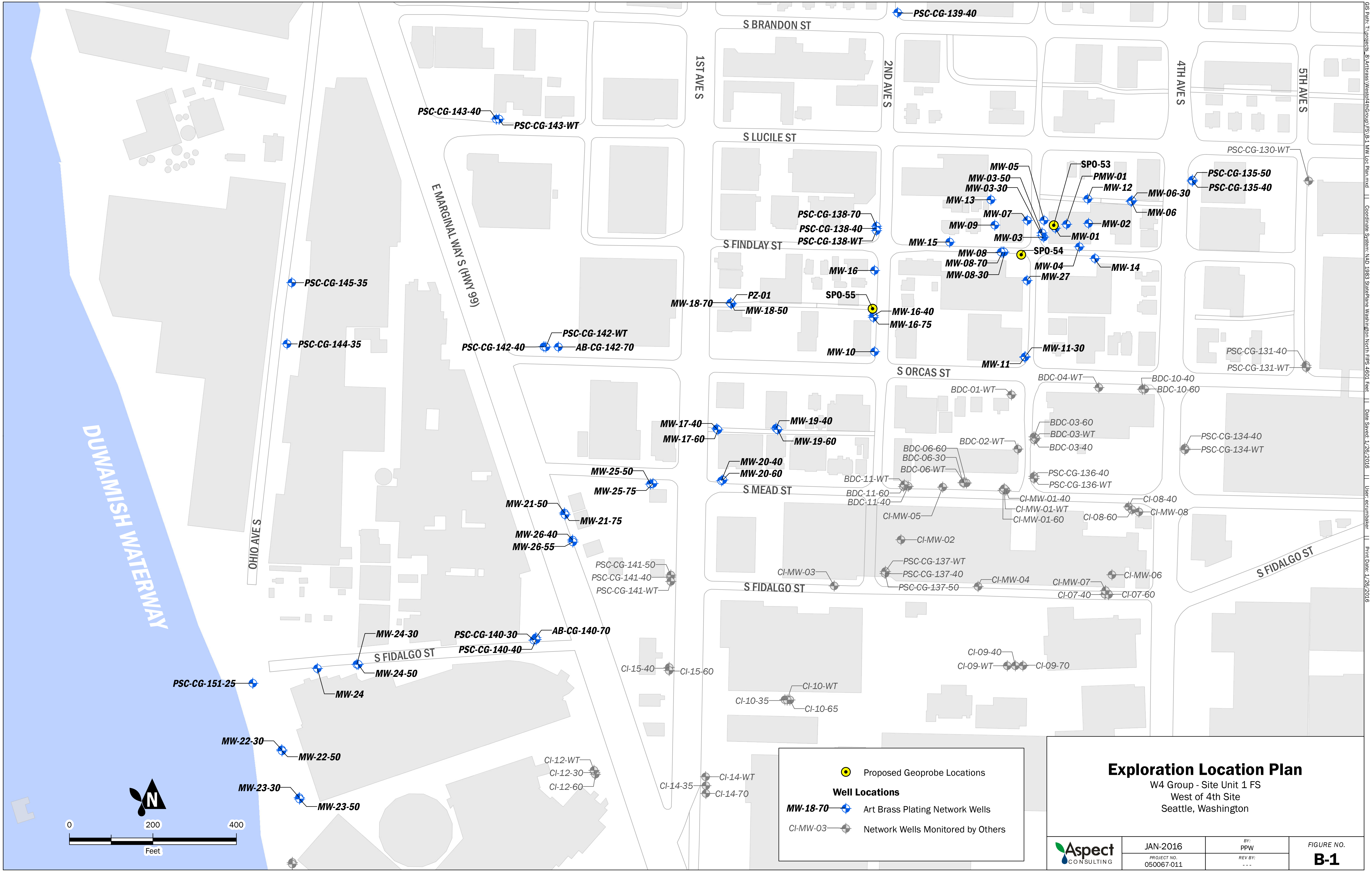
FIGURES



Exploration Location Plan

W4 Group - Site Unit 1 FS
West of 4th Site
Seattle, Washington

Aspect CONSULTING

JAN-2016	BY: PPW	FIGURE NO. B-1
PROJECT NO. 050067-011	REV BY: - - -	

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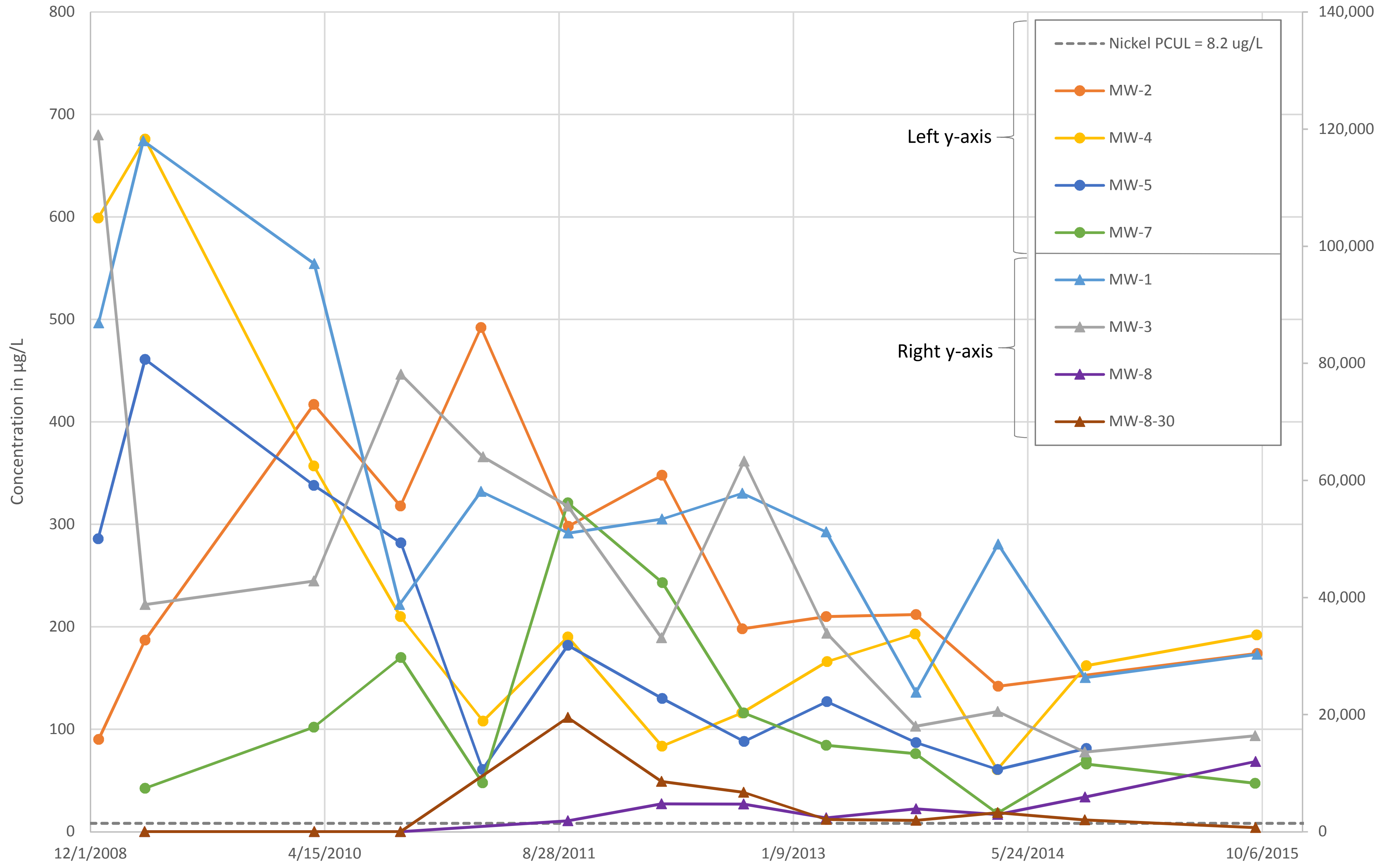

Figure B-2

Dissolved Nickel Concentrations in Groundwater

SU1 Feasibility Study
West of 4th Site, Seattle, WA

Aspect Consulting
8/11/2016
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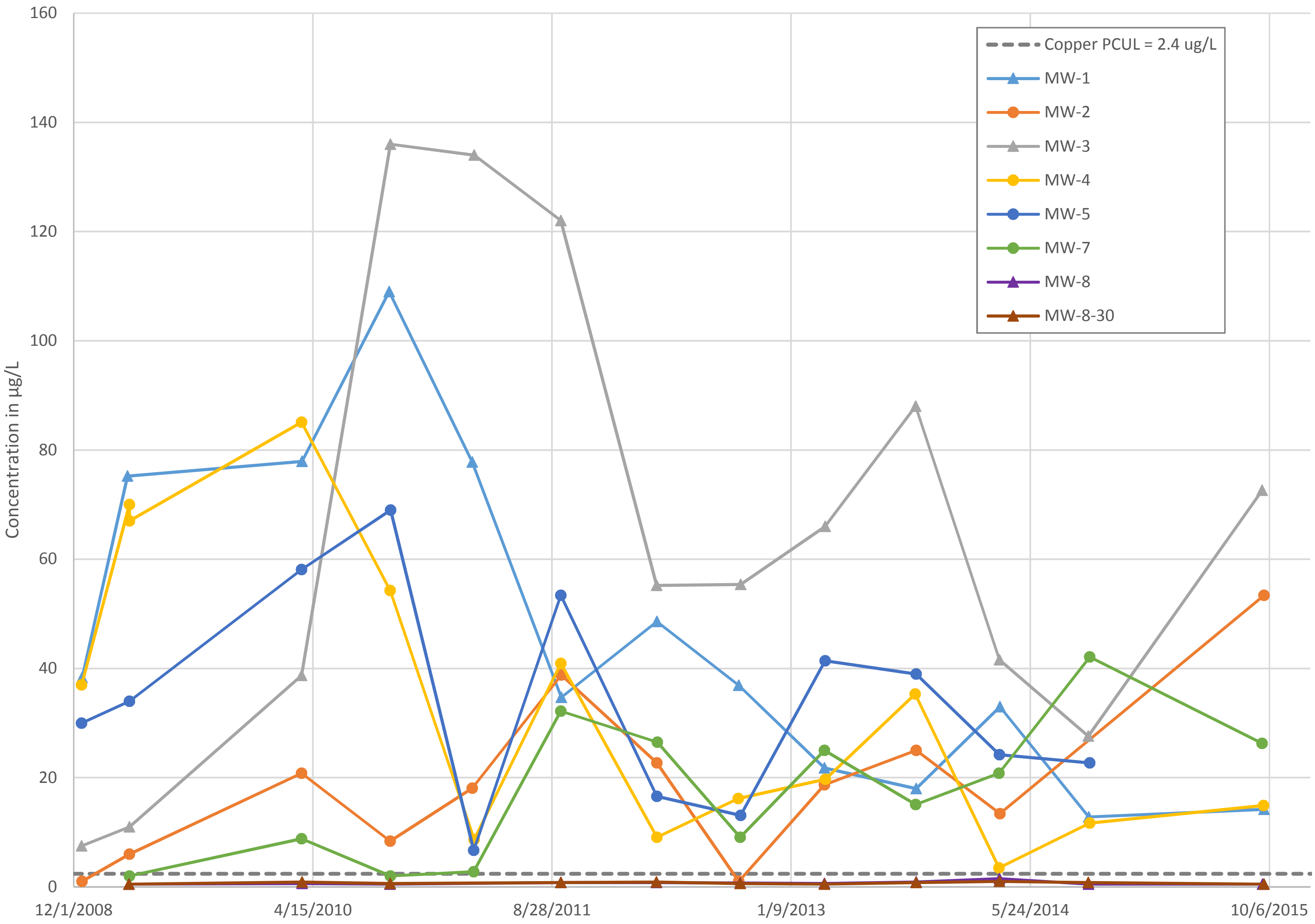

Figure B-3
Dissolved Copper Concentrations in Groundwater

SU1 Feasibility Study
West of 4th Site, Seattle, WA

Aspect Consulting
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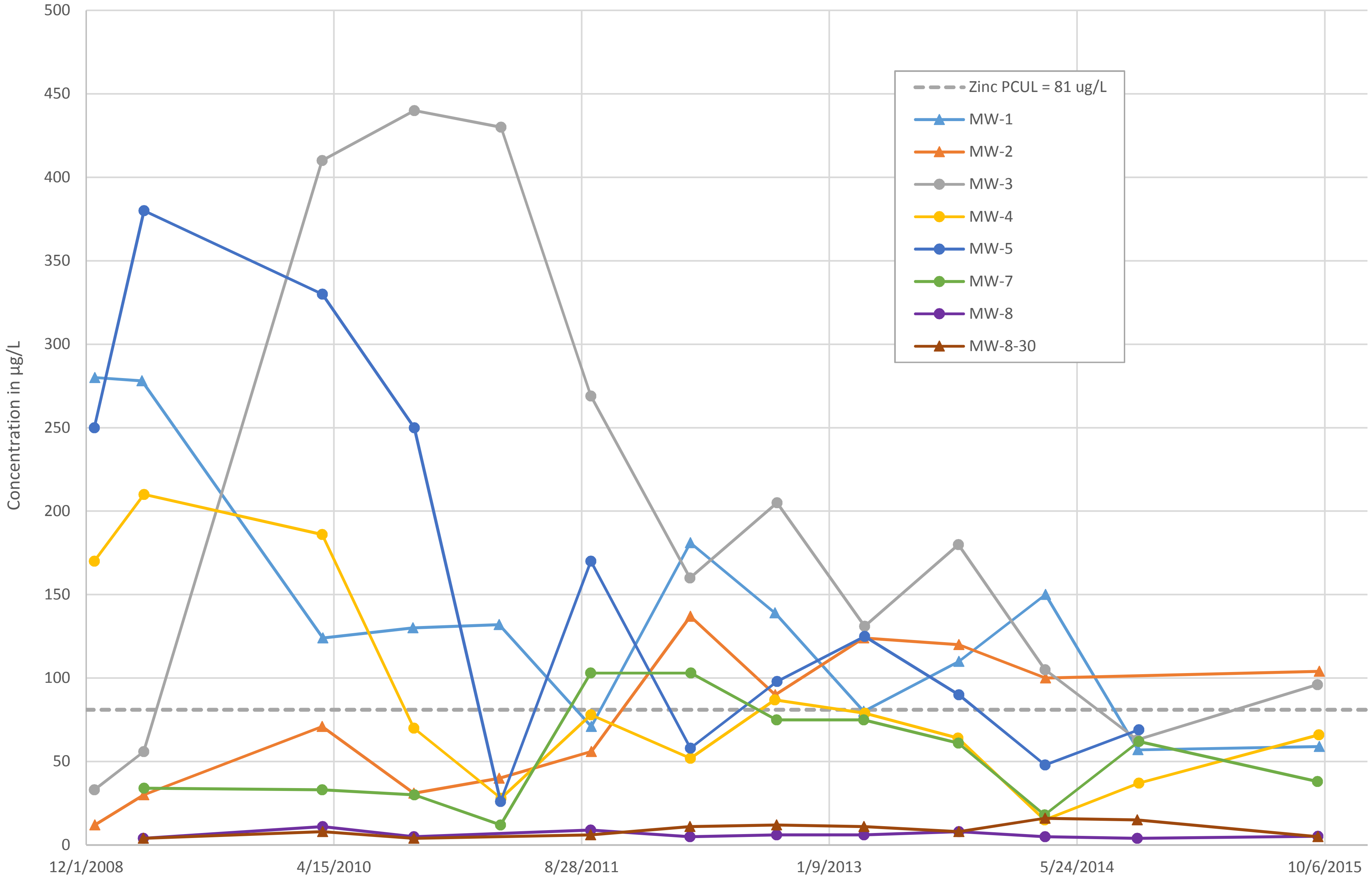

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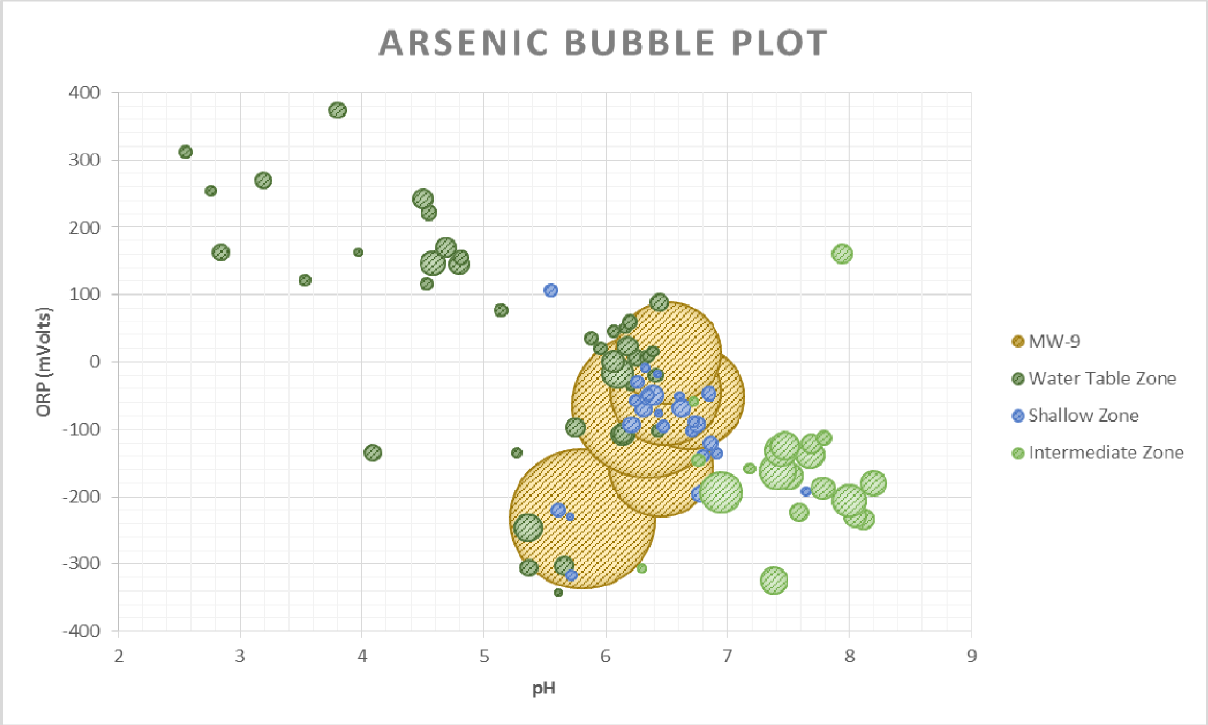
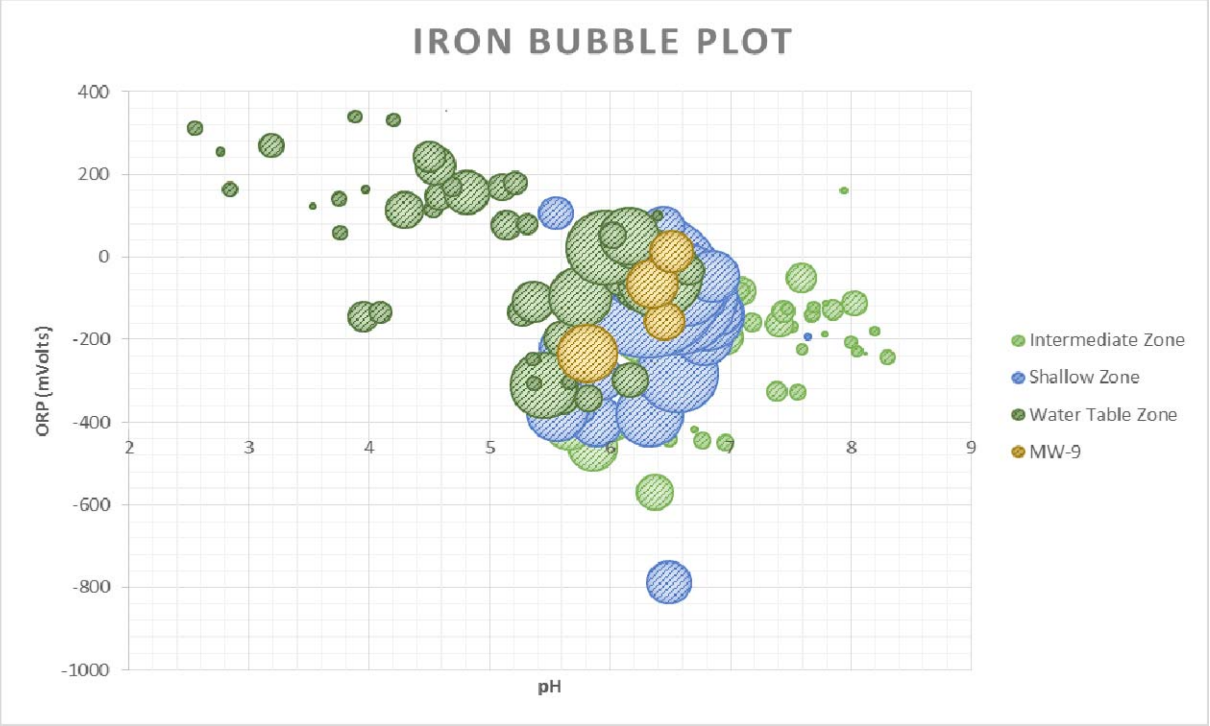
Figure B-4
Dissolved Zinc Concentrations in Groundwater

SU1 Feasibility Study
West of 4th Site, Seattle, WA





Aspect Consulting
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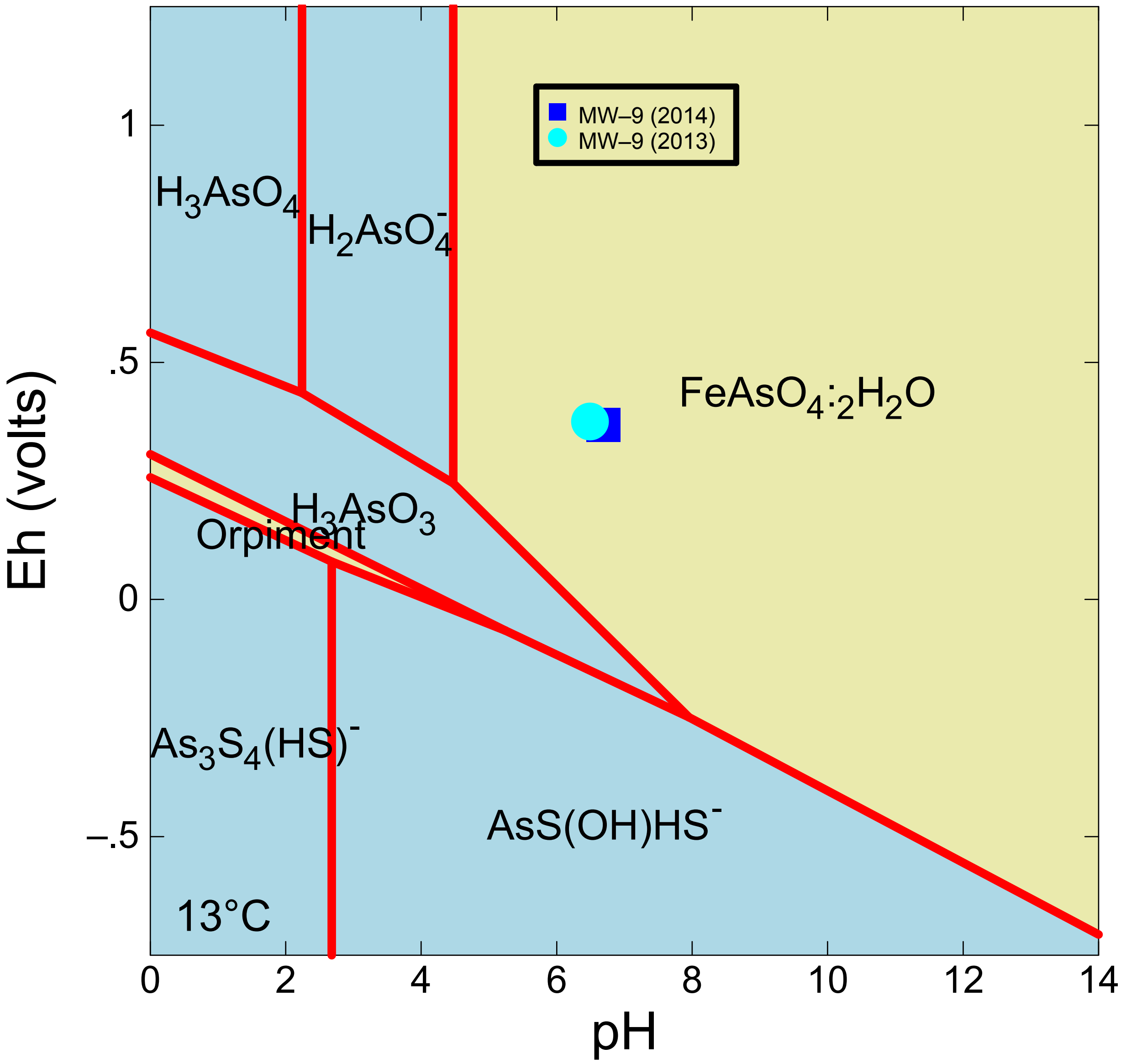
Figure B-5
Arsenic and Iron Bubble Plots - SU1
West of 4th Site



Note: Arsenic minerals (solid phase) are shown in yellow. Aqueous species are in blue.

Arsenic Eh-pH Diagram for MW-9

W4 Group - Site Unit 1 FS
Seattle, Washington

JUL-2016	BY: DLC / EAC	FIGURE NO.
PROJECT NO. 050067-011	REVISED BY: ---	**B-6**

GIS Path: T:\projects_8\Artbrass\Westof4thGroup\FS\Arsenic Eh-Ph Diagram for MW-9.mxd || Coordinate System: NAD 1983 HARN StatePlane Washington North FIPS 4601 Feet || Date Saved: 7/25/2016 || User: ecrumbaker || Print Date: 7/25/2016

ATTACHMENTS

A: Site Unit 1 Geochemical Fate and Transport Evaluation (Anchor QEA)

B: Plating Operations and Utilities

ANCHOR QEA

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MEMORANDUM

To:	Dana Cannon, Aspect Consulting	**Date:**	July 12, 2016
From:	Dimitri Vlassopoulos, Ph.D., and Masa Kanematsu, Ph.D., Anchor QEA, LLC	**Project:**	140204-01.01
Re:	Site Unit 1 Geochemical Fate and Transport Evaluation		

This memorandum presents the results of geochemical evaluations performed as part of the *Revised Remedial Investigation Data Gaps and Supplemental Work Plan for Site Unit 1* (SU1; Aspect Consulting 2014) for the Art Brass Plating (ABP) facility. The purpose of the present report is 1) to document lines of evidence for the fate and transport of metals in groundwater that were introduced or mobilized as a result of past release(s) of acidic metals plating solutions at the ABP facility and created a groundwater plume; and 2) to evaluate the extent to which naturally occurring aquifer processes can be relied on to attenuate metals concentrations and pH in groundwater downgradient of the ABP facility prior to its discharge to the Duwamish Waterway.

This memorandum is organized in the following sections: description of the data collected in support of the geochemical evaluations, discussion of the nature and extent of redox metals in groundwater (specifically iron and manganese), assessment of the acid-neutralizing capacity of the aquifer, documentation of natural attenuation mechanisms for plating metals (cadmium, copper, nickel, and zinc), and evaluation of the stability of the attenuation processes based on reactive transport modeling simulations.

DATA COLLECTED IN SUPPORT OF THIS STUDY

As part of this investigation, three soil borings were advanced in September 2014 along a transect beginning at the ABP facility, along the principal groundwater flow direction downgradient (SPO-53, SPO-54, and SPO-55, respectively). The release was most likely to have occurred near the southwest corner of the building when operations were located there between 1983 and 1999, and plating baths were located on concrete floors without secondary containment. Cores were retrieved and characterized for metals concentrations, sulfide, and pH (Table 1). Selected samples from these cores were also analyzed for bulk mineralogy by powder X-ray diffraction (XRD; Table 2), selective sequential extraction (Table 3), and acid-base accounting (Table 4). Metals concentrations in sequential extraction solutions and the calculation procedures for converting these to a soil dry weight concentration basis as reported in Table 3 are described in Attachment B.

Table 1
Soil Chemistry Data

Location	Depth Interval (ft)	Cadmium	Copper	Iron	Manganese	Nickel	Zinc	Sulfide	Total Sulfur (Acid Insoluble)	Soil pH
SPO-53	0-3	0.3	21.8	17,100	243	20	59	1.22 U	16,900	4.36
	3-6	0.2	21.5	12,200	96.3	55	23	1.19 U	100	4.54
	6-9	0.2 U	74.1	11,900	102	684	34	1.26 U	300	4.98
	9-12	0.2 U	21.9	12,100	102	440	34	1.26 U	1,400	4.64
	12-15	0.2 U	8.4	9,980	72	32	19	2.1	100	4.00
	15-18	0.2 U	5.6	8,560	65.6	16	15	1.2 U	400	4.03
	18-21	0.2 U	8.7	9,910	79.8	6	19	1.24 U	100	5.73
	21-24	0.2 U	8.2	10,700	81	6	19	1.52	100	5.01
	24-27	0.2 U	6.8	10,500	74.1	5	16	1.26 U	100	4.26
	27-30	0.2 U	7	8,540	67.5	5	15	1.3 U	100	4.99
SPO-54	0-3	0.5	25.2	18,600	174	13	148	1.07 U	400	5.14
	3-6	0.2 U	15.4	12,800	90.1	8	28	1.2 U	200	5.15
	6-9	0.2 U	15	10,900	81	9	25	3.48	900	4.55
	9-12	0.2 U	13.2	14,600	131	25	30	2.74	300	4.19
	12-15	0.2 U	7	9,180	77	182	19	2.53	200	4.21
	15-18	0.2 U	10.9	12,700	103	585	21	1.23 U	900	4.22
	18-21	0.2 U	8.1	10,100	88.5	206	18	2.84	400	4.21
	21-24	0.2 U	12.5	11,300	94.2	82	19	1.3 U	1,200	4.25
	24-27	0.2 U	7.2	8,940	75.4	32	16	1.26 U	600	4.15
	27-30	0.2 U	17.8	10,900	82.7	19	18	2.12	1,600	4.54
SPO-55	0-3	0.4	21	15,200	295	40	74	1.11 U	1,100	4.29
	3-6	0.2 U	17.1	15,000	132	12	27	1.2 U	200	5.02
	6-9	0.2 U	13.4	11,100	92.4	7	21	1.24 U	300	5.10
	9-12	0.2 U	14.5	10,400	78.7	10	25	2.6	800	4.95
	12-15	0.2 U	11.5	10,200	78.7	8	22	1.22 U	400	5.07
	15-18	0.2 U	11.1	10,900	85.9	8	23	1.61	200	5.16
	18-21	0.2 U	10.5	10,700	81.5	8	20	1.81	500	4.16
	21-24	0.2 U	9.6	10,500	87.1	6	20	2.33	300	4.29
	24-27	0.2 U	7.5	10,300	88.2	7	19	1.46	200	4.73
	27-30	0.2 U	7.1	9,710	83	6	18	1.27 U	300	4.26
	30-33	0.2 U	7.4	9,960	88	7	18	1.22 U	100	4.23
	33-36	0.2 U	8.3	9,230	74.4	6	17	1.76	200	4.13
	36-39	0.2 U	7.3	8,610	68.6	5	16	1.24 U	200	4.24

Notes:

1. Concentrations are in mg/kg.
2. U = Analyte was not detected above the method detection limit (MDL). Reported value is MDL.

Table 2
Minerals Identified by X-ray Diffraction

Mineral	Formula	SP053 06-09	SP053 09-12	SP054 15-18	SP054 21-24	SP055 15-18	SP055 27-30
Albite	$NaAlSi_3O_8$	X	X	X	X	X	
Anorthoclase	$(Na,K)AlSi_3O_8$	X					
Diopside	$CaMgSi_2O_6$		X				
Labradorite	$(Ca,Na)(Al,Si)_4O_8$	X					X
Quartz	SiO_2	X	X	X		X	X

The Data Gaps Work Plan recognized that identification and quantification of specific plating metals minerals by XRD in site soils may not be possible due to well-known limitations of the method, which can include low mineral abundances below detection limits (typically on the order of 1 %) and phase crystallinity. Given the range of plating metals concentrations detected in the soil samples (Table 1), we would not expect to detect any mineral phases in which plating metals constitute a major component. Furthermore, important mineral phases responsible for attenuation of metals in groundwater, such as ferrihydrite (iron oxyhydroxide) and amorphous iron sulfide, are X-ray amorphous and not easily detected by XRD. To address these limitations, additional lines of evidence based on bulk chemistry, sequential extraction, and evaluation of mineral saturation indices (SI), computed from groundwater chemistry using PHREEQC are also examined. The SI's indicate whether a particular phase is stable and used to infer whether it could (or could not) precipitate from groundwater. The sequential extraction results and bulk chemistry data (e.g. total sulfide concentrations) are used to test whether the inferred precipitation reaction actually occurred and the extent to which plating metals are associated with the inferred phases (e.g. iron concentration in the reducible fraction provides an estimate of the iron oxide content of the soil, and nickel in the reducible fraction represents the fraction of that metal that is bound to iron oxides). Although it is often not possible to directly detect specific phases associated with trace metals due to their low concentrations, the use of multiple geochemical lines of evidence based on testable hypotheses is a valid and useful approach and consistent with EPA guidance on monitored natural attenuation of inorganics in groundwater (EPA 2007). The converging lines of evidence described above are therefore considered sufficient to draw conclusions regarding the association of plating metals with specific phases at the site.

Table 3
Selective Sequential Extraction Results (mg/kg)

Metal	Fraction	SP053 06-09	SP053 09-12	SP054 15-18	SP054 15-18 (D)	SP054 21-24	SP055 15-18	SP055 27-30
Cadmium	Exchangeable	2 U	2 U	2 U	2 U	2 U	2 U	2 U
	Weak Acid Soluble	0.4 J	0.4 J	0.4 J	0.4 J	0.5 J	0.5 J	0.4 J
	Reducible	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
	Oxidizable	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
	Residual	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Copper	Exchangeable	2 U	2 U	2 U	2 U	2 U	2 U	2 U
	Weak Acid Soluble	7.9	4.4	1.3	1.3	2.2	1.6	1.5
	Reducible	17.3	8.3	2.9 B	3.1 B	4.7 B	4.2 B	3.0 B
	Oxidizable	15	3.9 B	1.5 B	1.7 B	3.0 B	1.8 B	1.6 B
	Residual	25	7.4 B	3.5 B	3.7 B	3.3 B	3.9 B	3.6 B
Iron	Exchangeable	44 U	44 U	79	44 U	46 U	45 U	45 U
	Weak Acid Soluble	65	126	196	215	451	324	255
	Reducible	2,690	1,950	1,250	1,290	1,800	1,390	1,280
	Oxidizable	1,080	2,170	1,170	1,280	1,800	842	828
	Residual	8,780	9,690	8,360	8,750	7,410	8,580	8,550
Manganese	Exchangeable	1 U	4 B	5 B	4 B	10 B	2 B	1 U
	Weak Acid Soluble	15.9 B	15.4 B	11.5 B	12.8 B	15.3 B	11.3 B	11.1 B
	Reducible	26.7	17.2 B	10.4 B	10.6 B	23.4	11.6 B	11.1 B
	Oxidizable	7.9 B	8.5 B	9.0 B	8.7 B	11.4 B	7.0 B	7.7 B
	Residual	62	83	71	77	61	70	71
Nickel	Exchangeable	80	87	120	89	20	9 U	9 U
	Weak Acid Soluble	241	192	110	125	57	1	1
	Reducible	107	85	60	58	44	1	1
	Oxidizable	124	58	37	35	28	3	2
	Residual	157	53	18	20	8	4	4
Zinc	Exchangeable	9 U	9 U	9 U	9 U	9 U	9 U	9 U
	Weak Acid Soluble	3	2	2	2	2	2	2
	Reducible	11	9	5	6	6	7	5
	Oxidizable	16	7	4	4	5	4	4
	Residual	19	16	14	15	12	14	14

Notes:

1. U = Analyte was not detected above the MDL.
2. B = Analyte was detected in associated procedural blank; sample result is less than 10 times greater than the reported blank value and the reported result may overestimate the true value. B-flagged data are not used for data analysis, but provide an upper bound estimate of metals distribution in the affected fraction.
3. J = Estimated value due to matrix interference.

Table 4
Acid-Base Accounting

Parameter	Units	SP053 06-09	SP053 09-12	SP054 15-18	SP054 15-18 (D)	SP054 21-24	SP055 15-18	SP055 27-30
Total Carbon [TC]	% wt	0.165	0.652	0.636	0.332	0.189	0.161	0.075
Total Organic Carbon [TOC]	% wt	0.260	0.485	0.495	0.287	0.141	0.135	0.067
Total Inorganic Carbon [TIC][1]	% wt	0	0.167	0.141	0.045	0.048	0.026	0.008
Total Acid Insoluble Sulfur[2]	% wt	0.03	0.14	0.09	0.09	0.12	0.02	0.03
Neutralization Potential [NP][3]	g $CaCO_3$ equivalent/ kg soil	0.0	13.9	11.7	3.7	4.0	2.2	0.7
	millimoles $CaCO_3$ equivalent/ kg soil	0.0	139	117	37	40	22	7
Acid Production Potential [APP][4]	g pyrite equivalent/ kg soil	0.6	2.6	1.7	1.7	2.2	0.4	0.6
	millimoles pyrite equivalent/ kg soil	5	22	14	14	19	3	5
Net Neutralization Potential [NNP][5]	millimoles/ kg soil	-5	117	103	23	21	19	2

Notes:

1. By difference [TIC = TC – TOC]
2. Assumed to be equal to pyrite sulfur [PS]
3. NP = TIC × 83.3 [g $CaCO_3$/kg] = TIC × 833 [millimoles/kg]
4. APP = PS × 18.7 [g pyrite/kg] = PS × 156 [millimoles/kg]
5. NNP = NP - APP

In addition to the core sampling, during the September 2014 monitoring event, selected monitoring wells were sampled for an extended suite of analytes to support the geochemical evaluations discussed herein. The supplemental RI sampling locations are shown in Figure 1 of Attachment A. Geochemical speciation-solubility modeling was performed using the geochemical modeling code PHREEQC to evaluate saturation states of selected minerals in groundwater and identify potential solubility controls on metals concentrations. The mineral saturation state results are summarized in Table 5. Mineral saturation indices were also presented in the 2012 RI Report using data from April 2012. The 2012 results may differ slightly form the 2014 results due to differences in the chemical data set; however the hypotheses have remained the same as this analysis builds on and refines the work completed in 2012.

Table 5
Mineral Saturation States

Aquifer Interval	**Water Table**						**Shallow**				
Distance from Source Area (ft)	**-180**	**-100**	**0**	**40**	**140**	**2,000**	**-180**	**40**	**140**	**460**	**2,200**
Mineral Phase	**MW-6**	**MW-12**	**MW-1**	**MW-3**	**MW-8**	**MW-24**	**MW-6-30**	**MW-3-30**	**MW-8-30**	**MW-16-40**	**MW-22-30**
Ferrihydrite [$Fe(OH)_3$]	-0.55*	**0.21**	-2.07	-1.16*	**0.54**	**0.87**	**0.72**	**1.23**	**0.78**	***0.00***	***-0.08***
Goethite [FeOOH]	**5.03***	**5.80**	**3.57**	**4.50***	**6.16**	**6.64**	**6.28**	**6.83**	**6.34**	**5.53**	**5.52**
Mackinawite [FeS]	-1.68*	-0.39	-6.72*	-5.56*	**0.31***	**1.52**	**1.03***	**1.30***	**0.82***	**0.79***	**1.21**
Pyrite [FeS_2]	**20.95***	**21.39**	**23.49***	**23.21***	**21.44***	**1.51**	**20.86***	**21.27***	**21.05***	**19.94***	**21.78**
Siderite [$FeCO_3$]	-1.98*	-0.57	-5.84*	-5.68*	-0.73	**0.81**	**0.60**	**1.02**	**0.27**	***-0.04***	**0.16**
Rhodochrosite [$MnCO_3$]	-2.56	-1.55	-4.22*	-4.30*	-1.57	-0.32	-0.75	***0.02***	-0.84	-1.57	-0.62
Calcite [$CaCO_3$]	-1.21	-2.13	-5.12*	-5.07*	-2.48	-0.42	-1.50	-0.94	-1.86	-2.14	-0.64
Gibbsite [$Al(OH)_3$]	**2.40***	**2.11***	-1.88	**0.47**	**2.22***	**2.15***	**2.41***	**2.24***	**2.34***	**2.28***	**2.31***
$Ni(OH)_2$	-4.94	-5.32	-6.01	-4.90	-2.17	-5.66	-5.19	-5.15	-2.33	-5.30	-5.32
$NiCO_3$	-7.75	-7.88	-7.24*	-7.35*	-5.49	-7.65	-8.15	-7.94	-5.47	-8.70	-7.88
Millerite [NiS]	**0.21***	***-0.06****	-0.51*	**0.36***	**3.18***	**0.57**	***-0.04****	***-0.02****	**2.75***	**-0.18***	**0.81**
α-NiS	**1.79***	**1.53***	**1.08***	**1.96***	**4.77***	**2.19**	**1.54***	**1.57***	**4.33***	**1.40***	**2.40**
Heazlewoodite [Ni_3S_2]	-17.36*	-17.33*	-27.13*	-23.10*	-6.97*	-14.52	-15.31*	-15.39*	-7.34*	-15.02*	-13.51
Vaesite [NiS_2]	**5.52***	**5.60***	**6.31***	**6.54***	**8.87***	**5.77**	**5.21***	**4.74***	**8.36***	**5.62***	**6.73**
Sphalerite [ZnS]	**2.72***	**2.92***	**0.45***	**1.63***	**2.55***	**1.91***	**2.71***	**2.78***	**3.31***	**2.64***	**1.78***
Wurtzite [ZnS]	**0.71***	**0.92***	-1.54*	-0.35*	**0.55***	***-0.05****	**0.70***	**0.78***	**1.30***	**0.63***	-0.22*
ZnS(a)	**0.05***	**0.26***	-2.20*	-1.00*	-0.11*	-0.69*	***0.04****	**0.12***	**0.63***	***-0.04****	-0.88*
Anilite [$Cu_{0.25}Cu_{1.5}S$]	**6.85***	**7.25***	**3.56***	**6.52***	**6.38***	**4.96**	**7.20***	**6.81***	**7.90***	**8.49***	**3.08**
Blaublei I [$Cu_{0.9}Cu_{0.2}S$]	**9.02***	**8.99***	**9.90***	**11.28***	**8.24***	**7.56**	**8.17***	**8.06***	**8.75***	**8.65***	**5.93**
Blaublei II [$Cu_{0.6}Cu_{0.8}S$]	**7.14***	**7.32***	**6.18***	**8.33***	**6.55***	**5.75**	**6.83***	**6.63***	**7.45***	**7.62***	**3.76**
Chalcocite [Cu_2S]	**5.56***	**6.13***	**0.70***	**4.29***	**5.23***	**3.65**	**6.36***	**5.88***	**7.09***	**7.93***	**1.53**
Chalocopyrite [$CuFeS_2$]	**16.23***	**17.38***	**12.53***	**14.75***	**17.30***	**17.46**	**17.96***	**18.04***	**18.32***	**18.18***	**16.07**
Covellite [CuS]	**9.32***	**9.18***	**10.70***	**11.79***	**8.41***	**7.50**	**8.31***	**8.16***	**8.88***	**8.75***	**6.28**
Djurleite [$Cu_{0.066}Cu_{1.868}S$]	**5.92***	**6.45***	**1.48***	**4.91***	**5.56***	**4.02**	**6.61***	**6.15***	**7.33***	**8.11***	**1.96**

Notes:

1. Calculated using PHREEQC.
2. Distances are from MW-1 projected along transect in Figure 1 of Attachment A.
3. * indicates that one or more constituent ion concentrations were below detection limits. SI was calculated by setting non-detect results to the detection limit. SI values are therefore upper bound estimates.
4. Positive values (**bold**) indicate supersaturation; mineral precipitation from groundwater is thermodynamically favorable. Negative values indicate undersaturation; mineral cannot precipitate but could be dissolved if present. Values close to 0 (±0.1, in ***bold italic***) indicate groundwater is at equilibrium with mineral.
5. SI values for zinc and copper carbonates (Smithsonite [$ZnCO_3:H_2O$] and Azurite [$Cu_3(CO_3)_2(OH)_2$], not shown) were negative.

NATURE AND EXTENT OF REDOX METALS (IRON AND MANGANESE)

Iron and manganese behave similarly in groundwater systems. Iron and manganese are soluble under naturally occurring, mildly to moderately reducing conditions. Iron and manganese concentrations are controlled by formation of oxyhydroxides (e.g., ferrihydrite [$Fe(OH)_3$], pyrolusite [MnO_2]) in aerobic groundwater (dissolved oxygen [DO] > approximately 1 mg/L), and by formation of sulfide minerals (e.g., mackinawite [FeS], pyrite [FeS_2]) and/or carbonate minerals (e.g., siderite [$FeCO_3$], rhodochrosite [$MnCO_3$]) under reducing conditions. Elevated iron and manganese is commonly associated with dissolution of sulfide minerals via oxidation reactions or dissolution of oxyhydroxides via acid hydrolysis or reduction reactions. However, under reducing conditions, dissolved iron is not typically detected when sulfide is present, and vice versa, due to the low solubility of iron sulfide minerals.

Elevated concentrations of iron and manganese in SU1 groundwater are hypothesized to be 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. This hypothesis was tested by reviewing existing geochemical conditions in SU1 groundwater, evaluating the observed distributions of iron and manganese in groundwater in context of site conditions, and geochemical modeling to identify potential mineral controls on dissolved concentrations.

Groundwater Geochemical Conditions

Figure 1 shows the distribution of groundwater pH in wells in the water table (screened between 4 to 15 feet below ground surface [bgs]), shallow (20 to 40 feet bgs), and intermediate (40 to 75 feet bgs) aquifer intervals as a function of distance downgradient from monitoring well MW-1, a well near the probable location of the past release of acidic plating solution at the ABP facility. The transect parallels the predominant groundwater flow direction from left to right (NE-SW), and the Duwamish Waterway is located approximately 2,400 feet downgradient of MW-1.

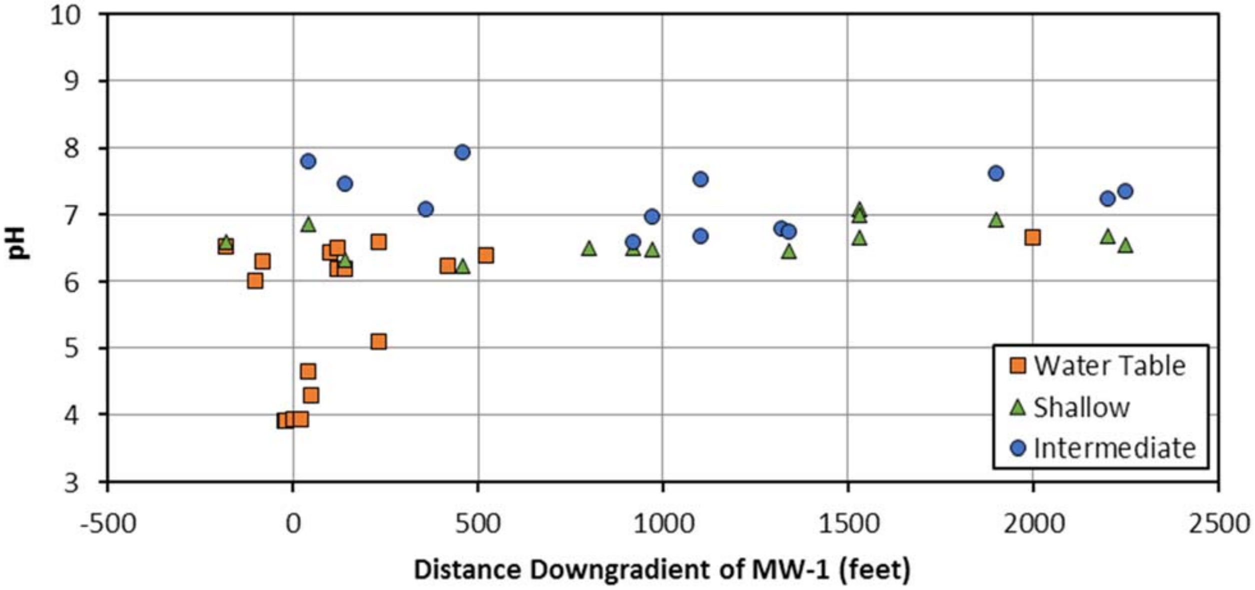


Figure 1
Downgradient trend in pH of SU1 groundwater.

Groundwater pH is circumneutral (6 to 8) across SU1 at all depths except for the water table interval in the vicinity of MW-1, where acidic pH values as low as 4 are observed, consistent with this being near the source area where plating solution releases occurred. The water table interval groundwater pH increases to background values within approximately 200 feet downgradient of the source area.

Figure 2 displays the distribution of oxidation-reduction potential (ORP) in SU1 groundwater. Mildly to moderately reducing conditions in the shallow and intermediate aquifer intervals are indicated by negative ORP values which range between 0 to -200 millivolts (mV). Redox conditions in the water table interval are generally more oxidizing (0 to +200 mV). In the source area near MW-1, ORP is anomalously high (up to +500 mV), indicating oxidizing conditions.

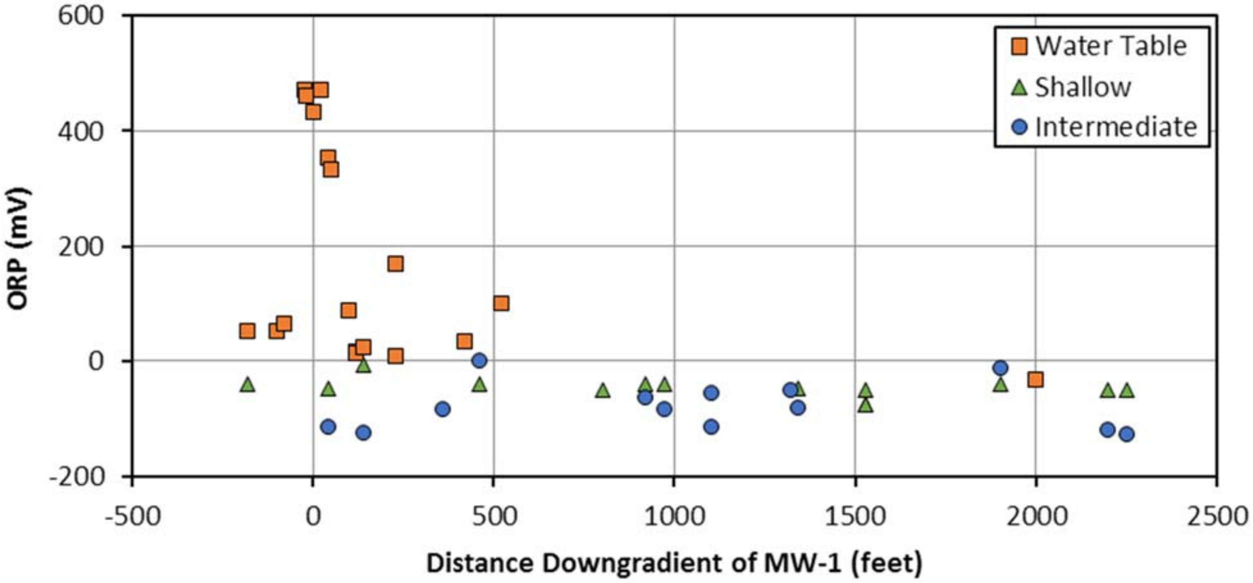


Figure 2
Downgradient trend in oxidation-reduction potential of SU1 groundwater.

Figure 3 shows the distribution of DO in groundwater along the groundwater transect. Consistent with the ORP data, the very low DO concentrations (<0.2 mg/L) confirm the prevalence of anaerobic groundwater conditions across SU1 except in the vicinity of the source area, where an air sparging system is operating for volatile organic compound (VOC) removal, which results in locally oxygenated conditions. This also explains the high positive ORP readings in this area.

Figure 4 presents available groundwater data for sulfide concentrations along the transect. Sulfide concentrations are detected at the far downgradient end of the transect, confirming the occurrence of sulfate reduction in the aquifer. As noted earlier in this section, under sulfate-reducing conditions, sulfide concentration may be very low or even below detection limits when dissolved iron is present, due to the low solubility of iron sulfide minerals. Therefore, the absence of detectable sulfide in groundwater is not a reliable indicator of the absence of sulfate reduction (and sulfide mineral precipitation).

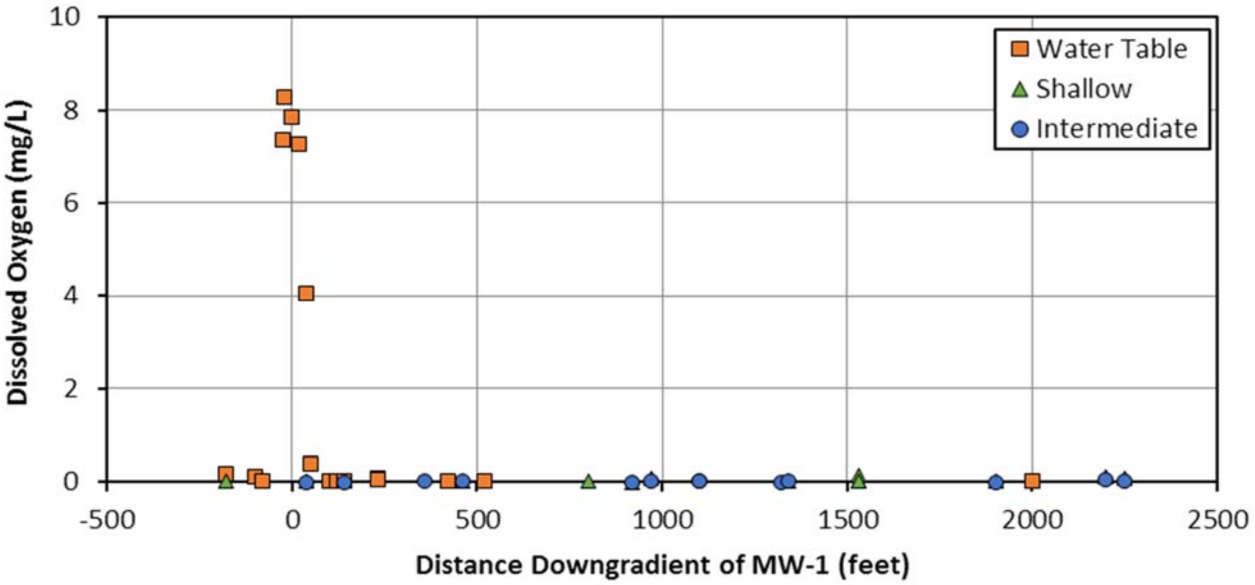


Figure 3
Downgradient trend in dissolved oxygen concentrations in SU1 groundwater.

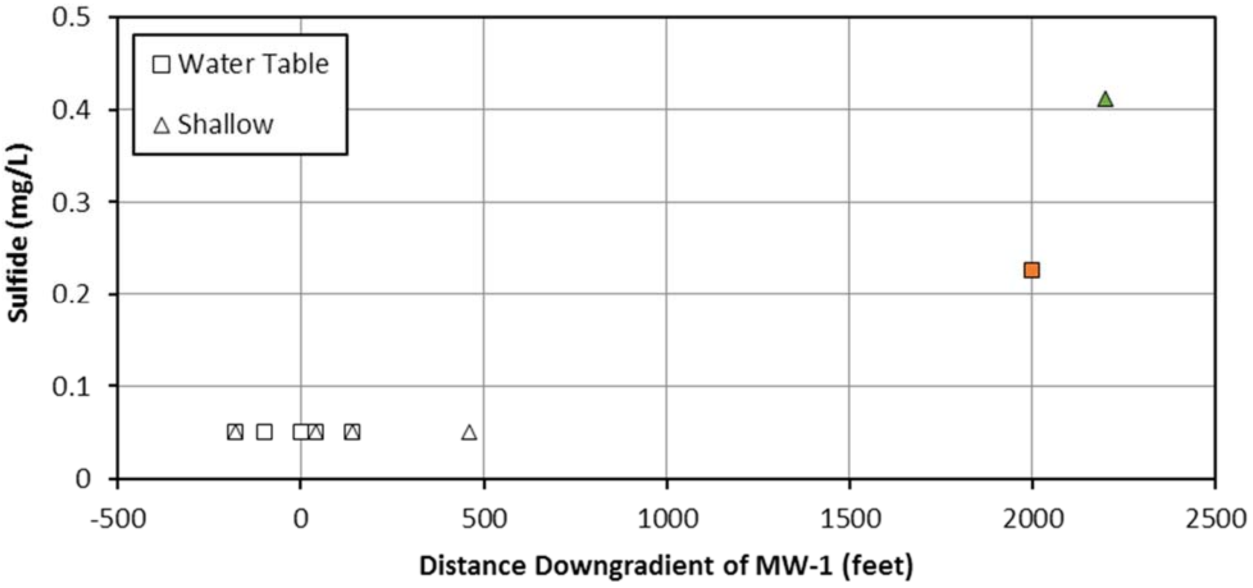


Figure 4
Downgradient trend in sulfide concentrations in SU1 groundwater. Non-detect samples are plotted as open symbols at the detection limit.

Iron

Iron is detected in groundwater across SU1, at concentrations ranging from non-detect to more than 50 mg/L (Figure 5). The fact that elevated iron concentrations are detected in wells upgradient of the source area is compelling evidence that iron is naturally occurring and the elevated iron concentrations observed in SU1 groundwater are not directly related to releases of acidic plating solutions. Furthermore, in the vicinity of the source area, iron concentrations in the water table interval are below detection limits, due to the aerobic conditions created by the air sparging system, which promotes iron oxidation and precipitation as iron oxyhydroxides.

Depending on pH both iron and sulfide may be detected at low levels. Low levels of iron, in addition to sulfide, were detected at the downgradient end of the transect. Dissolved iron and sulfide concentrations are controlled by solubility of iron sulfides, iron carbonate (siderite), and ferric iron (oxy)hydroxides, as indicated by saturation index calculations (Table 5). Mackinawite (FeS) solubility is strongly pH dependent. Downgradient of the low pH source area, as conditions become more reducing and pH increases, mackinawite becomes stable. Depending on pH both iron and sulfide may be detected at low levels.

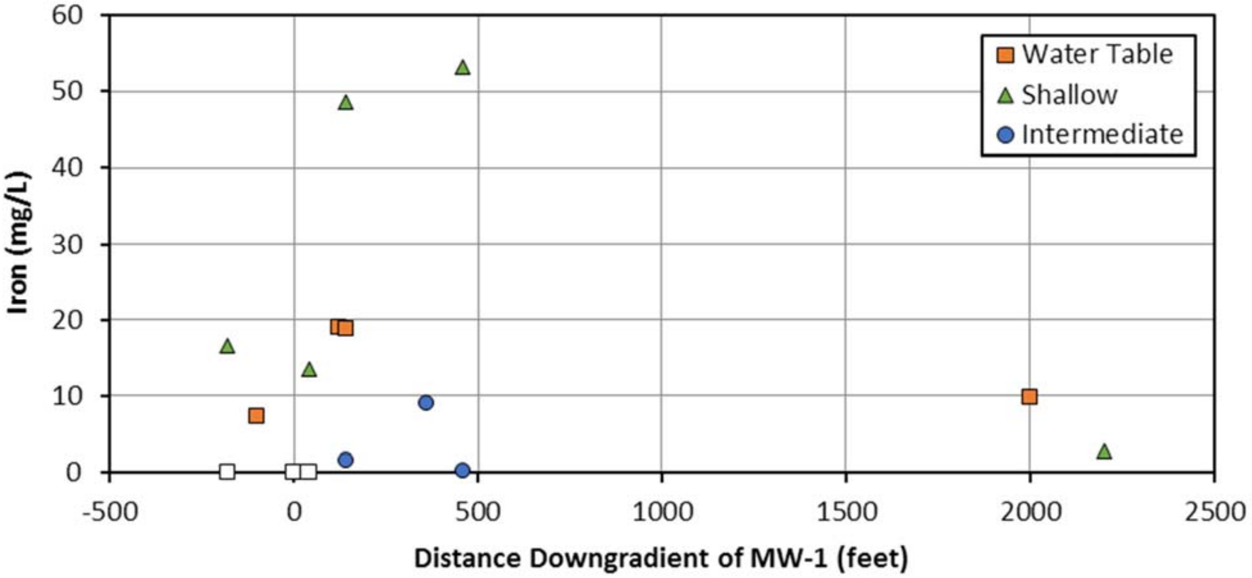


Figure 5

Downgradient trend in dissolved iron concentrations in SU1 groundwater. Non-detect samples are plotted as open symbols at the detection limit.

An Eh-pH diagram for iron is presented in Figure 6. The diagram was constructed for chemical conditions similar to SU1 and depicts the stability regions of some iron oxyhydroxide, carbonate, and sulfide minerals commonly occurring in soils and groundwater systems. Eh (calculated from ORP) and pH data for SU1 monitoring wells are also plotted on the diagram.

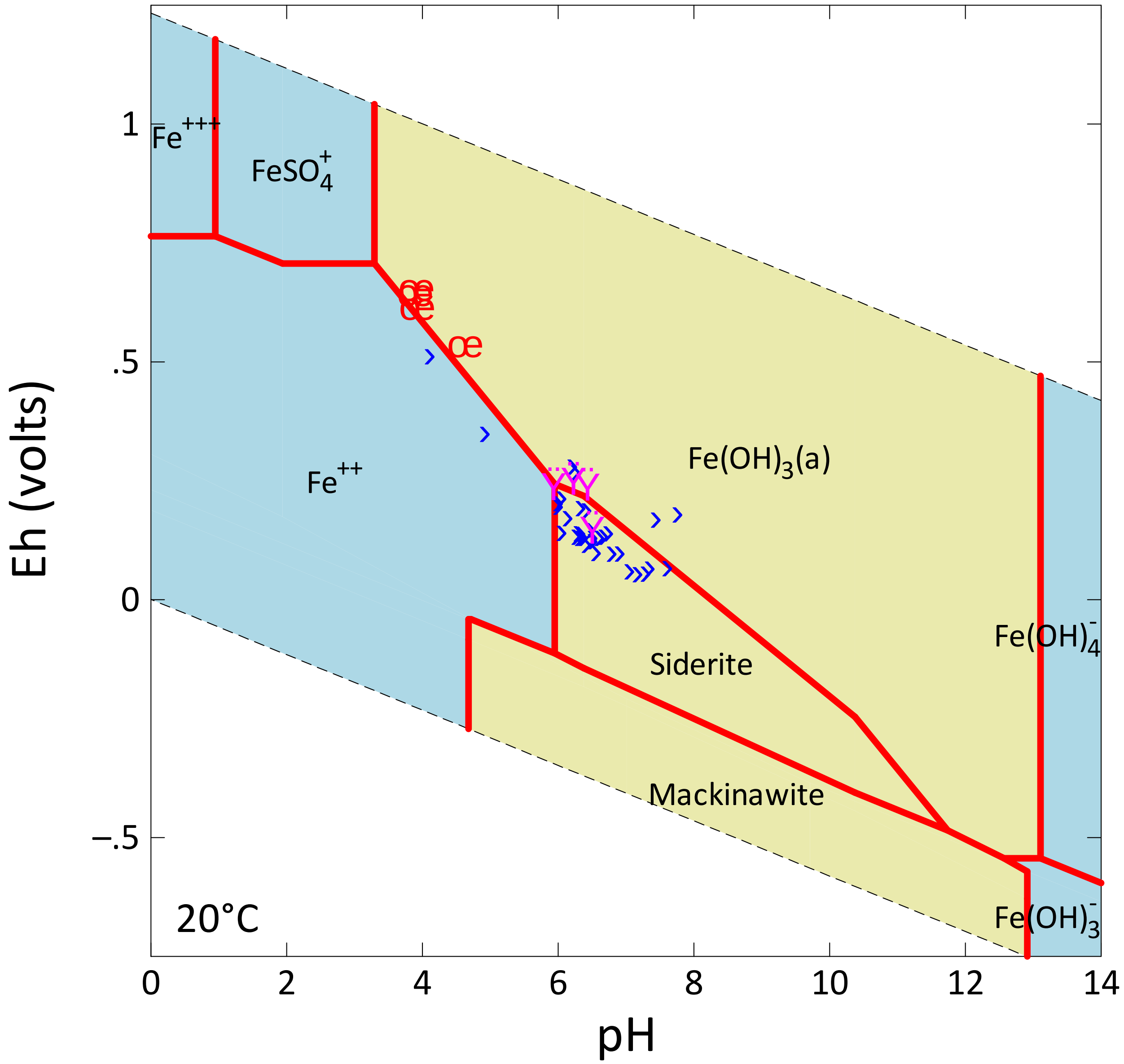


Figure 6
Eh-pH diagram for iron showing equilibrium stability relations of potential iron minerals [red circles are source area wells; blue squares are downgradient wells, and pink diamonds are upgradient wells].

The data indicate that iron concentrations may be controlled by ferrihydrite (iron hydroxide) and siderite (iron carbonate) equilibria in upgradient areas, switch to ferrihydrite alone in the source area where conditions are more acidic and oxidizing, and gradually shift back to ferrihydrite and siderite downgradient as pH is attenuated.

These trends are also supported by the mineral saturation modeling results presented in Table 5, where most of the water table and shallow aquifer wells sampled are close to saturation or slightly supersaturated with respect to ferrihydrite. All of the shallow aquifer wells sampled are also close to saturation with siderite. The highest iron concentrations occur in shallow groundwater wells with pH greater than 6. The fact that the Eh-pH data follow the equilibrium boundary between ferrihydrite and dissolved Fe^{++} suggests that iron concentrations in groundwater respond to changes in Eh-pH conditions in the aquifer that affect mineral solubility and are not the direct result of plating solution releases. Thus the elevated iron concentrations in groundwater can be explained by dissolution of iron minerals from the aquifer matrix under reducing conditions.

Manganese

Manganese is also detected in groundwater across SU1 at concentrations up to 2 mg/L (Figure 7). Manganese concentrations approaching 0.4 mg/L are detected in wells upgradient of the source area and provide evidence that manganese is naturally occurring and the elevated concentrations observed in SU1 groundwater are not directly related to releases of acidic plating solutions.

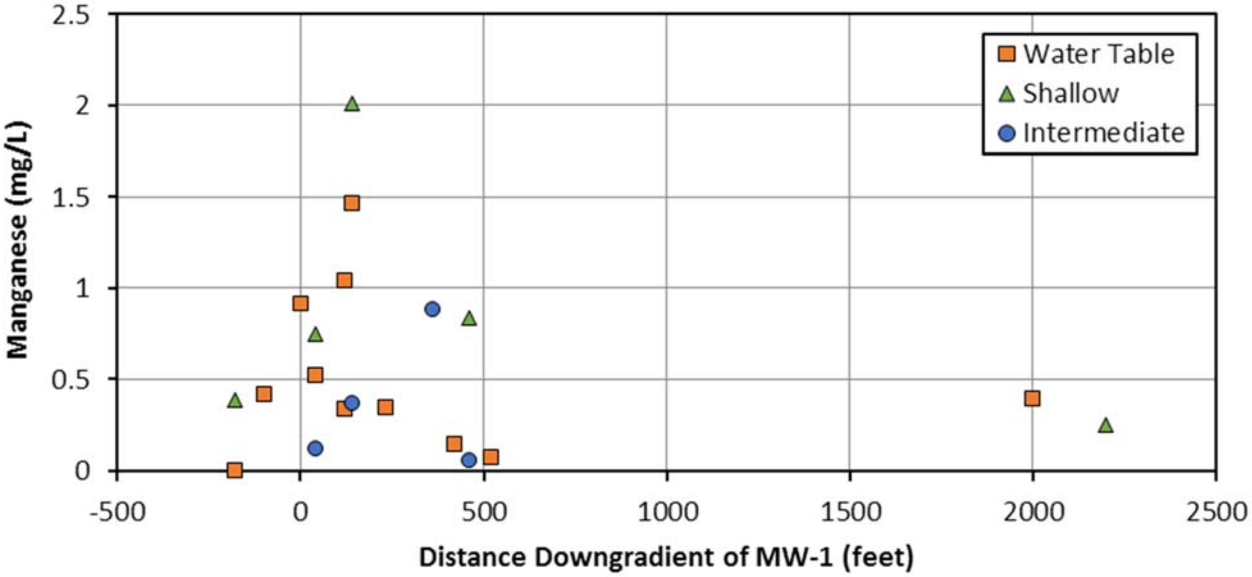


Figure 7
Downgradient trend in dissolved manganese concentrations in SU1 groundwater.

An Eh-pH diagram for manganese is presented in Figure 8. The diagram was constructed for chemical conditions similar to SU1 and depicts the stability regions of some manganese oxyhydroxide and carbonate minerals commonly occurring in soils and groundwater systems. Eh and pH data for SU1 monitoring wells are also plotted on the diagram. The data indicate that dissolved manganese concentrations may be controlled by rhodochrosite (manganese carbonate) equilibria in areas upgradient and downgradient areas, but manganese is soluble within and immediately downgradient of the acidic plume. These trends are also partly supported by the mineral saturation modeling results presented in Table 5, where some of the water table and shallow aquifer wells downgradient of the source area approach saturation with respect to rhodochrosite. The data points that plot within the stability field of dissolved Mn^{++} in Figure 8 (conditions where manganese is soluble) are wells within the acidic plume; however, the highest manganese concentrations occur outside the acidic plume in groundwater with pH greater than 6. If manganese were introduced into groundwater as a constituent of the plating solution, then wells within the acidic plume would be expected to have the highest manganese concentrations. This is strong evidence that manganese concentrations in groundwater, like iron, respond to changes in Eh-pH conditions in the aquifer and are not the direct result of plating solution releases.

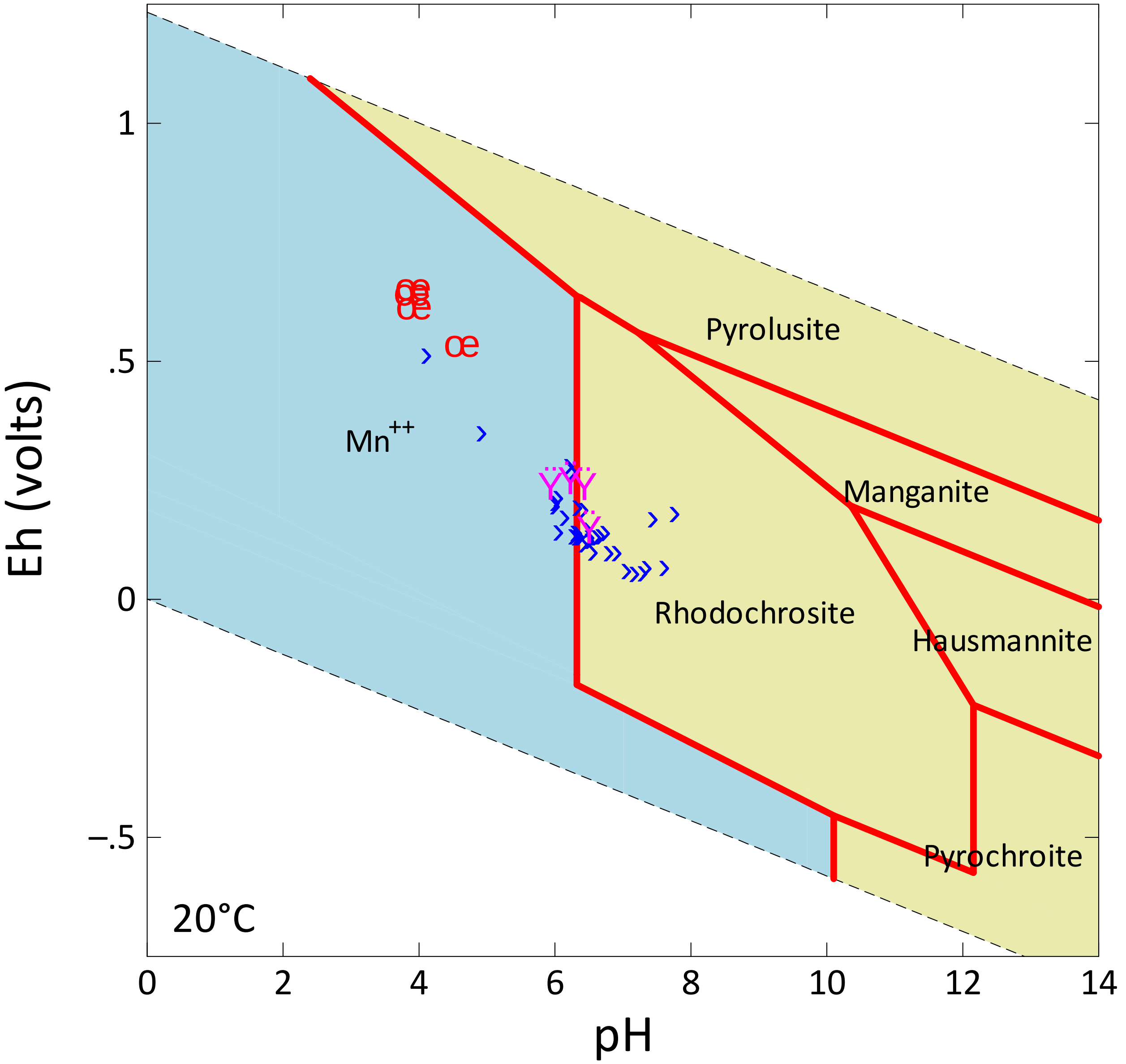


Figure 8
Eh-pH diagram for manganese showing equilibrium stability relations of potential manganese minerals [red circles are source area wells; blue squares are downgradient wells, and pink diamonds are upgradient wells].

The source of elevated manganese concentrations appears to be dissolution of manganese minerals from the aquifer matrix under mildly reducing conditions characteristic of SU1 groundwater, with pH conditions in the acidic plume favoring manganese in the dissolved phase.

METALS ATTENUATION MECHANISMS

Elevated dissolved nickel concentrations (up to 26,300 micrograms [µg]/L) are detected near the source area; however, nickel concentrations are attenuated to less than the groundwater screening level (8.2 µg/L) within approximately 200 feet downgradient of MW-1 (Figure 9). The purpose of the figures in this section is to illustrate a current spatial snap shot of the plume. Dissolved metals concentrations are representative of metals transported by groundwater. Total metals concentrations include variable amounts of metals associated with particulate matter which is not considered representative of transportable concentrations.

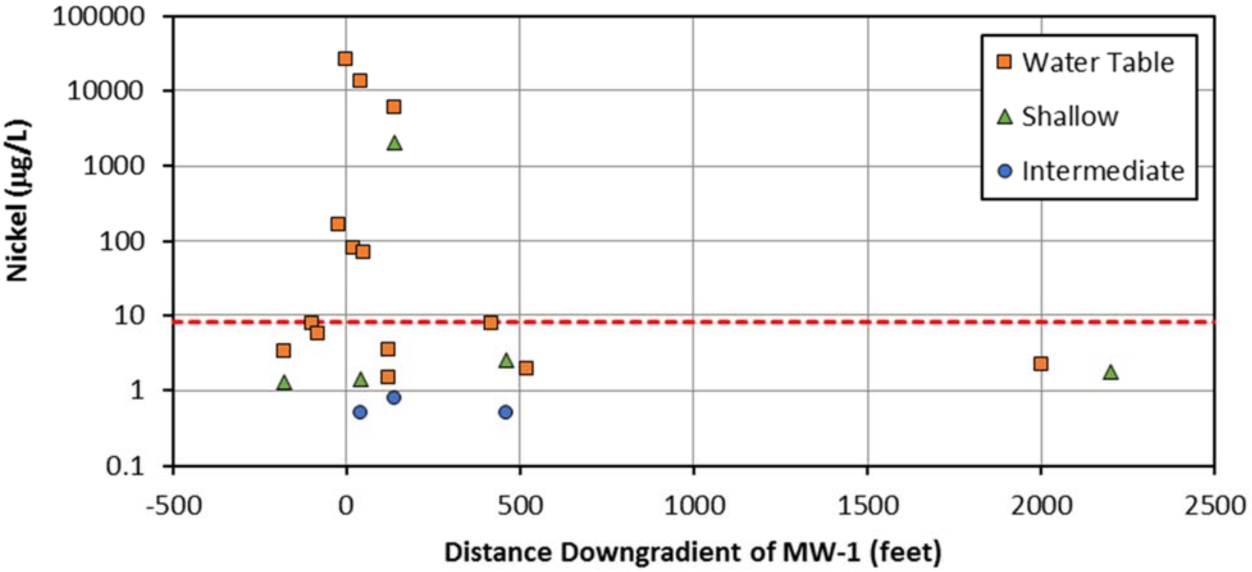


Figure 9
Downgradient trend in dissolved nickel concentrations in SU1 groundwater. The red dashed line indicate the nickel clean-up level of 8.2 µg/L.

Similar spatial patterns are observed for the other plating metals—cadmium, copper, and zinc (Figures 10 to 12, respectively). This indicates that plating metals are being attenuated by naturally occurring processes within the SU1 aquifer.

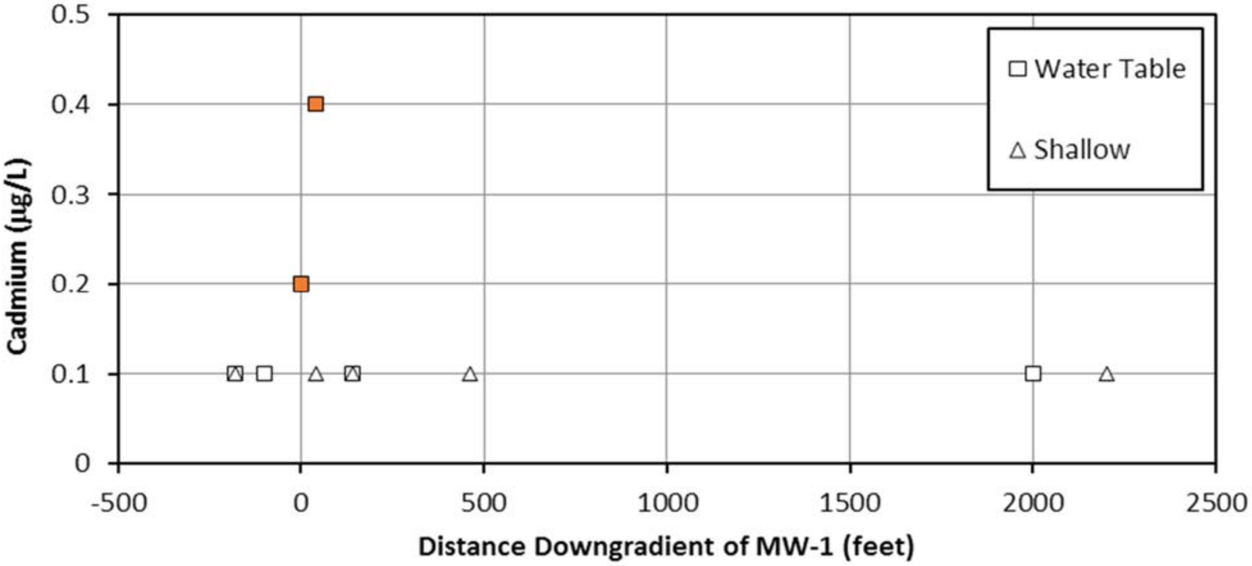


Figure 10
Downgradient trend in dissolved cadmium concentrations in SU1 groundwater. Non-detect samples are plotted as open symbols at the detection limit.

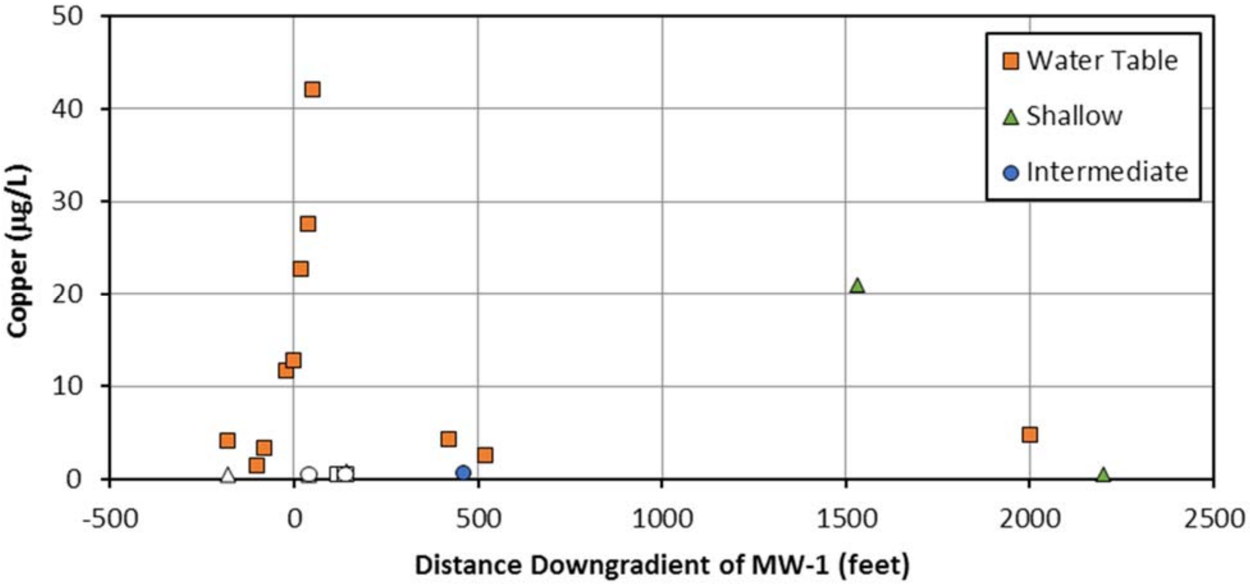


Figure 11
Downgradient trend in dissolved copper concentrations in SU1 groundwater. Non-detect samples are plotted as open symbols at the detection limit.

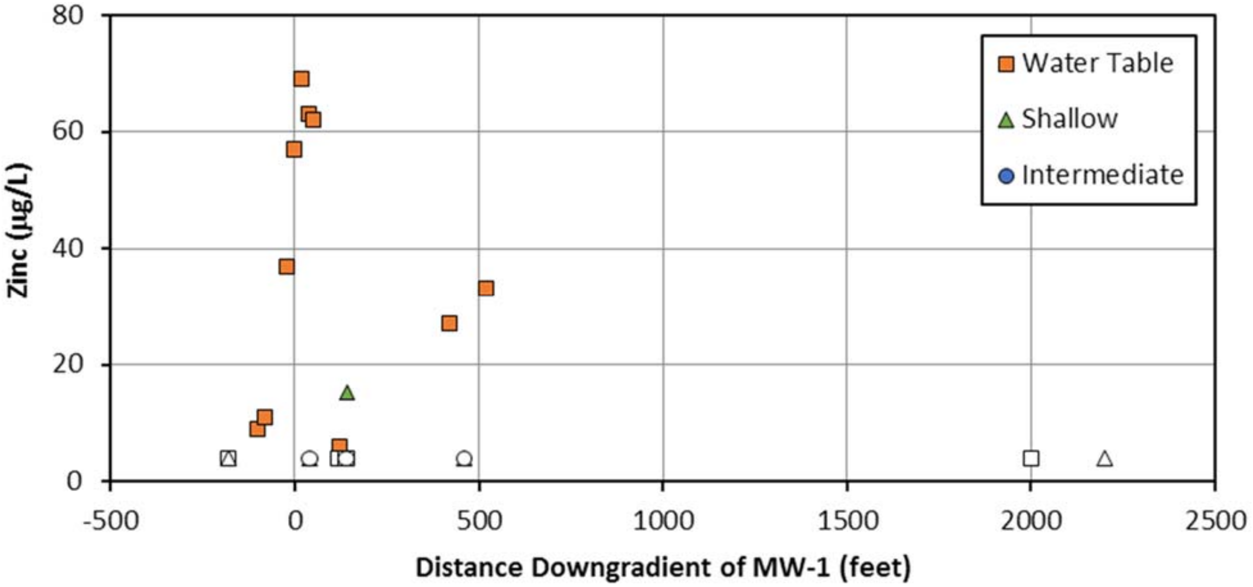


Figure 12
Downgradient trend in dissolved zinc concentrations in SU1 groundwater. Non-detect samples are plotted as open symbols at the detection limit.

It should be noted that operation of the air sparging system has locally disturbed the ambient subsurface conditions near the source area by introducing oxygen, creating a localized increase in dissolved metals concentrations in groundwater. In the future, as the sparging system is phased out, it is expected that subsurface conditions will again return to mildly to moderately reducing.

The discussion of metals attenuation mechanisms that follows is focused primarily on nickel because nickel is the plating metal detected at highest concentrations relative to screening levels in SU1 groundwater. However, the fate and transport of other plating metals (cadmium, copper, and zinc) is also affected by similar attenuation processes as nickel.

The Eh-pH diagram for nickel (Figure 13) suggests that under site conditions the stable form of nickel is in the dissolved phase as aqueous ions, such as Ni^{2+} and $NiCO_3$, depending on pH. However, because aquifer geochemical conditions are favorable for the formation of iron oxyhydroxides, such as ferrihydrite and goethite (Figure 6 and Table 5), it is expected that adsorption on and co-precipitation of nickel and other plating metals in these phases plays an important role in their fate and transport at the site.

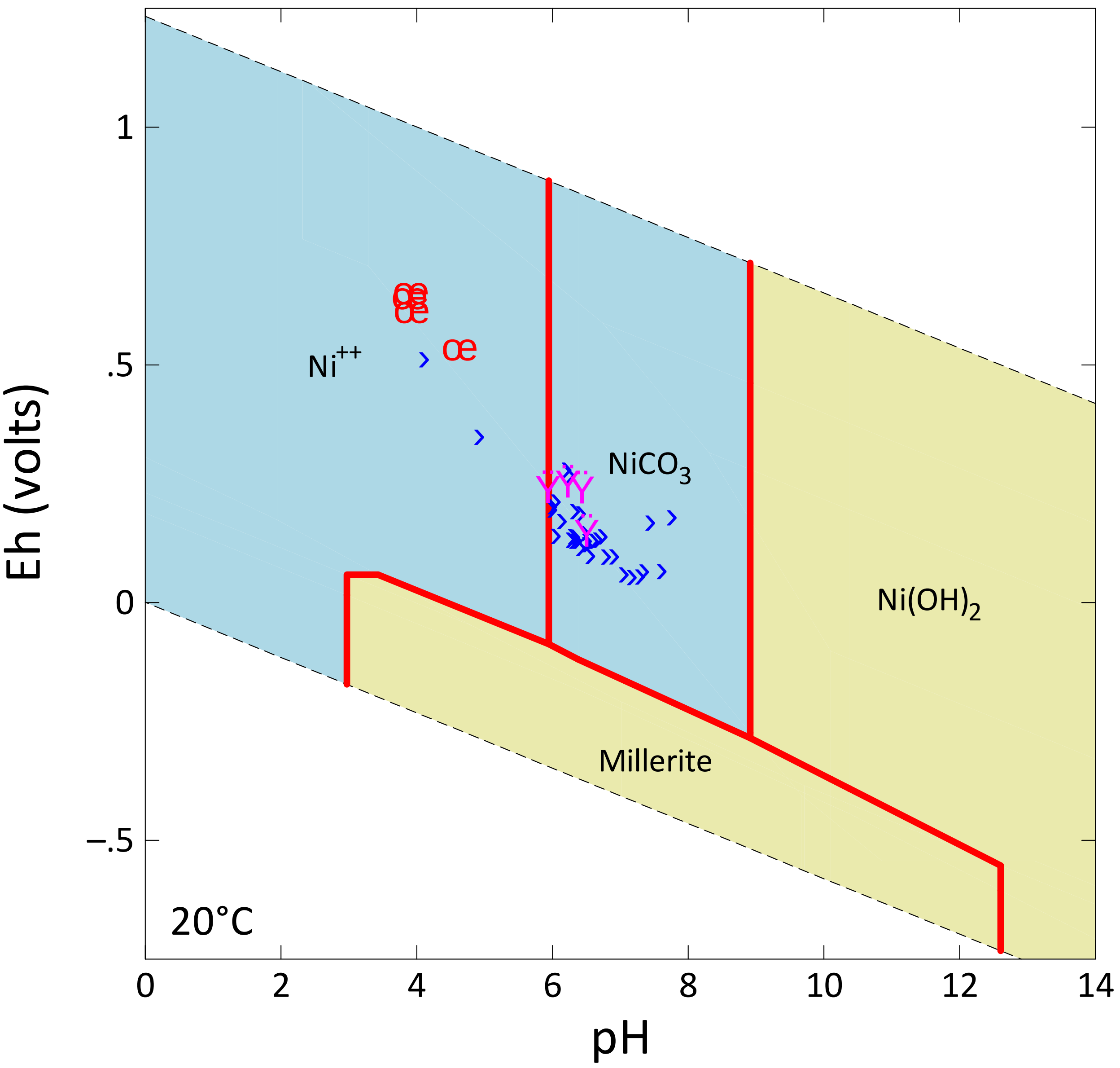


Figure 13
Eh-pH diagram for nickel showing equilibrium stability relations of dissolved (blue shaded) and solid (yellow shaded) nickel phases [red circles are source area wells; blue squares are downgradient wells, and pink diamonds are upgradient wells].

The nickel Eh-pH diagram also shows that the nickel sulfide phase millerite [NiS] is stable over a wide pH range under reducing conditions. However, Eh measurements in SU1 groundwater generally appear to reflect equilibrium between the $Fe(OH)_3/Fe^{++}$ redox couple (Figure 6), partly due to the very low concentrations of sulfide (typically below detection limits). Plotting groundwater data on Eh-pH stability diagrams is, therefore, not a useful approach for evaluating the potential for sulfide mineral precipitation under site conditions.

Because both adsorption on iron oxyhydroxides and precipitation of metal sulfide minerals are potentially important mechanisms for reducing plating metals mobility at the site, bulk chemical, mineralogical (XRD), and sequential extraction analyses of aquifer materials were performed to provide more direct lines of evidence for these processes. These results, which are summarized in Tables 1 through 3, are discussed in the following sections.

Metal Oxide/Hydroxide Precipitation

Although iron concentrations in the soil samples range from 8,540 to 18,600 mg/kg (0.85 to 1.86 percent by weight; Table 1), no iron oxide minerals were identified by XRD (Table 2). This is not surprising because iron minerals present at these concentrations would not be detectable by XRD, especially if they occur as poorly crystalline iron oxides, such as ferrihydrite. However, sequential extraction results provide direct evidence for the presence of iron oxides. The reducible fraction is extracted with 0.1 M hydroxylamine hydrochloride adjusted to pH 2 with nitric acid. This procedure is based on one of several methods commonly employed to quantify amorphous iron oxides in soil (Loeppert and Inskeep. 1996). The reducible iron fraction concentrations range from 1,250 to 2,690 mg/kg (0.13 to 0.27 percent by weight; Table 3). This represents 11 to 21 percent of the total iron these samples.

Nickel and other plating metals have a strong affinity for adsorption on and co-precipitation with iron and manganese oxides, and these mineral phases are important in controlling metals fate and transport in groundwater. Manganese concentrations in the soils are relatively low compared to iron (Table 4), therefore iron oxides are expected to be more important than manganese oxides in controlling metals fate in SU1 soils and groundwater. The concentrations of nickel and other plating metals associated with iron oxides are quantified by the exchangeable and reducible sequential extraction fractions. The exchangeable fraction is extracted by 1 M magnesium chloride (pH 7), which represents plating metals bound to soil minerals by ion exchange and includes a fraction of metals weakly bound to iron oxide surfaces. The second fraction (the weak acid soluble fraction) is extracted by 1 M sodium acetate (pH 5). This fraction targets carbonate minerals and does not appreciably affect the stability of iron oxides (or release metals associated with iron oxides). The third step in the sequential extraction (reducible fraction) uses a strong reducing agent (0.1 molar hydroxylamine hydrochloride adjusted to pH 2 with nitric acid) to dissolve iron oxides and extract associated metals which are strongly (i.e. irreversibly) adsorbed on or incorporated into the mineral structure of iron oxides. Therefore, the sum of the exchangeable and reducible fractions provides an estimate of the plating metals concentrations associated with iron oxides.

Nickel concentrations in the sequential extraction samples range from 6 to 684 mg/kg. Of the total nickel in these samples, 11 to 52 percent is associated with iron oxides. Similarly, 27 to 37 percent of the total copper (7.1 to 74.1 mg/kg; Table 1) and 20 to 26 percent of the total zinc (18 to 34 mg/kg; Table 1) are associated with iron oxides. Nickel, copper, and zinc concentrations in the reducible fraction show good correlation with reducible iron concentrations (Figure 14), therefore it is concluded that the metals quantified in these fractions are indeed associated with iron oxides.

The reducible metals fraction is considered relatively immobile since strongly reducing or strongly acidic conditions are required to solubilize the metals associated with amorphous iron oxides. Over time, amorphous iron oxides transform to more crystalline forms such as goethite [FeOOH] which are more stable and less reactive than their amorphous precursor. The reducible fraction may therefore not entirely account for iron and plating metals associated with crystalline iron oxides. The more recalcitrant iron oxides (and associated metals) would be accounted for in the residual fraction, which can also include naturally occurring metals that are bound up in very unreactive soil particles.

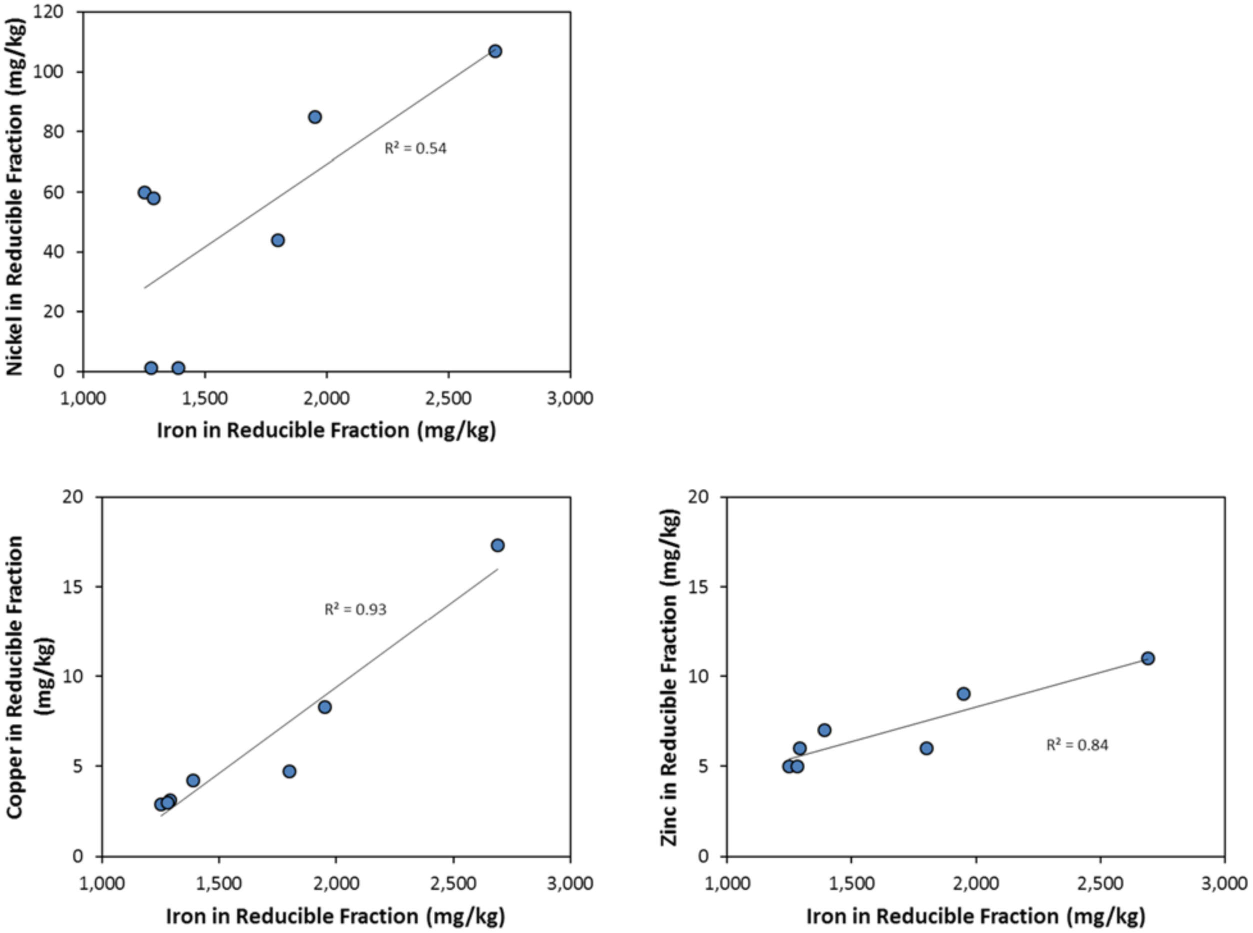


Figure 14
Correlation of nickel, copper and cadmium concentrations to iron concentrations in the reducible fraction.

Metal Sulfide Precipitation

Soil samples were analyzed for total sulfide and acid insoluble sulfur to determine the presence of metal sulfides (Table 1). Total sulfide was generally low (less than 3.5 mg/kg), and many samples were non-detect, whereas total acid insoluble sulfur (by combustion) ranged from 100 to 16,900 mg/kg (0.01 to 1.69 percent by weight). Analytical methods for total sulfide that rely on acid leaching of the sample to liberate soluble sulfides, such as Standard Methods 4500-S^{2-}, may not quantitatively recover all sulfide if insoluble metal sulfides are present in the sample. Total acid insoluble sulfur measurements by combustion are more representative of actual total sulfide concentrations. These results indicate that small quantities of metal sulfides are present in all site soil samples analyzed.

Sulfide minerals were not identified by XRD (Table 2). This is not surprising given that sulfide minerals present at abundance levels indicated by the acid insoluble sulfur concentrations measured in the samples would be below the detection limit of XRD. From a mass balance perspective, however, the sulfur content is in excess of that required to accommodate the plating metals as metal sulfides. Sequential extraction results provide more direct evidence for the presence of metal sulfides in the samples, which are targeted by the oxidizable metals fraction. The oxidizable metals fraction is associated with sulfides and/or organic matter bound metals. Total organic carbon content is low (0.075 to 0.636 percent by weight; Table 4) and iron complexed by natural organic matter is negligible based on the low TOC content. Iron in the oxidizable fraction therefore should mainly reflect the presence of iron sulfides. Oxidizable iron concentrations ranged from 828 to 2,170 mg/kg (0.08 to 0.22 percent by weight to total solid; Table 3). For samples with relatively high sulfur concentrations (greater than 0.05 weight percent), significant to strong correlations are observed between sulfur concentration and the concentrations of iron, nickel, copper, and zinc in the oxidizable fraction (Figure 15). The slope of the linear least squares fit to the oxidizable iron versus sulfur concentrations in Figure 15 is 1.89, which is very close to the theoretical value of 1.75 based on the stoichiometry of iron monosulfide (i.e., mackinawite or amorphous FeS). The correlation between oxidizable Ni concentrations (mg/kg) and acid-insoluble S concentrations (mg/kg) is weaker (R^2 =0.37), and exhibits more scatter. This may indicate that nickel in the oxidizable fraction is associated with both sulfides and organic matter.

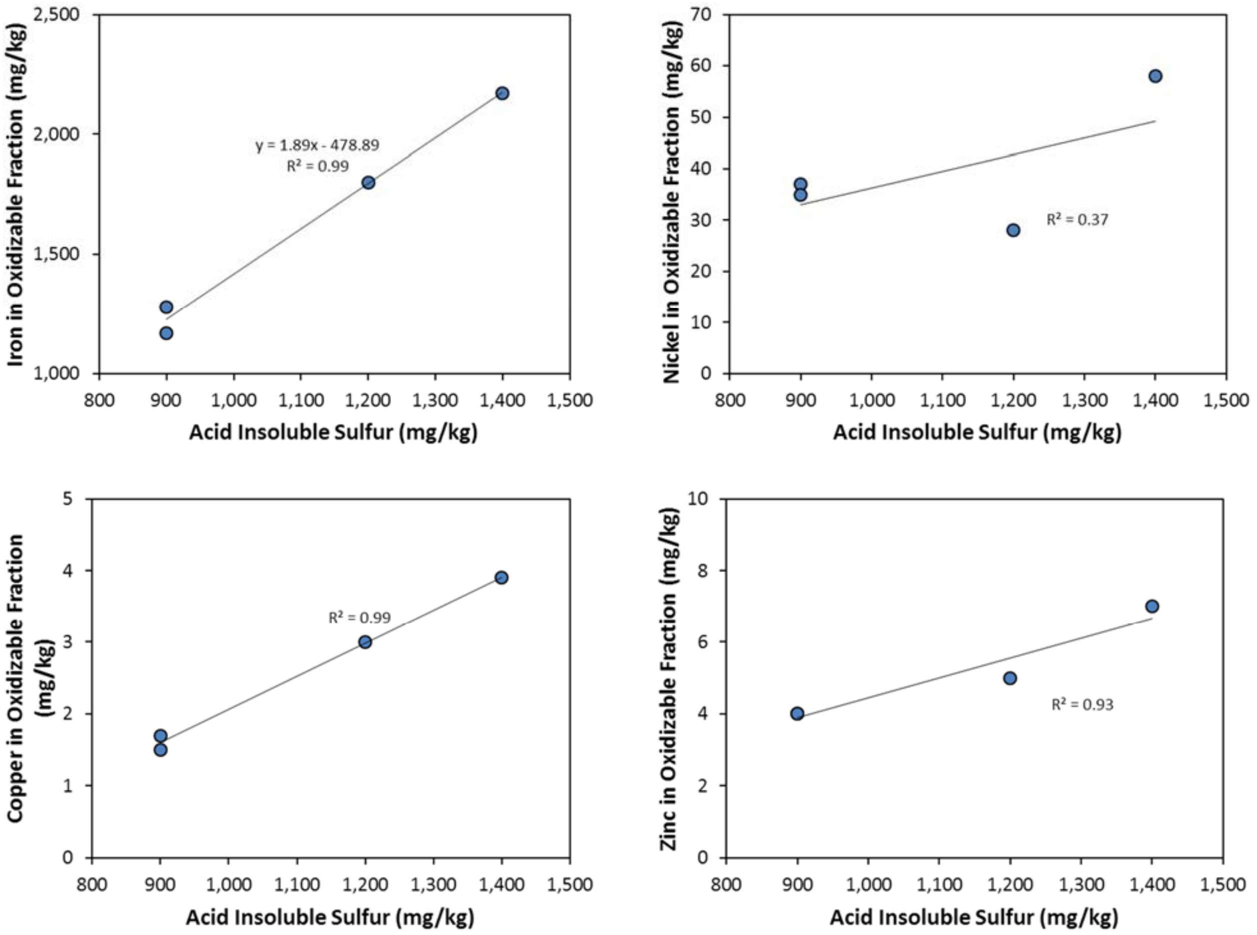


Figure 15
Correlation of iron, nickel, copper, and cadmium concentrations in the oxidizable fraction to acid insoluble sulfur concentrations.

Mineral saturation calculations (Table 5) indicate that metal sulfides such as mackinawite and millerite [NiS] are thermodynamically stable in the water table and shallow aquifer downgradient of the source area, and provide additional support for the interpretation that the oxidizable metals fraction represents metals associated with sulfide mineral phases.

Of the total iron concentrations in the sequential extraction sample dataset, 8 to 16 percent is associated with iron sulfide. In SP053 and SP054, 11 to 18 percent of the total nickel is associated with iron sulfides. In SP055, 33 percent of the total nickel is associated with iron sulfide (setting the non-detect "exchangeable" fraction concentrations to 0). Similarly, 16 to

23 percent of the total copper and 15 to 33 percent of the total zinc are associated with metal sulfides. Metal sulfide precipitation is, therefore, of comparable importance as adsorption on iron oxides as a natural attenuation mechanism for plating metals.

Aquifer Buffering Capacity

The data analyses presented in previous sections demonstrate that subsurface processes neutralize and buffer acidic groundwater pH and limit the mobility of dissolved metals at SU1. This section evaluates the capacity of minerals in the aquifer matrix to neutralize acidity and sustain attenuation of the contaminant mass within the groundwater plume.

Acid-base accounting was performed to evaluate the capacity of SU1 soils to neutralize the acidic groundwater plume as it migrates downgradient. The net neutralization potential (NNP) represents the quantity of acid that could be neutralized by soil, based on the measured carbonate (i.e., total inorganic carbon) concentration corrected for the acid production potential (APP) due to sulfides, which can produce acidity if they were to be oxidized. NNP is expressed in units of millimoles per kilogram of soil (mmol/kg). The results, summarized in Table 4, show that the NNP is exhausted in the core of the acidic plume in the water table interval (SP053 6-9, saturated in winter and spring) but is still present downgradient of the source area and deeper in the soil column. NPP ranges from 2 to 117 mmol/kg with an average of 48 mmol/kg.

REACTIVE TRANSPORT MODELING OF METALS ATTENUATION

A reactive transport model was developed to simulate fate and transport of the acidic metals plume and evaluate natural attenuation of plating metals using nickel as proxy for the other metals. The model provides a quantitative technical basis for understanding the processes controlling currently observed and likely future groundwater geochemical conditions and, ultimately, for evaluating the behavior of and potential downgradient extent of elevated plating metals concentrations. The following key geochemical processes that control the fate and transport of plating metals along the flow path were simulated to assess the capacity of the aquifer to sustain natural attenuation of contaminants within the groundwater plume:

- Neutralization of acidic groundwater pH due to dispersive mixing and mineral buffering

- Adsorption on mineral surfaces (i.e., iron oxides)
- Sulfate reduction and precipitation of metal sulfides

Modeling objectives, methods, and model development are summarized in the following sections. For a detailed discussion, refer to Attachment A of the *Revised Remedial Investigation Data Gaps and Supplemental Work Plan for Site Unit* (Aspect Consulting 2014).

Objectives

Reactive transport modeling was conducted to address the following objectives:

- Evaluate the future extent of the acidic groundwater plume
- Model the impact of mineral surface adsorption reactions on the mobility of plating metals
- Investigate the potential for sulfate reduction and sulfide mineral precipitation to attenuate plating metals concentrations in groundwater downgradient of the source area

Modeling Methods

The reactive transport model was developed using the numerical groundwater flow and reactive transport simulator PHAST (Parkhurst et al. 2010). PHAST is a well-documented, robust computer code capable of simulating groundwater flow and chemical transport with equilibrium and kinetic reactions developed by the U.S. Geological Survey (USGS).

Model Development

Input Data

Site-specific hydraulic data, groundwater and soil chemistry data, soil mineralogy, and results from previous geochemical modeling conducted for the Remedial Investigation (RI) provided input for the reactive transport model. A high-quality, internally consistent thermodynamic database developed by the USGS (*wateq4f.dat*) was used for reaction equilibrium constants. The *wateq4f.dat* database file also includes the surface complexation model of Dzombak and Morel for sorption of metals on hydrous ferric oxide (HFO or ferrihydrite).

Model Configuration

The model domain was constructed on a rectangular grid as a vertical two-dimensional cross-section of the aquifer oriented parallel to the direction of groundwater flow and centered along the axis of the dissolved plating metals plume (Figure 16). The horizontal extent of the model domain is 2,800 feet and extends 400 feet upgradient of the source area. The source area is defined in the model as a zone 200 feet long by 25 feet deep. The model domain extends 2,200 feet downgradient from the source area to the shoreline of the Duwamish Waterway. The alignment of the reactive transport model domain is shown on Figure 1 in Attachment A.

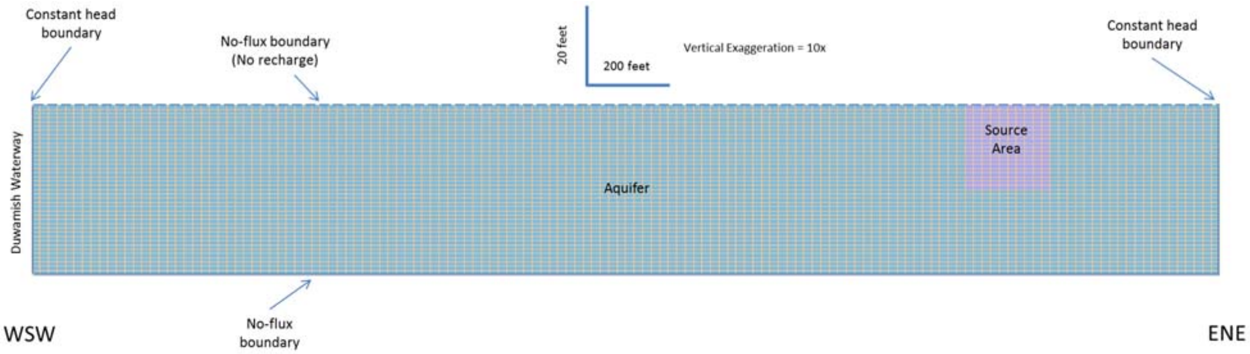


Figure 16
Model domain, initial and boundary conditions.

Hydrologic Parameters

Hydrologic parameters used in the model were derived largely from previous field work and modeling conducted as part of the RI. For purposes of modeling, the aquifer is treated as homogenous and anisotropic. Aquifer parameters are based on values used in the BIOCHLOR modeling in the RI:

- Horizontal hydraulic conductivity = 0.017 centimeters per second (cm/sec)
- Vertical hydraulic conductivity = 0.0017 cm/sec (anisotropy factor = 10)
- Hydraulic gradient = 0.002 (constant)
- Effective porosity = 0.25
- Steady state flow

Groundwater Chemistry

Groundwater data collected in September 2014 provide a complete groundwater geochemistry dataset and were used to define initial chemistry conditions. The flow path evaluated in the model extends from immediately upgradient of the source area, through the source area, and downgradient to the Duwamish Waterway. Groundwater chemistry in these areas is represented by water chemistry data from the following wells:

- Upgradient wells: MW-12, MW-6, and MW-6-30
- Source area: MW-3 (nickel concentration is the highest at the source area)
- Downgradient wells: MW-8, MW-8-30, and MW-16-40
- Downgradient wells near the Duwamish Waterway: MW-24 and MW-22-30

Aquifer Mineralogy and Sorption Capacity

Soil chemistry and mineralogy data were used to define aquifer matrix mineralogy and constrain initial concentrations of minerals and adsorption sites. Reactive minerals include ferrihydrite [$Fe(OH)_3$], siderite [$FeCO_3$], mackinawite [FeS], and millerite [NiS]. Ferrihydrite is present in the aquifer initially, and the concentration of adsorption sites is linked to its abundance. Siderite is assumed to be initially present throughout the aquifer, outside the low pH source area. The other phases are not present initially but are allowed to precipitate during the course of a simulation in grid cells if their solubility is exceeded.

The acid-neutralizing capacity of the aquifer matrix is represented by calcium carbonate in the model, which is distributed uniformly throughout the domain, except within the source area where it is assumed to be depleted. The initial amount of calcium carbonate is based on the average NNP determined from the acid-base accounting (48 mmoles/kg soil).

Sulfate Reduction and Sulfide Precipitation

While adsorption/desorption reactions are assumed to be equilibrium reactions, sulfate reduction was treated as a microbial kinetic process. The rate expression for sulfate reduction is represented by the Monod equation:

$$R = R_{max} \times \frac{[SO_4]}{[SO_4] + K_m}$$

where R is the sulfate reduction rate, R_{max} is the maximum rate and K_m is the half-saturation constant.

Sulfate reduction rates in soil and groundwater have been reported in numerous studies (e.g. Amos et al. 2004; McGuire et al. 2002; Sitte et al. 2010). Amos et al. (2004) determined the kinetic parameters for sulfate reduction in groundwater impacted by acid mine drainage in column experiments with porous media containing relatively high organic matter content. Compared to the other studies cited above, the water chemistry in that study was most similar to that of acidic plating metal plume.

The kinetic parameters used to model sulfate reduction are shown in Table 6. The higher organic content in the column experiments may have resulted in enhanced sulfate reduction rates relative to the low organic content aquifer at the Site. Therefore, for modeling sulfate reduction and sulfide precipitation, the maximum rate of sulfate reduction R_{max} was treated as a sensitivity parameter and reduced by up to three orders of magnitude to assess its impact on predicted nickel transport.

Table 6
Kinetic Parameters for Sulfate Reduction

Parameter	Value	Unit	Reference; Comments
R_{max}	1.6×10^{-8}	mol L^{-1} s^{-1}	Amos et al. (2004), adjusted for porosity
	1.6×10^{-9} 1.6×10^{-10} 1.6×10^{-11}		Range of values used for sensitivity analysis
K_m	1.62×10^{-3}	M	Sulfate half-saturation concentration (Amos et al. 2004)

Metal sulfide minerals allowed to precipitate in the model include mackinawite [FeS] and millerite [NiS]. These minerals, once precipitated, were allowed to react to equilibrium at each time step.

Model Results

Two scenarios were simulated to evaluate the effect of geochemical attenuation mechanisms on predicted plating metals concentrations within SU1. The first scenario includes only adsorption on iron oxides, and the second scenario also includes sulfate reduction and metal sulfide precipitation as additional mechanisms. Model simulations were run for a simulation period of 1,000 years with 0.1-year time steps to minimize numerical dispersion (Parkhurst et al. 2010). The model results, as they pertain to the stated modeling objectives, are discussed in this section.

Future Extent of the Acid Groundwater Plume

The reactive transport simulations illustrate how the acid plume is neutralized downgradient of the source area by dispersive mixing with neutral pH groundwater and reaction with aquifer minerals. The initial pH is 4.0 in the source area and 7.0 in the aquifer outside the source area (Figure 17). The minimum groundwater pH within the model domain is predicted to increase to 6.2, 6.5, 6.6, and 6.7 after 10, 20, 50, and 100 years, respectively. The simulation results also indicate that the acid plume will be effectively contained by the dispersive mixing and reaction with aquifer minerals.

Time = 0 years

Time = 10 years

Time = 20 years

Time = 50 years

Time = 100 years

Figure 17
Modeled groundwater pH after 10, 20, 50, and 100 years simulation time.

Nickel Attenuation by Adsorption on Iron Oxides

Figure 18 presents simulation results for a scenario in which adsorption to iron oxides is considered the only geochemical mechanism for nickel attenuation (i.e., sulfate reduction and sulfide precipitation are not included). The model-predicted dissolved nickel concentrations and the extent of the plume exceeding 0.0082 mg/L are shown for simulation times of 1, 10, 100, and 1,000 years.

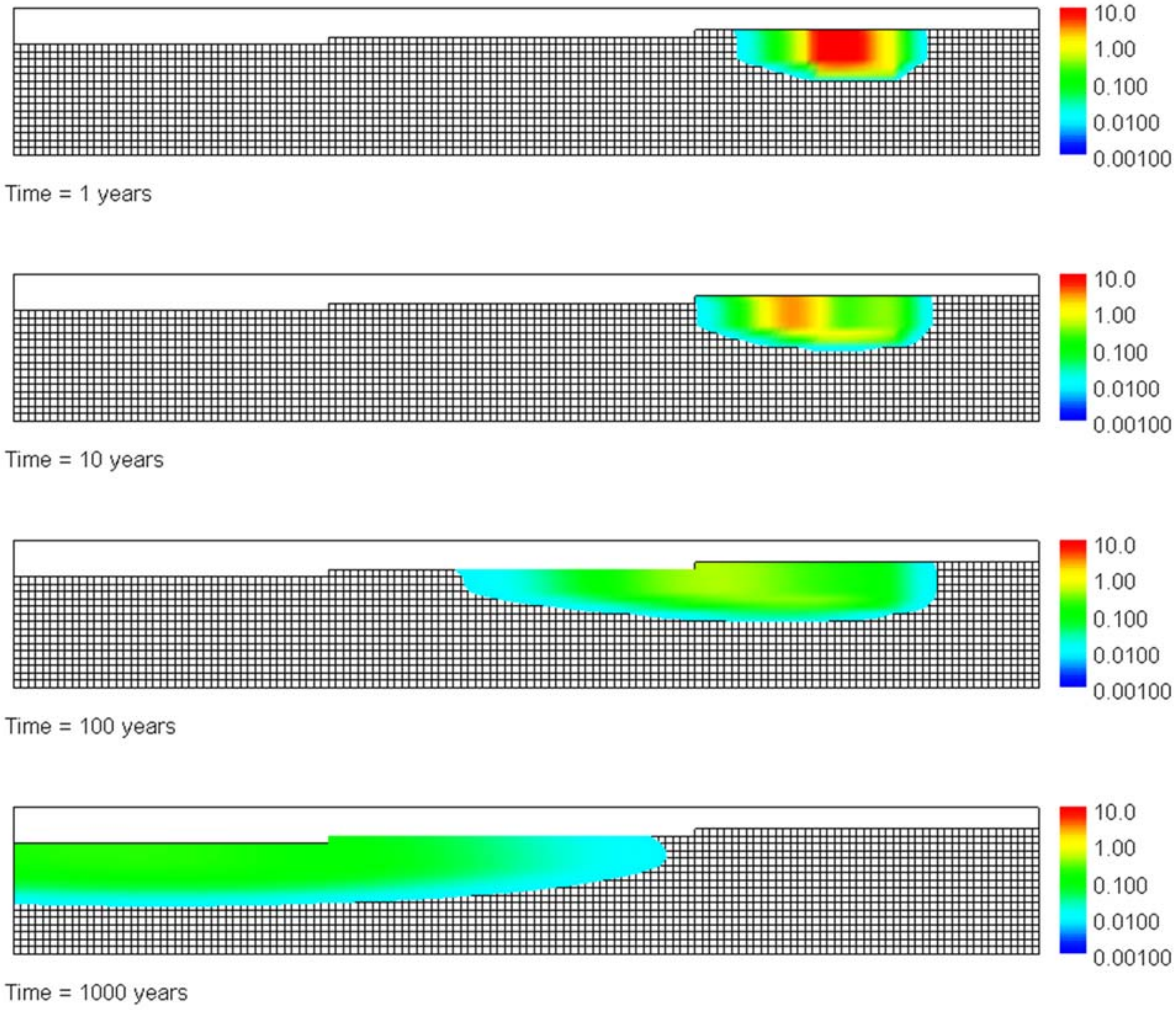


Figure 18
Modeled dissolved nickel plume at 1, 10, 100, and 1,000 years simulation time. In this scenario, the only geochemical mechanism for nickel attenuation is adsorption to iron oxides. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

The plume is predicted to expand downgradient with decreasing dissolved nickel concentrations. The rapid downgradient expansion of the model plume within the first 10 years is inconsistent with the observed extent of the plating metals plume and indicates that additional geochemical attenuation processes must be active at the Site.

In this scenario, the model predicts that the maximum nickel concentration in groundwater discharging to the Duwamish Waterway (i.e., in the furthest downgradient column of grid cells within in the model domain) will remain below 0.0082 mg/L for approximately 500 years (Figure 19).

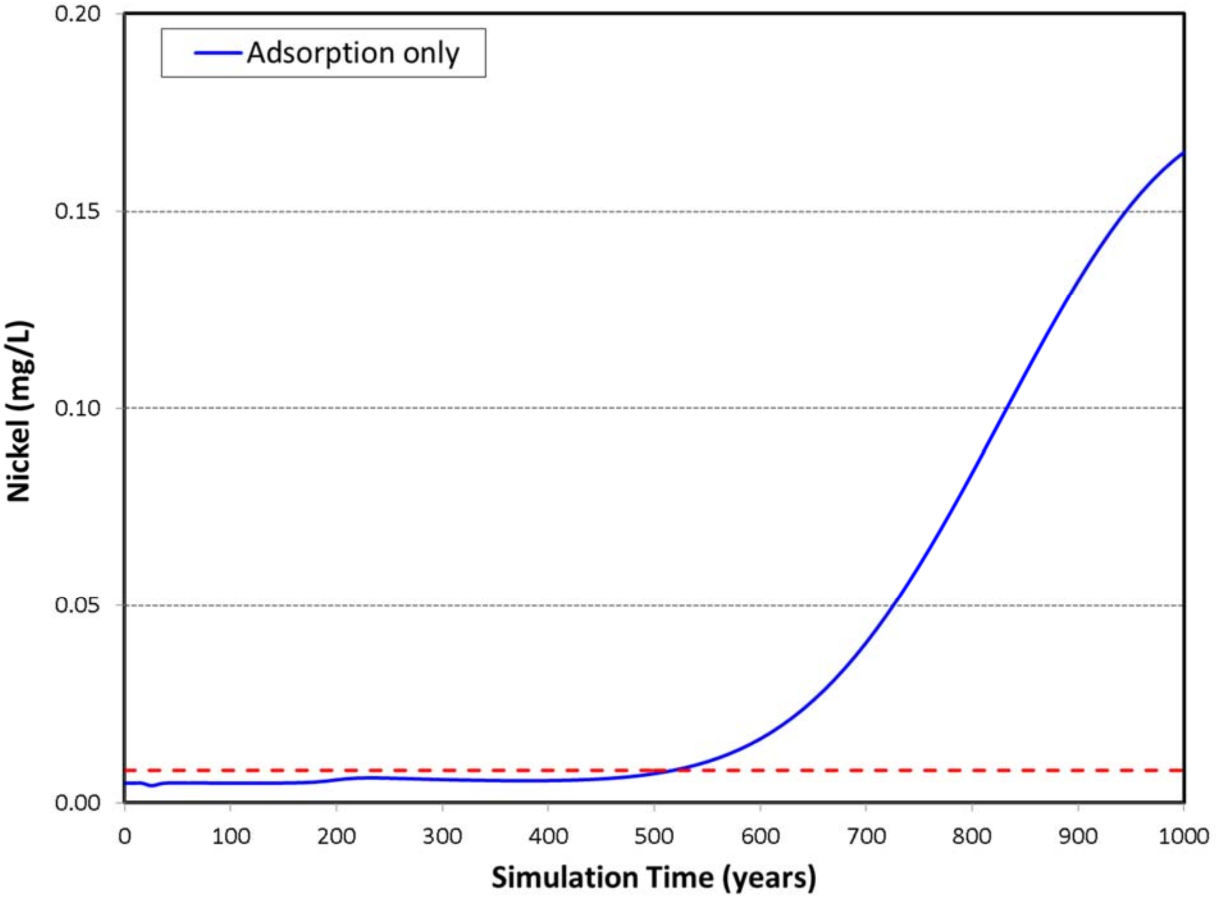


Figure 19
Predicted maximum nickel concentrations in groundwater discharging to the Duwamish Waterway (downgradient end of the model domain) for the scenario including only adsorption to iron oxides. Results shown are for the grid cell with the highest final nickel concentration.

Nickel Attenuation by Sulfide Precipitation

For this scenario, both adsorption and sulfide precipitation reactions were included in the model. The model-predicted dissolved nickel concentrations and the extent of the plume exceeding 0.0082 mg/L for $R_{max} = 1.6\times10^{-8}$ mol L^{-1} s^{-1} are shown for simulation times of 1, 10, 100, and 1,000 years in Figure 20.

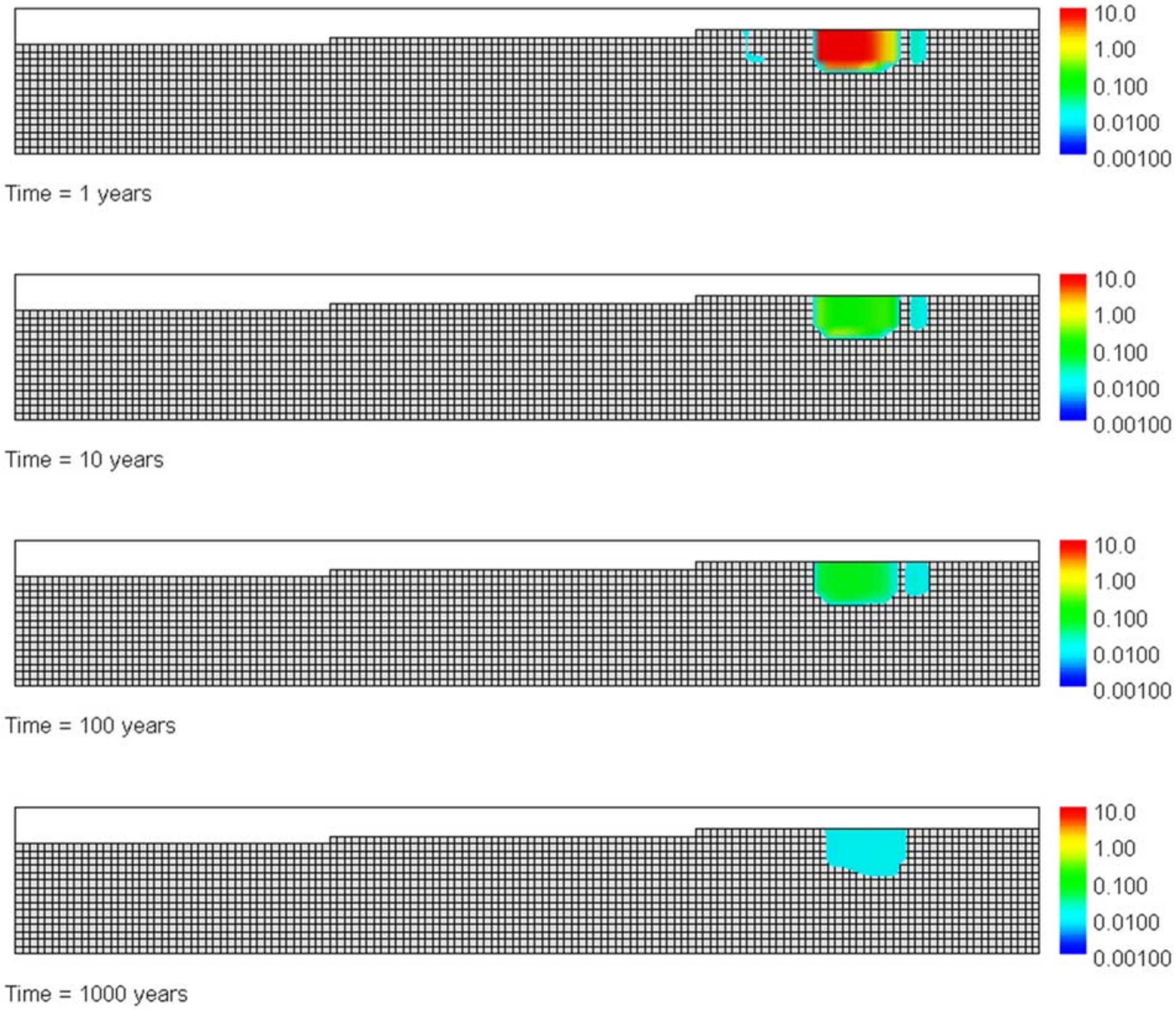


Figure 20

Modeled dissolved nickel plume at 1, 10, 100, and 1,000 years simulation time including adsorption and sulfide precipitation for $R_{max} = 1.6\text{x}10^{-8}$ mol L^{-1} s^{-1}. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

Millerite is observed to precipitate within and downgradient the source. In this scenario, the nickel plume is attenuated by millerite precipitation in addition to adsorption to iron oxides and nickel transport in groundwater is very limited. The plume appears to remain essentially stationary and dissolved nickel concentrations decrease over time. This simulation demonstrates the importance of both iron oxide adsorption and metal sulfide precipitation as attenuation mechanisms for the metals plume.

Sensitivity Analysis: Sulfate Reduction Rate

A sensitivity analysis was performed to examine the impact of sulfate reduction rate on the predicted fate of the nickel plume. R_{max} was systematically reduced by factors of 10, 100, and 1,000 times relative to the Amos value, as listed in Table 6. The simulated evolution of the nickel plume for the sensitivity runs is displayed in Figures 21 to 23.

For the 10-fold and 100-fold lower R_{max} simulations (Figures 21 and 22, respectively), the model plumes are also predicted to remain essentially stationary with dissolved concentrations decreasing over time. In contrast, in the 1,000-fold lower R_{max} simulation (Figure 23), the plume is predicted to spread initially downgradient before dissolved nickel concentrations are attenuated by millerite precipitation. The rapid initial expansion of the model plume downgradient contradicts the presently observed extent of the plating metals plume. This indicates that the site-specific value for R_{max} must be greater than 1.6×10^{-11} mol L^{-1} s^{-1}. The sensitivity analysis results further indicate that nickel fate and transport is not very sensitive to the value of R_{max} for values greater than 1.6×10^{-11} mol L^{-1} s^{-1} and that sulfide precipitation is a robust attenuation mechanism for plating metals in SU1.

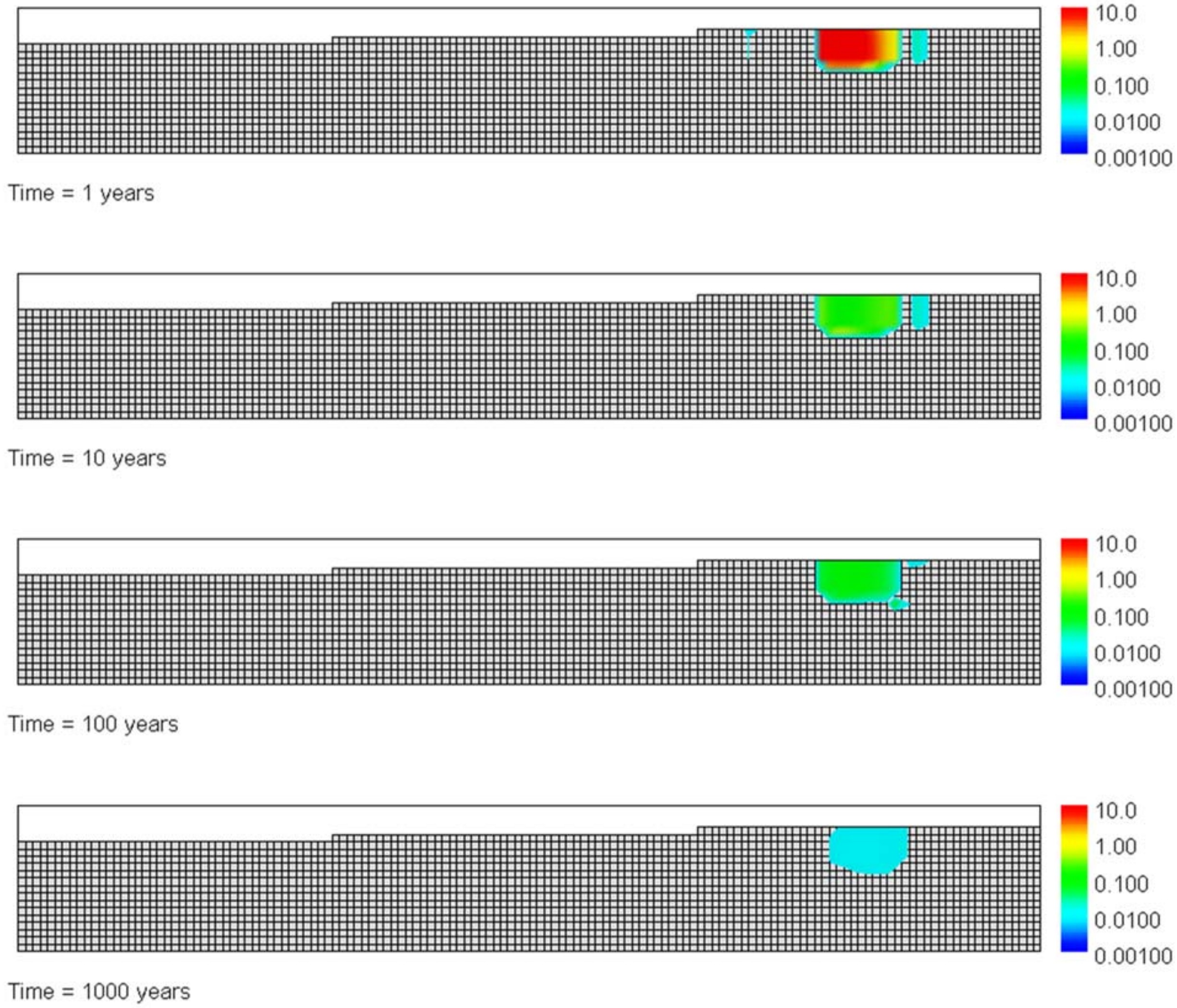
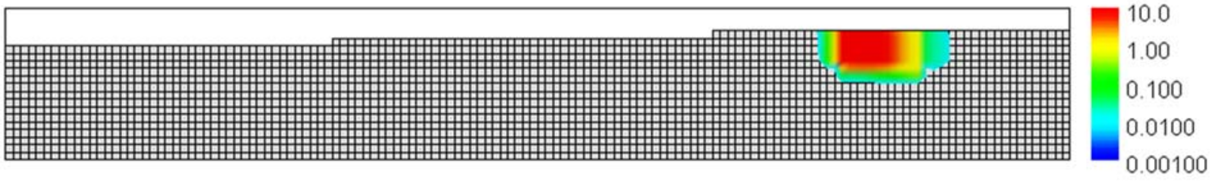
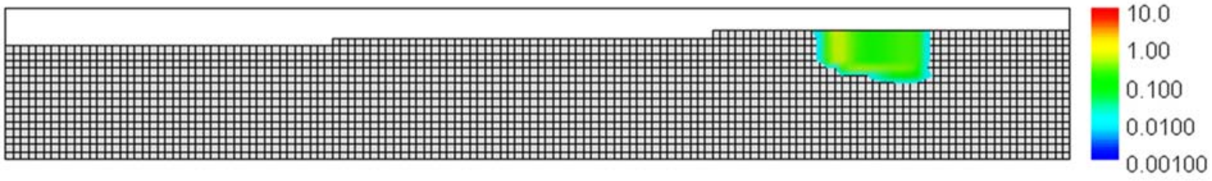


Figure 21

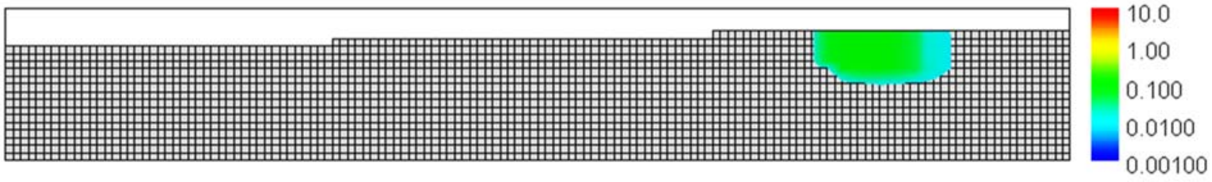
Modeled dissolved nickel plume at 1, 10, 100, and 1,000 years simulation time including adsorption and sulfide precipitation for $R_{max} = 1.6\times10^{-9}$ mol L^{-1} s^{-1}. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.



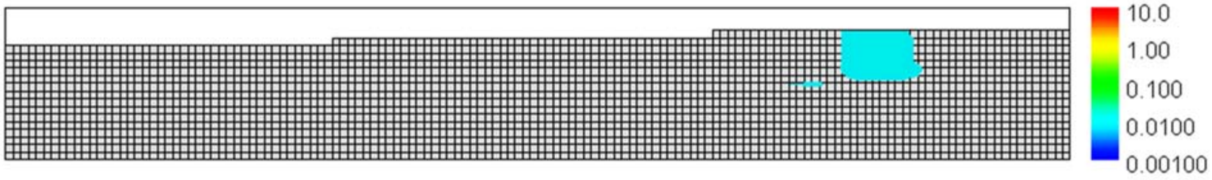
Time = 1 years



Time = 10 years



Time = 100 years



Time = 1000 years

Figure 22
Modeled dissolved nickel plume at 1, 10, 100, and 1,000 years simulation time including adsorption and sulfide precipitation for $R_{max} = 1.6x10^{-10}$ mol L^{-1} s^{-1}. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

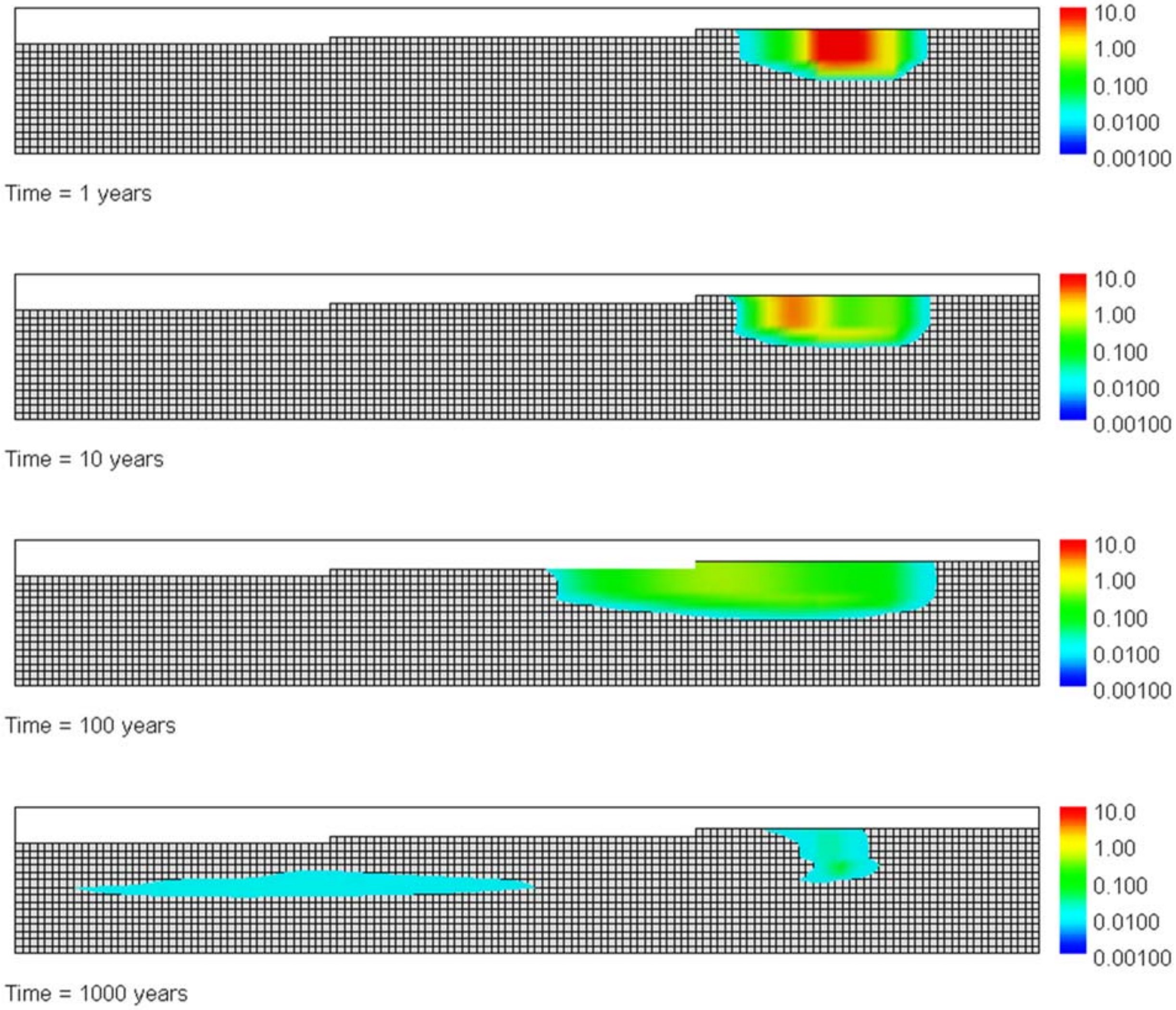


Figure 23
Modeled dissolved nickel plume at 1, 10, 100, and 1,000 years simulation time including adsorption and sulfide precipitation for $R_{max} = 1.6x10^{-11}$ mol L^{-1} s^{-1}. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

Over the entire range of R_{max} values evaluated, the maximum nickel concentration in groundwater discharging to the Duwamish Waterway (i.e., in the leftmost or furthest downgradient column of cells in the model domain) is predicted to remain below 0.0082 mg/L for at least than 1,000 years (Figures 24 and 25). For site-specific R_{max} values (1.6×10^{-10}

mol L^{-1} s^{-1} or greater), natural attenuation processes in SU1 groundwater are protective of surface water quality.

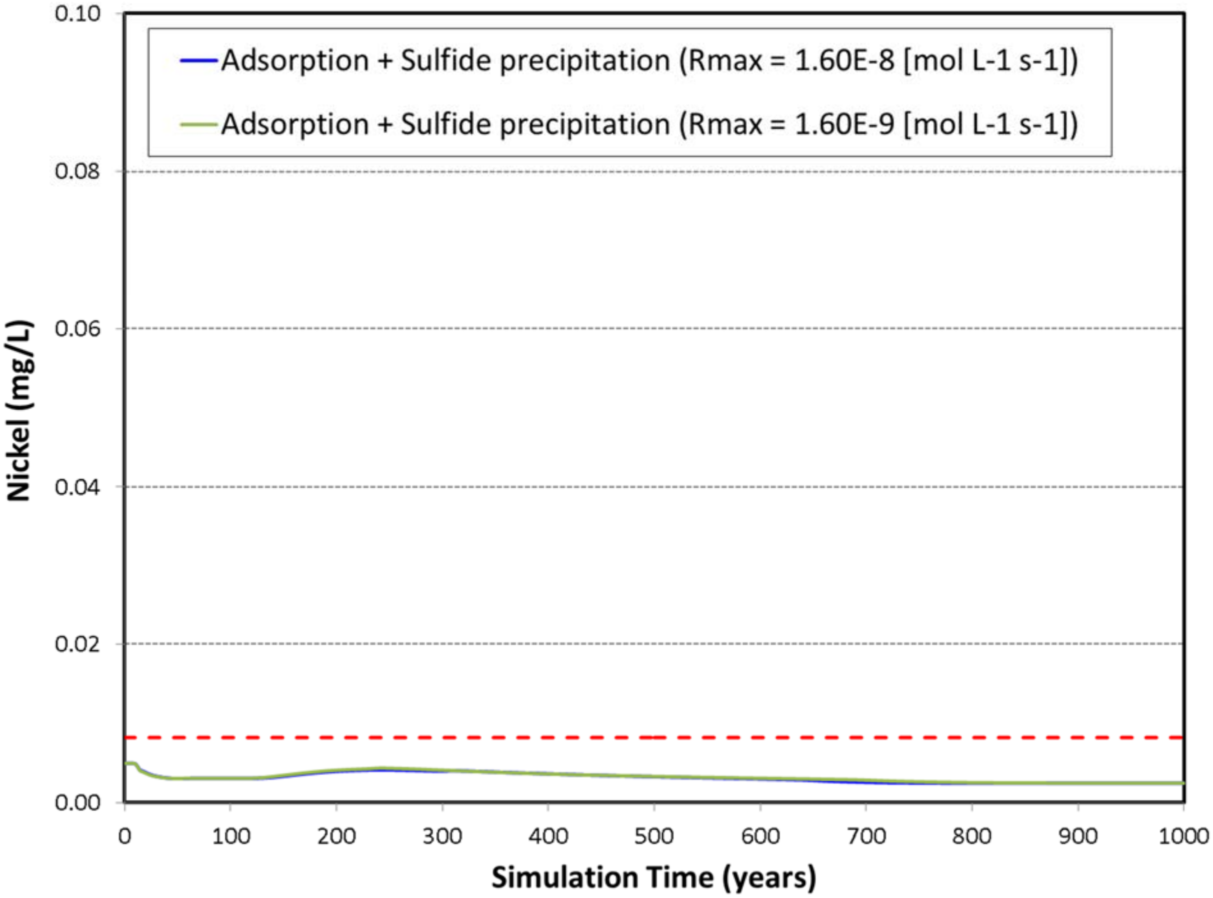


Figure 24
Predicted maximum nickel concentrations in groundwater discharging to the Duwamish Waterway for the scenarios including adsorption to iron oxides and sulfide precipitation with R_{max} = 1.6x10^{-8} and 1.6x10^{-9} mol L^{-1} s^{-1}. Results shown are for the grid cell with the highest final nickel concentration.

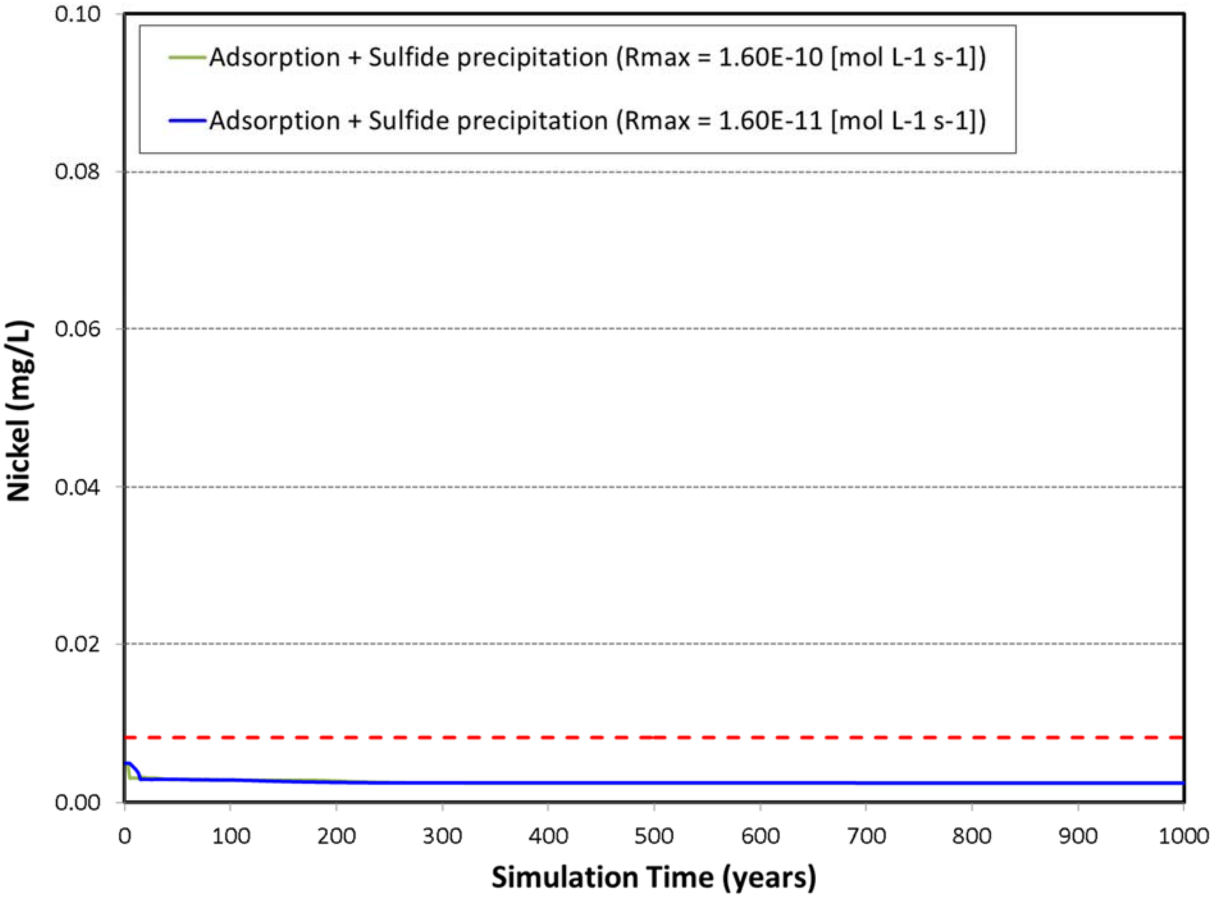


Figure 25
Predicted maximum nickel concentrations in groundwater discharging to the Duwamish Waterway for the scenarios including adsorption to iron oxides and sulfide precipitation with R_{max} = 1.6×10^{-10} and 1.6×10^{-11} mol L^{-1} s^{-1}. Results shown are for the grid cell with the highest final nickel concentration.

STABILITY OF ATTENUATION PROCESSES

The model simulations demonstrate the impact of acidity neutralization, adsorption of iron oxides, and metal sulfide precipitation on the natural attenuation of the plating metals plume. Model simulations predict that, with all three processes operating, 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 cleanup level of 8.2 µg/L for at least 1,000 years.

Although the other plating metals were not modeled explicitly, cadmium, copper, and zinc are also attenuated by the same processes as nickel. These metals are all adsorbed on iron oxides and can form sulfide solids. Since cadmium, copper, and zinc concentrations are lower than nickel concentrations in source area groundwater, they are also attenuated near the source area.

This section addresses the stability and capacity of these processes to sustain long-term natural attenuation of the plating metals plume.

Mineral Stability

The minerals responsible for the attenuation of plating metals include iron oxyhydroxides (ferrihydrite) and metal sulfides (millerite). Geochemical modeling of groundwater chemistry indicates that these minerals are thermodynamically stable under the mildly to moderately reducing conditions currently present throughout the aquifer in SU1 (Table 5). Reactive transport simulations also suggest these minerals will continue to be stable downgradient of the source area into the foreseeable future.

Acid Neutralizing Capacity

The average NNP of SU1 soils outside the source area was determined to be 48 mmoles of $CaCO_3$ per kg soil based on acid-base accounting. The amount of $CaCO_3$ needed to neutralize the acid groundwater plume pH was estimated by geochemical modeling using the REACT program of the Geochemist's Workbench software suite (www.gwb.com).

The acid plume chemistry was represented by the average chemistry of the September 2014 samples from MW-1, MW-4, and MW-5 with pH 3.9. One liter of solution with this chemistry was titrated by reacting with $CaCO_3$ to a final endpoint pH of 7 or until equilibrium with calcite was attained. The amount of $CaCO_3$ reacted to the endpoint depends on the assumed partial pressure of CO_2 (P_{CO2}) in the aquifer, which ranges from approximately 0.01 to 0.1 bar based on speciation modeling (Table 5). The $CaCO_3$ demand to neutralize acidic source area groundwater was found to range from 1.2 mmoles $CaCO_3$ per L for $P_{CO2} = 0.01$ to 4.2 mmoles $CaCO_3$ per L for $P_{CO2} = 0.1$.

The total volume of the acidic plume at present is estimated to be 3.5×10^6 L (assuming a source area 200 feet long by 100 feet wide by 25 feet deep [500,000 ft^3] and 25 % porosity). Using the upper end value for $CaCO_3$ demand of 4.2 mmoles/L, the $CaCO_3$ demand to neutralize the entire plume is estimated to be 15,000 moles. Neutralization of the plume acidity would require 312,000 kg of soil. This quantity of soil is contained in 5,500 ft^3 of aquifer (assuming a soil grain density of 2.7 kg/L and porosity of 25 %). For an aquifer cross-section 100 feet wide by 25 feet deep, this corresponds to a length of 2.2 feet. In other words, there is sufficient NNP in soil to neutralize the pH of the entire acid plume within a few feet along groundwater flow. This is consistent with the reactive transport modeling presented in the previous section and also appears to be supported by site observations, which show that acidic pH is attenuated within a short distance downgradient of the release.

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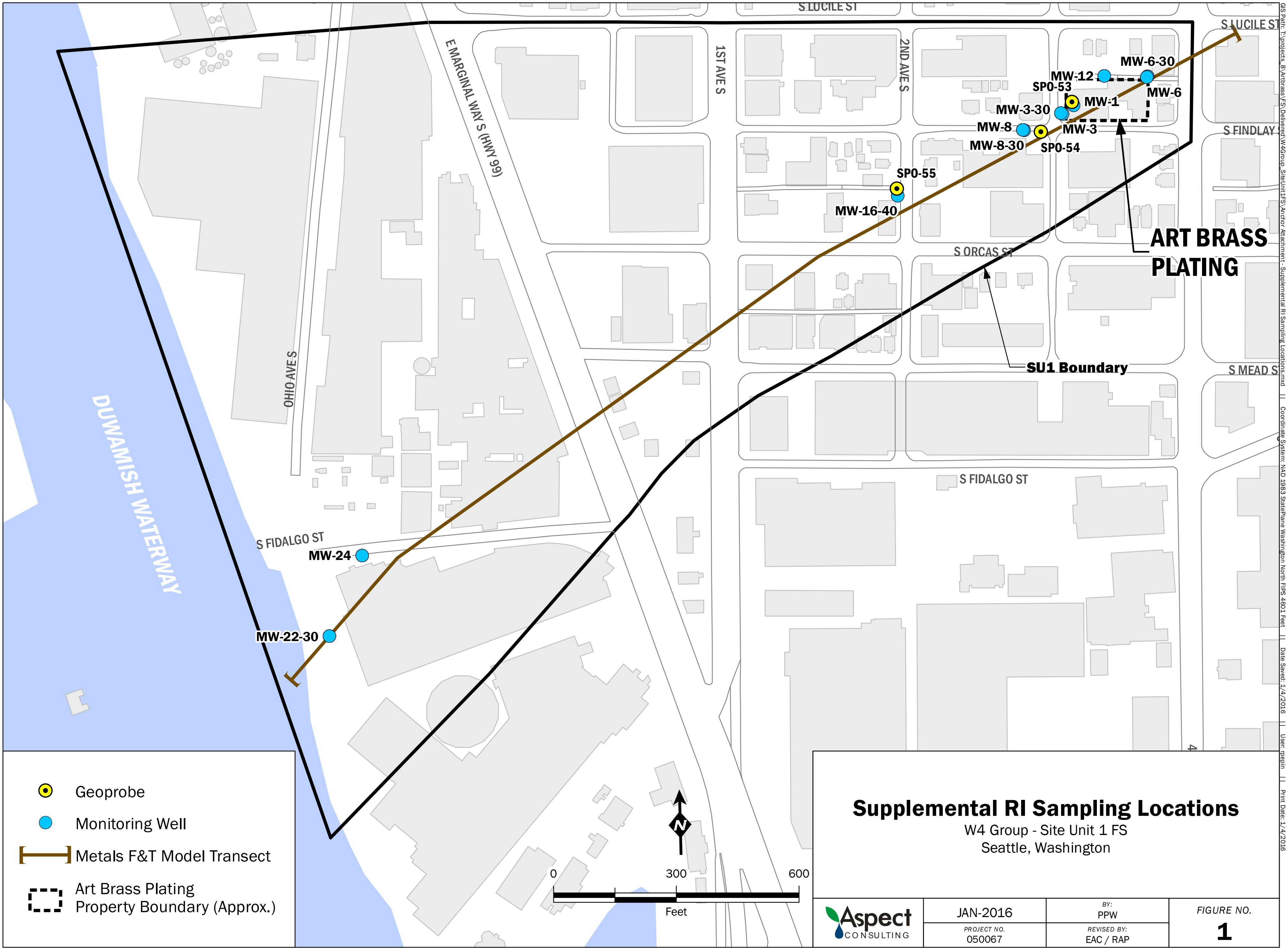
ATTACHMENT A
SUPPLEMENTAL RI SAMPLING LOCATIONS



Supplemental RI Sampling Locations

W4 Group - Site Unit 1 FS
Seattle, Washington

Aspect CONSULTING

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

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\Anchor Attachment - Supplemental RI Sampling Locations.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/4/2016 || User: rpepin || Print Date: 1/4/2016

ATTACHMENT B
SEQUENTIAL EXTRACTION FRACTION CALCULATIONS

1 SEQUENTIAL EXTRACTION FRACTION CALCULATIONS

Table 1 summarizes the metals concentrations measured in the four sequential extraction solutions (the exchangeable, weak acid soluble, reducible, and oxidizable fractions), the dry weight metals concentrations in the residual fraction, the extracted soil sample masses (wet and dry weight), and their calculated total solids content. To convert the concentrations in the extraction solutions to the soil dry weight concentrations reported in Table 3 of the memorandum the following equation was used:

$$C_s = \frac{C_L}{M \times (TS/100)} \times V \times 1{,}000$$

where:

C_S = metal concentration of fraction in soil (milligram per kilogram [mg/kg])
C_L = metal concentration in extraction fluid (milligram per liter [mg/L])
M = wet mass of soil sample used for sequential extraction (gram [g])
TS = total solids of soil sample (weight percent [%])
V = volume of the extraction fluid (liter [L]) (= 0.100 [L])

TABLE

Table 1
Metal Concentrations in Sequential Extraction Fractions (mg/L)

Sequential Extraction			Metal Concentration in Fraction						
			Sample ID						
Metal	**Fraction**	**Units**	**SP053 6-9**	**SP053 9-12**	**SP054 15-18**	**SP054 15-18 (DUP)**	**SP054 21-24**	**SP055 15-18**	**SP055 27-30**
Cadmium	Exchangeable	mg/L	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	Weak Acid Soluble	mg/L	0.005 J	0.005 J	0.005 J	0.005 J	0.005 J	0.006 J	0.005 J
	Reducible	mg/L	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U
	Oxidizable	mg/L	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U
	Residual	mg/kg	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U
Copper	Exchangeable	mg/L	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U
	Weak Acid Soluble	mg/L	0.09	0.051	0.015	0.015	0.024	0.018	0.017
	Reducible	mg/L	0.196	0.095	0.033 B	0.035 B	0.052 B	0.047 B	0.033 B
	Oxidizable	mg/L	0.174	0.045 B	0.017 B	0.019 B	0.033 B	0.02 B	0.018 B
	Residual	mg/kg	25	7.4 B	3.5 B	3.7 B	3.3 B	3.9 B	3.6 B
Iron	Exchangeable	mg/L	0.5 U	0.5 U	0.9	0.5 U	0.5 U	0.5 U	0.5 U
	Weak Acid Soluble	mg/L	0.74	1.44	2.24	2.43	4.95	3.63	2.84
	Reducible	mg/L	30.6	22.4	14.3	14.6	19.8	15.6	14.2
	Oxidizable	mg/L	12.3	24.9	13.4	14.5	19.8	9.44	9.22
	Residual	mg/kg	8,780	9,690	8,360	8,750	7,410	8,580	8,550
Manganese	Exchangeable	mg/L	0.01 U	0.05 B	0.06 B	0.04 B	0.11 B	0.02 B	0.01 U
	Weak Acid Soluble	mg/L	0.181 B	0.177 B	0.132 B	0.144 B	0.168 B	0.127 B	0.123 B
	Reducible	mg/L	0.303	0.197 B	0.119 B	0.12 B	0.257	0.13 B	0.123 B
	Oxidizable	mg/L	0.09 B	0.098 B	0.103 B	0.098 B	0.125 B	0.079 B	0.086 B
	Residual	mg/kg	62.4	83	71	77.4	60.7	70	71.2
Nickel	Exchangeable	mg/L	0.9	1	1.4	1	0.2	0.1 U	0.1 U
	Weak Acid Soluble	mg/L	2.74	2.2	1.26	1.41	0.63	0.01	0.01
	Reducible	mg/L	1.22	0.97	0.69	0.66	0.48	0.01	0.01
	Oxidizable	mg/L	1.41	0.67	0.42	0.4	0.31	0.03	0.02
	Residual	mg/kg	157	53	18	20	8	4	4

Table 1
Metal Concentrations in Sequential Extraction Fractions (mg/L)

Sequential Extraction			Metal Concentration in Fraction						
			Sample ID						
Metal	**Fraction**	**Units**	**SP053 6-9**	**SP053 9-12**	**SP054 15-18**	**SP054 15-18 (DUP)**	**SP054 21-24**	**SP055 15-18**	**SP055 27-30**
Zinc	Exchangeable	mg/L	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U
	Weak Acid Soluble	mg/L	0.03	0.02	0.02	0.02	0.02	0.02	0.02
	Reducible	mg/L	0.13	0.1	0.06	0.07	0.07	0.08	0.06
	Oxidizable	mg/L	0.18	0.08	0.05	0.04	0.05	0.04	0.04
	Residual	mg/kg	19	16	14	15	12	14	14
Total Solids		% wt	83.17	81.79	81.60	81.60	82.18	83.27	84.31
Soil mass	wet	g	1.366	1.402	1.404	1.384	1.336	1.347	1.320
	dry	g	1.136	1.147	1.146	1.129	1.098	1.122	1.113
Extract Volume		L	0.100	0.100	0.100	0.100	0.100	0.100	0.100

Notes:
g = gram
L = liter
mg/kg = milligram per kilogram
mg/L = milligram per liter
U = Analyte was not detected above the MDL.
B = Analyte was detected in associated procedural blank; result is less than 10 times the reported blank value.
J = Estimated value due to matrix interference.

ATTACHMENT B

Plating Operations and Utilities

Plating Operations

As detailed in the Remedial Investigation Report for Art Brass Plating, plating operations started at the facility in 1983. From 1983 until 1999, plating baths were located at the southwest corner of the existing building (Figure 1). During this period, plating baths were located on concrete floors without secondary containment (Merryfield, 2015).

In 1999, the old plating area was closed and new plating lines were installed in the room east of the old plating area. This central plating area remains in operation today. The central plating area is contained in a bermed area. The floor of the bermed area is one foot thick concrete with an epoxy coating, then a 1/8-inch polyvinyl liner. A sump collects any fluids that accumulate in the area. Additional plating lines have been installed east and west of the central plating line. These newer lines are also contained in bermed areas with polyvinyl liners with epoxy coated concrete flooring beneath. All plating baths have overflow alarms. All piping in all three plating areas is above ground. Waste waters are piped above ground to the water treatment area in the southwest corner of the facility. Following on-site treatment, aqueous wastes are discharged to King County sanitary sewer under a King County Industrial Waste Permit (Permit number 7722-05). A flow-portioned sample is collected every 24 hours and samples are collected weekly for metals analysis, per the permit. (Merryfield, 2015)

Mike Merryfield is the current owner of Art Brass Plating and he has worked on site since this transition to the new containment procedures implemented in 1999. Spills and leaks to the subsurface from the plating operations or subsurface utilities is very unlikely based on the current configuration of the plating lines and above ground aqueous waste transfer to the water treatment system.

Plating Solutions

Plating solutions have remained unchanged since 1983. Since 1983, metal plating has included nickel, chrome, brass (an alloy of copper and zinc), copper, and gold. The most common plating solutions and their composition include (Merryfield, 2015):

- **Nickel**: nickel sulfate, nickel chloride, boric acid;
- **Copper**: copper sulfate, hydrochloric acid;
- **Chrome**: Chromic acid and sulfuric acid;
- **Brass**: sodium cyanide, copper cyanide, zinc cyanide; and
- **Gold**: Potassium gold cyanide and nickel metal.

Subsurface Utilities

The locations of subsurface utilities are illustrated in Figure 1. Connections to the sanitary sewer in Findlay Street from Art Brass Plating have been examined via a 2012 sewer camera survey, Seattle side sewer cards available online, and GIS data from King

County. Based on the camera survey and side sewer card information, three active sewer connections exist from the Facility to the combined sewer line in Findlay Street. From east to west, connection one services the bathrooms and lunch area at the east end of the Facility. Connection two services the stormwater collection lines in the central portion of the site. Connection three is at the west end of the Facility. This is where treated water discharges (King County Industrial Waste Permit 7722-05) as well as the bathrooms and showers located at the west end of the Facility.

The side sewer cards and county GIS data illustrate two other sewer lines beneath the facility. These lines appeared inactive (dry with cobwebs) during the 2012 camera survey. A side sewer card of the block indicates that these two lines were from the older residences that were on the property before the Art Brass building.

Attachments

Figure B-1 – Subsurface Utilities with Sewer Camera Survey Observations

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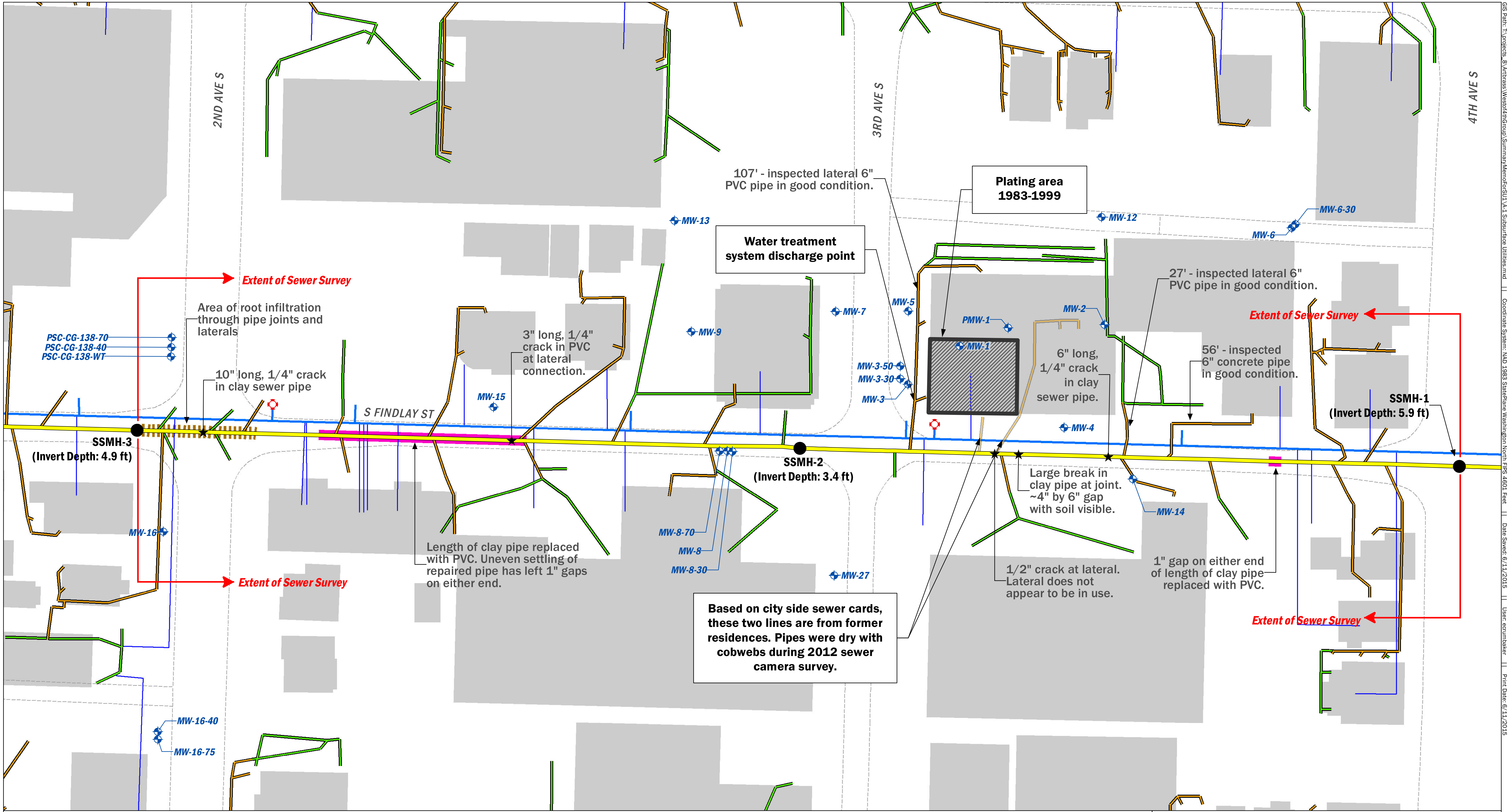
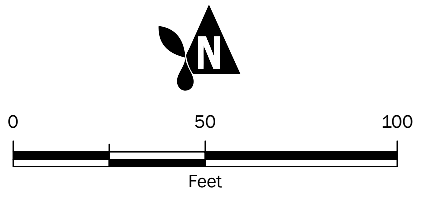


- ⌖ Monitoring Wells
- ▨ Plating Area 1923-1999
- ● Manholes
- ○ Hydrants
- ★ Sewer Survey Observation Points
- 🟨 Combined Sewer Main Line*
- 🟩 Storm Lateral Line
- 🟧 Sewer Lateral Line
- 🟦 Water Main Line
- Water Service Line
- ▥ Area of Root Infiltration Through Pipe Joints and Laterals
- 🟪 Segment of PVC on Combined Sewer Main Line*

In the extent of the sewer survey, the Combined Sewer Main Line is 24" clay pipe except where highlighted in pink, where it has been replaced with PVC pipe.

- Building Footprint
- Road Outlines



Subsurface Utilities with Sewer Camera Survey Observations

West of 4th Site
Seattle, Washington

Aspect CONSULTING	JUN-2015	BY: DLC / EG / PPW	FIGURE NO. 1
	PROJECT NO. 050067	REVISED BY: RAP/EAC	

GIS Path: T:\projects_8\Artbrass\Westof4thGroup\SummaryMemoForSU1\A-1 Subsurface Utilities.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 6/11/2015 || User: ecrumbaker || Print Date: 6/11/2015

APPENDIX C

BIOCHLOR Modeling Calculations

Contents – Appendix C

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C. BIOCHLOR Modeling Calculations

This appendix documents the groundwater fate-and-transport modeling and supplemental calculations used to develop preliminary remediation levels and to assess restoration time frames for various alternatives in the Feasibility Study (FS).

A draft *Fate and Transport Summary Memorandum for SU1* (Aspect, 2015) was prepared on behalf of the four 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 West of 4th (W4) Site. The AO requires the four PLPs (the W4 Group) to complete a FS and prepare a draft Cleanup Action Plan (dCAP) for the W4 Site. The environmental consultants addressing technical aspects of the FS and dCAP on behalf of the W4 Group (W4 Consultants) are: Aspect Consulting, LLC (Aspect) for ABP; Farallon Consulting (Farallon) for CI; Pacific Groundwater Group (PGG) for BDC; and Pacific Crest Environmental (Pacific Crest) for Stericycle.

Background and Purpose

The analyses provided in this appendix are focused on the fate and transport of chlorinated volatile organic compounds (cVOCs) in SU1. Separate analyses for the fate and transport of metals in SU1 and for cVOCs in SU2 are provided in Appendix B of this report, and in the separate FS report being developed for SU2, respectively.

The *Revised Fate and Transport Modeling Plan—W4 Feasibility Study* (Modeling Plan; PGG, 2015) presented the planned modeling approach to establish preliminary remediation levels and evaluate cVOC attenuation in support of restoration time-frame evaluation. On March 19, 2015, Ecology conditionally approved the Modeling Plan, noting that the purposes of modeling in the FS are to:

- Refine modeling from the Remedial Investigation (RI) to integrate new data that were unavailable during previous modeling;
- Provide a unified assessment of cVOC fate and transport from the different PLPs for SU1 and SU2;
- Refine estimates of restoration time frame with no further action (e.g., monitored natural attenuation [MNA]);

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[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.

- Refine predictions of whether/when surface water-based groundwater cleanup levels will be exceeded at the waterway, if no further site actions are implemented;
- Estimate constituent of concern (COC) source and hot-spot mass removal required to reach groundwater cleanup levels plume-side within a reasonable restoration time frame;
- Help estimate how quickly COC mass/concentration reduction, per source or hot-spot area, must occur in order to meet remedial action objectives; and
- Supplement the evaluation of each remedial alternative's probable effects on groundwater quality, to help predict post-implementation effects on groundwater geochemistry, gradients, and bioactivity.

Ecology's letter conditionally approved the Modeling Plan as sufficient to address the first five bullets, but requested additional consideration of if, and how, modeling would address the last two bullets.

The draft *Fate and Transport Summary Memorandum for SU1* provided results for the analyses described in the Modeling Plan, including preliminary remediation levels and a sensitivity analysis of the effect of uncertainty in model input parameters on model results. The modeling presented in this appendix expands on the modeling and results presented in the Modeling Plan.

Modeling Approach

Modeling of cVOC fate and transport to support evaluation of remediation levels and restoration time frame was performed using the BIOCHLOR spreadsheet model (Aziz and Newell, 2002). The BIOCHLOR input parameters and modeling approaches are generally consistent with the Modeling Plan, with deviations as described below to support assessment of the restoration time frame.

Two different sets of models were developed. The first set of models were used to determine preliminary remediation levels (i.e., groundwater concentrations in the source areas or downgradient locations that would be protective of surface water quality), assuming reduction in concentrations due to some unspecified remedial action. The second set of models were developed to assess the effects of different remedial actions (e.g., source control, treatment walls in public rights-of-way [ROWs]) on the restoration time frame.

Six BIOCHLOR models were developed to determine preliminary remediation levels at the following locations (Figure C-1):

- The ABP Facility;
- Downgradient locations at 2nd Avenue South, 1st Avenue South, East Marginal Way South (EMW), and South Fidalgo Street; and

- The vinyl chloride (VC) hot spot located south of the ABP plume on 1st Avenue South and defined by well PSC-CG-141-40.

Nine additional BIOCHLOR models were developed to assess the restoration time frame for the plume extending downgradient from the ABP Facility with the following remedial actions:

- No active treatment, with MNA only;
- A treatment wall at South Fidalgo Street;
- Treatment walls at South Fidalgo Street and EMW;
- Treatment walls at areas exceeding remediation levels (South Fidalgo Street, EMW, and 1st Avenue South);
- Treatment walls at areas exceeding cleanup levels and downgradient of the ABP Facility (South Fidalgo Street, EMW, 1st Avenue South, and 2nd Avenue South);
- Complete source removal/stabilization at ABP Facility, treatment walls at areas exceeding cleanup levels, and areal treatment at accessible private, downgradient properties;
- Source treatment only at ABP Facility;
- Source treatment at ABP Facility, adjacent ROWs, and 220 Findlay building; and
- Source treatment at ABP Facility, a treatment wall at South Fidalgo Street, and a sparge line at the nearshore monitoring wells.

A tenth BIOCHLOR model was developed to assess the restoration time frame for the VC hot spot at well PSC-CG-141-40.

The following sections present input parameters selected for the modeling and modifications to the model parameters presented in the Modeling Plan and the *Fate and Transport Summary Memorandum for SU1* to allow evaluation of the restoration time frame.

Model Parameters

The models were constructed using the transport and source area model parameters described in the Modeling Plan and revised in the *Fate and Transport Summary Memorandum for SU1*. Parameters are summarized on Tables C-1 and C-2 and discussed below.

Transport Parameters

BIOCHLOR calculates groundwater concentrations along a plume centerline based on a combination of advection and dispersion parameters, biodegradation parameters, source area concentrations, source area concentration decay rates (if applicable), and source area general characteristics. This approach assumes that loss rates are consistent or conservative with model parameters within a model zone, both laterally and longitudinally, and that there are centerline groundwater data available for comparison. Groundwater monitoring provides adequate hydraulic and empirical chemical data to constrain the plume position and centerline concentrations in near-source and downgradient locations.

Modeling documented in the *Fate and Transport Summary Memorandum for SU1* found that BIOCHLOR models using groundwater velocities calculated based on field data (i.e., hydraulic conductivity and gradient) did a poor job of matching observed cVOC concentrations; use of a groundwater velocity twice that estimated from field data provided a better match. The higher groundwater velocity from this Revised Base Case model was retained as most representative for determining preliminary remediation levels and for restoration time-frame modeling.

Source Area Parameters

Model source area concentrations and general characteristics were assigned to the BIOCHLOR models based on the location being simulated and on the specific model purpose; these parameters are discussed below. In this appendix, the term “model source area” refers to a location in the aquifer that is the upgradient extent of the model domain and does not necessarily correspond to a point of release of contaminants to soil and groundwater.

Source Area Geometry and Locations

For both the remediation level and the restoration time-frame analyses, model source areas were defined for the ABP Facility; four downgradient locations at 2nd Avenue South, 1st Avenue South, EMW, and South Fidalgo Street; and the VC hot spot defined by well PSC-CG-141-40. Model source areas were configured as single-planar sources the width of the groundwater plume at each source area location, and the thickness of the applicable groundwater depth interval or intervals (Water Table, Shallow, or Intermediate), as summarized on Table C-2.

Source Area Concentrations

Model source area concentrations representing current groundwater quality conditions were assigned as the maximum detected cVOC concentrations in a given model source area since the March 2014 sampling event. Model source areas and associated source-area concentrations were defined using concentration data from the listed wells for the following locations:

- 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);
- The area between South Fidalgo Street and EMW (well MW-24-30); and
- The VC hot spot (PSC-CG-141-40).

These data are summarized on Table C-2. Source area concentration ratios of cVOCs (e.g., TCE:DCE:VC ratios) were maintained as concentrations were adjusted to calculate remediation levels, as discussed below.

Additional Considerations for Restoration Time-Frame Models

The set of models developed to support evaluation of the restoration time frame deviated from the modeling approach described in the Modeling Plan, in order to accommodate model source-area concentration decay and allow inclusion of the effects of different remedial actions on groundwater quality. Planned deviations were discussed with Ecology at a meeting on November 23, 2015.

The models were developed to account for decreases in cVOC mass at the ABP Facility and at downgradient "sources," or hot spots, over time due to natural groundwater flushing. 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 ROW) and where cVOCs exceeding cleanup levels or preliminary remediation levels were detected in groundwater (see Figure C-1 for modeled treatment areas).

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 concentration, such as was used in the remediation level models, modeled source areas with concentrations that currently exceed cleanup levels would never meet cleanup levels. Source-area concentration decay rates due to flushing were estimated using a mass balance approach, as described below.

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 were installed at 2nd Avenue South, and it is expected to reduce incoming concentrations by 80 percent, then the modeled concentrations west of 2nd Avenue South associated with the Facility Source Area would be reduced by 80 percent.

Model results were treated as a single plume (vertically) from the ABP Facility to waterway, rather than distinguishing between the different depth intervals, since the plume moves through and across these artificial boundaries.

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 times ranging from 3 to 100 years. The concentration profiles were then compared to applicable cleanup levels to assess the likely restoration time frame.

Source Area Decay Rates for Restoration Time-Frame Modeling

Assessing the restoration time frame 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, such as source removal or stabilization. Model source-area decay rates accounting only for flushing of contaminants by groundwater flow were estimated based on a mass balance approach.

First, the model source areas to be simulated were defined at the areas, and with the concentrations, described above in the Source Area Concentrations section. The volume of each source area was then calculated based on the plume dimensions and distance to the next upgradient model source area. For example, the source area applied at 1st Avenue South would include cVOC mass in soil and groundwater between 1st Avenue South and 2nd Avenue South. Once the volume of the model source area was defined, a unit cVOC concentration in groundwater was assumed for calculation purposes, and apportioned between soil and groundwater based on assumed soil porosity and bulk density, soil total organic carbon, and the soil organic carbon-water partitioning coefficient. The partitioning coefficient for TCE was selected for this evaluation as the most sorptive cVOC at the Site and slowest to naturally flush. Using the groundwater velocity and length (parallel to the plume) of the model source area, the time to flush one pore volume through each model source area was calculated. Change in cVOC mass and concentration following flushing of one pore volume of groundwater was then calculated by reapportioning the cVOC mass between soil and groundwater, assuming no incoming cVOC mass from upgradient[2].

The source-area decay rate (ks) was then calculated as:

$$ks = -ln\left(\frac{C}{Co}\right)/t_{pv}$$

Where C is the groundwater concentration at time t_{pv} (i.e., the source-area groundwater concentration after one pore volume of flushing), Co is the initial model source-area groundwater concentration, and t_{pv} is the time in years to flush one pore volume. Calculations of source decay rates for the model source areas are provided on Table C-3. Use of a source-area decay rate in BIOCHLOR is constrained by model stability requirements, depending on the seepage velocity, retardation factor, biodegradation rates, and dispersivity. For the combination of parameters applied to the current modeling, the maximum source decay rate with which the model is stable was 0.28/yr. Source decay rates calculated using the mass balance approach slightly exceeded this limit for the models developed for the ABP Facility, 1st Avenue South, and South Fidalgo Street; source decay rates applied in the models for these locations were adjusted downward to

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[2] Note, mass from upgradient model source areas is accounted for in the restoration time-frame modeling by summing the results of the individual source-area models to arrive at a final plume profile.

meet the stability requirements, as shown on Table C-3. Use of the slightly lower source decay rates will result in a slightly slower rate of reduction in source area concentrations over time.

Preliminary Remediation Levels

To support estimates of remediation levels, five BIOCHLOR models were developed to assess plume attenuation downgradient from: 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 at well PSC-CG-141-40. Preliminary remediation levels protective of the surface water pathway were estimated by adjusting model source- area concentrations until model results met preliminary surface water-based cleanup levels at the point of discharge to the Duwamish Waterway.

At the ABP Facility and 2nd 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, nondecaying 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 cleanup levels, the source-area concentrations were reduced (while maintaining the observed ratios between cVOC constituents) until modeled concentrations at the waterway were less than cleanup levels.

Maintaining the observed ratios between cVOC constituents resulted in impractically low VC remediation levels (e.g., less than 0.1 μg/L) at 1st Avenue South, EMW, and South Fidalgo Street, and an impracticably low DCE remediation level (less than 0.9 μg/L) at EMW. The VC remediation levels in these locations were adjusted upward to the surface water cleanup level of 1.6 μg/L, and the DCE remediation level at EMW was adjusted upward to 4 μg/L, while adjusting the remaining cVOC constituent remediation levels downward to meet all surface water cleanup levels at the waterway. This final set of source-area concentrations that did not result in modeled exceedances at the waterway was selected as the preliminary remediation levels for a given location. Table C-4 summarizes the calculated remediation levels.

Remediation levels calculated with this method are only applicable at or upgradient of the modeled source area; application upgradient of the source area would be conservative. Note that 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 cleanup levels. As such, remediation levels may need to be revisited depending on future observed ratios of cVOC constituents.

Restoration Time-Frame Estimates

BIOCHLOR models to assess the restoration time frame for the cVOC plume downgradient of the ABP Facility were developed for the following sets of potential remedial actions:

- No active treatment, with MNA only;
- A treatment wall at South Fidalgo Street;
- Treatment walls at South Fidalgo Street and EMW;
- Treatment walls at areas exceeding remediation levels (South Fidalgo Street, EMW, and 1st Avenue South);
- Treatment walls at areas exceeding cleanup levels and downgradient of the ABP Facility (South Fidalgo Street, EMW, 1st Avenue South, and 2nd Avenue South);
- Complete source removal/stabilization at ABP Facility, treatment walls at areas exceeding cleanup levels, and areal treatment at accessible private, downgradient properties;
- Source treatment only at ABP Facility;
- Source treatment at ABP Facility, adjacent ROWs, and 220 Findlay building; and
- Source treatment at ABP Facility, a treatment wall at South Fidalgo Street, and a sparge line at the nearshore monitoring wells.

An additional BIOCHLOR model was developed to assess the restoration time frame for the VC hot spot at well PSC-CG-141-40. In addition to assessing restoration time frame, these models were also used to estimate the time to meet vapor intrusion-based cleanup levels at the ABP Facility and downgradient areas to 2nd Avenue South, and the time to meet the preliminary remediation levels on Table C-4.

These models were developed using the parameters and modeling approach described above. Treatment effectiveness at linear treatment features (e.g., treatment wall or sparge curtain along street ROWs) was assumed to be 80-percent effective in reducing concentrations across the treatment zone, assuming careful injection, or placement, of treatment medium or overlapping coverage with sparge wells. For source removal/stabilization at the ABP Facility, treatment was also assumed to be 80-percent effective in reducing source-area concentrations. For areal treatment at accessible locations on private property, treatment effectiveness was also assumed to be 80 percent, but was reduced in proportion to the accessible area within the treatment area. For example, if a proposed treatment area were 50-percent accessible with the remaining property covered by buildings, the final effectiveness of the areal treatment was estimated to reduce initial concentrations by 40 percent. Active treatment (areal or linear feature) was assumed to have an instantaneous effect, relative to groundwater transport rates.

When run under transient conditions, the BIOCHLOR model provides calculated cVOC concentrations at specified time steps; for the restoration time frame, modeling results were generated with a 3-year time step from years 3 to 30, and a 10-year time step to year 100. Model results were used to develop cVOC concentration profiles from the ABP

Facility to the waterway for times ranging from 3 to 100 years, accounting for the contribution of all source areas to and the effects of remedial actions on total groundwater concentrations. Concentration profiles at different times (expressed as years from implementation of the remedial actions) were then compared to applicable cleanup levels to identify when cVOC concentrations are expected to meet cleanup levels throughout SU1. For restoration time frames greater than 30 years, use of the 10-year time step in this analysis limited the precision of the estimates. For these cases, the estimated restoration time frame was refined further by interpolating modeled cVOC concentrations between time steps to arrive at a more precise time when cleanup levels would be met. The interpolated restoration time-frame estimates were rounded to the nearest 5-year increment. The concentration profiles generated using this approach are provided in Figures C-2 through C-20.

Figure C-2 provides the cVOC concentration profile at time equal zero (i.e., the initial concentration applied to each “source area”) applicable to all treatment scenarios. The concentration profiles generated for each treatment scenario at 20 years, and at the last time step before concentrations throughout SU1 meet cleanup levels protective of surface water (e.g., if the concentration profile for the 40-year time step exceeds cleanup levels anywhere, and the profile for the 50-year time step meets cleanup levels everywhere, the profile 40-year time step is shown).

Results of this analysis are provided in Tables C-5, C-6, and C-7. Table C-5 provides a summary of modeled treatment scenarios and the resulting restoration time frames to meet cleanup levels throughout SU1, with the exception of the PSC-CG-141-40 hotspot restoration time frame, which is applicable only to the VC contamination observed at this well. Table C-6 provides a more detailed breakdown of when groundwater cleanup levels protective of the vapor intrusion and surface water exposure pathways are modeled to be met at different locations in SU1. Table C-7 provides a summary of when groundwater remediation levels protective of surface water at the Duwamish Waterway are modeled to be met at different locations in SU1.

Estimated restoration time frames range from about 55 years with MNA only to about 40 years with the most aggressive remedial actions, including source stabilization and extensive groundwater treatment. Of note, the estimated restoration time frame for the VC hot spot at well PSC-CG-141-40 (20 years) under MNA is less than all restoration time frames for the main cVOC plume.

Estimated times to meet vapor intrusion-based cleanup levels at the ABP Facility and downgradient to 2nd Avenue South are about 10 to 15 years and about 20 to 25 years, respectively, for all modeled remedial actions, except the most aggressive set of actions (Table C-6). If the ABP Facility Source Area were completely removed or stabilized, then time to meet vapor intrusion-based cleanup levels at the ABP Facility would be expected to be less than 5 years; however, there would be minimal improvement in the time to meet vapor intrusion-based cleanup levels downgradient to 2nd Avenue South, which would remain at about 20 years.

Estimated times to meet remediation levels protective of surface water at downgradient locations range from less than 5 to 10 years at 2nd Avenue South for all sets of remedial actions to as high as 50 years at South Fidalgo Street for MNA or treatment focused on the ABP Facility and vicinity (Table C-7). The aggressiveness of the remedial actions has only modest effects on the times to meet remediation levels, decreasing the estimated times by, at most, about one-third to one-half at each location relative to MNA only.

Model Uncertainty

There is considerable uncertainty inherent in assessing fate and transport of cVOCs, and the expected effects of remedial actions on cVOC concentrations in groundwater. The sensitivity of the BIOCHLOR model to model inputs (biodegradation rates, groundwater velocity, etc.) is well understood, and reasonably conservative model inputs were selected to help account for model uncertainty. These included:

- Use of maximum detected cVOC concentrations since March 2014 to define model source area concentrations; and
- Use of a groundwater velocity higher than calculated based on field data to develop preliminary remediation levels.

Additional model runs were completed to assess uncertainty in the effectiveness of groundwater treatment (areal treatment or linear walls) on groundwater concentrations and the restoration time frame. Sensitivity to treatment effectiveness was evaluated by rerunning each of the modeled scenarios—except for the MNA-only case—with expected 50- and 90-percent treatment effectiveness and comparing the resulting restoration time frames to the estimates using 80-percent treatment effectiveness. Results of this analysis are shown on Table C-8.

In general, results are only modestly sensitive to treatment effectiveness, with the most sensitive models being the ones that include a greater number of treatment locations, especially treatment at EMW. For treatment focused at South Fidalgo Street or at the ABP facility, there was no change in the estimated restoration time frame with changes in treatment effectiveness[3]. For the scenarios with treatment walls at EMW, changing the treatment effectiveness from 80 percent to 50- or 90-percent results in about a five-year change in the restoration time frame.

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[3] Note that restoration time frames greater than 30 years were rounded to the closest five years. Although there are minor differences in the model results, they are not significant within the precision of this modeling.

References

Aspect, 2015, Draft Fate and Transport Summary Memorandum for SU1, June 18, 2015.

Aziz and Newell, 2002, Aziz, C.E. and Newell, C.J., 2002. BIOCHLOR Natural Attenuation Decision Support System Version 2.2, User’s Manual Addendum.

Pacific Groundwater Group, 2015, Revised Fate and Transport Modeling Plan – W4 Feasibility Study, W4 Joint Deliverable, February 27.

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TABLES

Table C-1 - BIOCHLOR Transport Parameters

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

Model Parameter	Units	Data Source	Water Table	Shallow	Intermediate
Hydraulic Gradient (G)					
Mean	ft/ft	PGG, 2012	0.0012	0.0011	0.0014
Hydraulic Conductivity (K)	cm/sec	Aquifer Slug Tests [2]	1.7E-02	1.0E-02	2.8E-03
Effective Porosity (n)	--	Nominal Value	0.25	0.25	0.25
Seepage Velocity (v) - Calculated [4]	ft/year	Calculated as: v = (K*G)/n	83	45	16
Seepage Velocity (v) - As Applied in Model [4]	ft/year	Twice calculated value	166	91	32
Anisotropy Factor	--		n/a	n/a	n/a
Model Length (Distance fromModel Source Area to Duwamish Waterway)					
ABP Facility	feet	Scaled fom map	2,300	2,300	2,300
2nd Avenue	feet	Scaled fom map	1,900	1,900	1,900
1st Avenue	feet	Scaled fom map	1,400	1,400	1,400
East Marginal Way	feet	Scaled fom map	1,000	1,000	1,000
Fidalgo Avenue	feet	Scaled fom map	400	400	400
PSC-CG-141-40 "Hot Spot"	feet	Scaled fom map	1,200	1,200	1,200
Dispersivity					
Longitudinal (α_x)	--	Xu - Eckstein [3]	Calculated from model length		
Transverse (α_y)	--	(α x) * 0.1	Calculated from model length		
Vertical (α_z)	--	No Vertical Dispersion	1E-99	1E-99	1E-99
Soil Bulk Density	kg/L	MTCA Common Assumption	1.51	1.51	1.51
Soil Fraction Organic Carbon (foc)	%	Soil Measurements	0.2	0.2	0.2
Koc					
Tetrachloroethene	L/kg	MTCA CLARC Tables	265	265	265
Trichloroethene	L/kg	MTCA CLARC Tables	94	94	94
cis-1,2 Dichloroethene	L/kg	MTCA CLARC Tables	35.5	35.5	35.5
Vinyl Chloride	L/kg	MTCA CLARC Tables	18.6	18.6	18.6
1,4 Dioxane	L/kg	Literature Value 2	3.5	3.5	3.5
Retardation Factor (R) [1]					
PCE	--	Calculated	4.2	4.2	4.2
TCE	--	Calculated	2.1	2.1	2.1
cis-1,2 DCE	--	Calculated	1.4	1.4	1.4
VC	--	Calculated	1.2	1.2	1.2
Average Value			2.2	2.2	2.2
Biodegradation Rates (as half-lives)					
PCE	years	Newell (2000) 25th Percentile	1.2	1.2	1.2
TCE	years	Newell (2000) 25th Percentile	1.8	1.8	1.8
cis-1,2 DCE	years	Newell (2000) 25th Percentile	1.6	1.6	1.6
VC	years	Newell (2000) 25th Percentile	1.7	1.7	1.7

Notes:

[1] R = 1 + (p/n) * Kd
Kd = foc * Koc
p = dry bulk density
n = porosity

[2] See Remedial Investigations for discussion of hydraulic conductivity values (PGG, 2012; Aspect, 2012, Farallon, 2012).

[3] Xu, M. and Y. Eckstein, 1995, Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Scale. J. Ground Water, 33(6): 905-908.

[4] See Aspect, 2015, Draft Fate and Transport Summary Memorandum for SU1. June 18, 2015 for rationale for use of higher groundwater velocity in the BIOCHLOR models.

Table C-2 - BIOCHLOR Source Area Parameters

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

Model Source Area and Parameters	Units	Value
ABP Facility		
Source Area Dimensions		
Source Area Width	ft	200
Source Area Length	ft	400
Source Area Thickness	ft	20
Source Area Concentrations - PMW-1		
PCE	ug/L	0
TCE	ug/L	320
cis-1,2 DCE	ug/L	55
VC[1]	ug/L	0
2nd Avenue		
Source Area Dimensions		
Source Area Width	ft	200
Source Area Length	ft	500
Source Area Thickness	ft	40
Source Area Concentrations - MW-16-40		
PCE	ug/L	0
TCE	ug/L	650
cis-1,2 DCE	ug/L	100
VC[1]	ug/L	0
1st Avenue		
Source Area Dimensions		
Source Area Width	ft	200
Source Area Length	ft	400
Source Area Thickness	ft	40
Source Area Concentrations - MW-17-40		
PCE	ug/L	0
TCE	ug/L	2700
cis-1,2 DCE	ug/L	72
VC	ug/L	33
East Marginal Way		
Source Area Dimensions		
Source Area Width	ft	300
Source Area Length	ft	600
Source Area Thickness	ft	40
Source Area Concentrations - MW-25-50		
PCE	ug/L	0
TCE	ug/L	6200
cis-1,2 DCE	ug/L	180
VC	ug/L	19
Fidalgo Avenue		
Source Area Dimensions		
Source Area Width	ft	300
Source Area Length	ft	400
Source Area Thickness	ft	20
Source Area Concentrations - MW-24-30		
PCE	ug/L	0
TCE	ug/L	150
cis-1,2 DCE	ug/L	207
VC	ug/L	27
PSC-CG-141-40 "Hot Spot"		
Source Area Dimensions		
Source Area Width	ft	400
Source Area Length	ft	400
Source Area Thickness	ft	40
Source Area Concentrations - MW-24-30		
PCE	ug/L	0
TCE	ug/L	0
cis-1,2 DCE	ug/L	1.2
VC	ug/L	150

Nc

[1] VC concentration assigned as 10 percent of DCE concentration for remediation level modeling

Table C-3 - Model Source Area Decay Rate Calculations

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

	Source Area Dimensions												
Model Source Area	**Length**	**Width**	**Depth**	**Time to Flush One Pore Volume (Years)**	**Initial Groundwater Concentration (mg/L)**	**Initial Mass in Groundwater (mg)**	**Initial Mass in soil (mg)**	**Total Initial Mass (mg)**	**Reapportioned Mass in Groundwater (mg)**	**Reapportioned Mass in Soil (mg)**	**Groundwater Concentration after One Pore Volume(mg/L)**	**Calculated Ks (1/yr)**	**Ks used for Model Stability (1/yr)[1]**
ABP Facility	400	200	20	4.4	1	33,980,160	3,215,429	37,195,589	2,937,467	277,963	0.26	0.30	0.28
2nd Avenue	500	200	40	5.5	1	84,950,400	8,038,573	92,988,973	7,343,667	694,907	0.26	0.24	0.24
1st Avenue	400	200	40	4.4	1	67,960,320	6,430,859	74,391,179	5,874,933	555,925	0.26	0.30	0.28
East Marginal Way	600	300	40	6.6	1	152,910,720	14,469,432	167,380,152	13,218,600	1,250,832	0.26	0.20	0.20
Fidalgo Avenue	400	300	20	4.4	1	50,970,240	4,823,144	55,793,384	4,406,200	416,944	0.26	0.30	0.28
CG-141-40 Hot Spot	400	400	40	4.4	1	135,920,640	12,861,717	148,782,357	11,749,866	1,111,851	0.26	0.30	0.28

Notes:

A unit value initial groundwater concentration was assumed for calculation purposes.

Partitioning between soil and groundwater was calculated using the Koc for TCE, see appendix text for additional explanation.

Reapportioned mass was calculated after subtracting mass removed by flushing one pore volume from total mass.

[1] The maximum allowable Ks for model stability is 0.28 1/yr.

Table C-4 - Preliminary Remediation Levels

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

	Location and Preliminary Remediation Level in ug/L						
Constituent	**ABP Facility**	**2nd Avenue**	**1st Avenue**	**East Marginal Way**	**Fidalgo Street**	**PSC-CG-141-40 VC Hot-Spot**	**Surface Water Cleanup Level**
TCE	1440	403	95	31	3.4	NA	7
DCE [1]	248	62	2.5	4	4.7	1.6	4,000
VC [2]	24.8	6.2	1.6	1.6	1.6	200	1.6

Notes:

[1] DCE cleanup level is for cis-1,2-DCE, the primary DCE isomer at the SU1. Trans-1,2-DCE and 1,1-DCE were largely not detected.

[2] VC was not detected in groundwater at the ABP Facility or Second Avenue; preliminary remediation levels for VC at these locations were set equal to 10 percent of the DCE remediation level. Minimum remediation levels for VC were set as the surface water cleanup level of 1.6 μg/L. Remediation levels for TCE and DCE at East Marginal Way, First Avenue, and Fidalgo Street were then adjusted downward to meet cleanup levels in groundwater at the waterway.

NA - TCE has not been detected at PSC-CG-141-40 since monitoring of this well started in 2002.

Table C-5 - Treatment Scenarios and Restoration Time-Frame Estimates

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

Modeled Scenario	Treatment Locations	Treatment Effectiveness	Modeled Restoration Time Frame
No Treatment, MNA only	None	Not applicable	55 years
Treatment wall at Fidalgo	Fidalgo	80 percent	50 years
Treatment walls at Fidalgo and East Marginal Way	Fidalgo and East Marginal Way	80 percent	40 years
Treatment walls at areas exceeding remediation levels	Fidalgo, East Marginal Way, and First	80 percent	40 years
Treatment walls at areas exceeding cleanup levels and downgradient of ABP Facility	Fidalgo, East Marginal Way, First, and Second	80 percent	40 years
Complete source removal/stabilization at ABP Facility, treatment walls at areas exceeding cleanup levels, and aerial treatment at accessible private property	Fidalgo, East Marginal Way, First, and Second plus ABP Facility and accessible private property	100 percent at ABP Facility, 80 percent elsewhere, with aerial treatment effectiveness reduced in proportion to accessible area.	40 years
Source treatment at ABP Facility.	ABP Facility	80 percent	55 years
Source treatment at ABP Facility, adjacent rights-ofway, and 220 Findlay Building	ABP Facility, rights-of-way, 220 Findlay	80 percent	55 years
Source treatment at ABP Facility, treatment wall at Fidalgo, sparge line at shoreline wells	ABP Facility, Fidalgo, Shoreline Wells	80 percent	50 years
PSC-CG-141-40 VC Hotspot, MNA only	None	Not applicable	20 years

Table C-6 - Estimated Times to Meet Cleanup Levels

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

	Time to meet Vapor Intrusion Cleanup Levels:		Time to Meet Surface Water Cleanup Levels at:					
Modeled Scenario	**at ABP Facility**	**between ABP Facility and Second Ave**	**Second Avenue**	**First Avenue**	**East Marginal Way**	**Fidalgo Street**	**Shoreline Monitoring Wells**	**Duwamish Shoreline**
No Treatment, MNA only	15 years	25 years	25 years	35 to 40 years	35 to 40 years	45 to 50 years	50 to 55 years	50 to 55 years
Treatment wall at Fidalgo	15 years	25 years	25 years	35 to 40 years	35 to 40 years	45 to 50 years	40 to 45 years	45 to 50 years
Treatment walls at Fidalgo and East Marginal Way	15 years	25 years	25 years	35 to 40 years	35 to 40 years	35 to 40 years	35 to 40 years	30 to 35 years
Treatment walls at areas exceeding remediation levels	15 years	25 years	25 years	35 to 40 years	35 to 40 years	35 to 40 years	30 to 35 years	30 to 35 years
Treatment walls at areas exceeding cleanup levels and downgradient of ABP Facility	15 years	25 years	25 years	25 to 30 years	35 to 40 years	35 to 40 years	30 to 35 years	30 to 35 years
Complete source removal/stabilization at ABP Facility, treatment walls at areas exceeding cleanup levels, and aerial treatment at accessible private property	< 5 years	20 years	20 years	20 years	30 to 35 years	35 to 40 years	25 to 30 years	25 to 30 years
Source treatment at ABP Facility.	10 years	20 years	20 years	30 to 35 years	35 to 40 years	45 to 50 years	50 to 55 years	50 to 55 years
Source treatment at ABP Facility, adjacent rights-of-way, and 220 Findlay building	10 years	20 years	20 years	25 to 30 years	35 to 40 years	45 to 50 years	50 to 55 years	50 to 55 years
Source treatment at ABP Facility, treatment wall at Fidalgo, sparge line at shoreline wells	10 years	20 years	20 years	30 to 35 years	35 to 40 years	45 to 50 years	40 to 45 years	30 to 35 years
PSC-CG-141-40 VC Hotspot, MNA only	Not applicable	Not applicable	Not applicable	20 years	20 years	Not applicable	Not applicable	Not applicable

Table C-7 - Estimated Times to Meet Remediation Levels

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

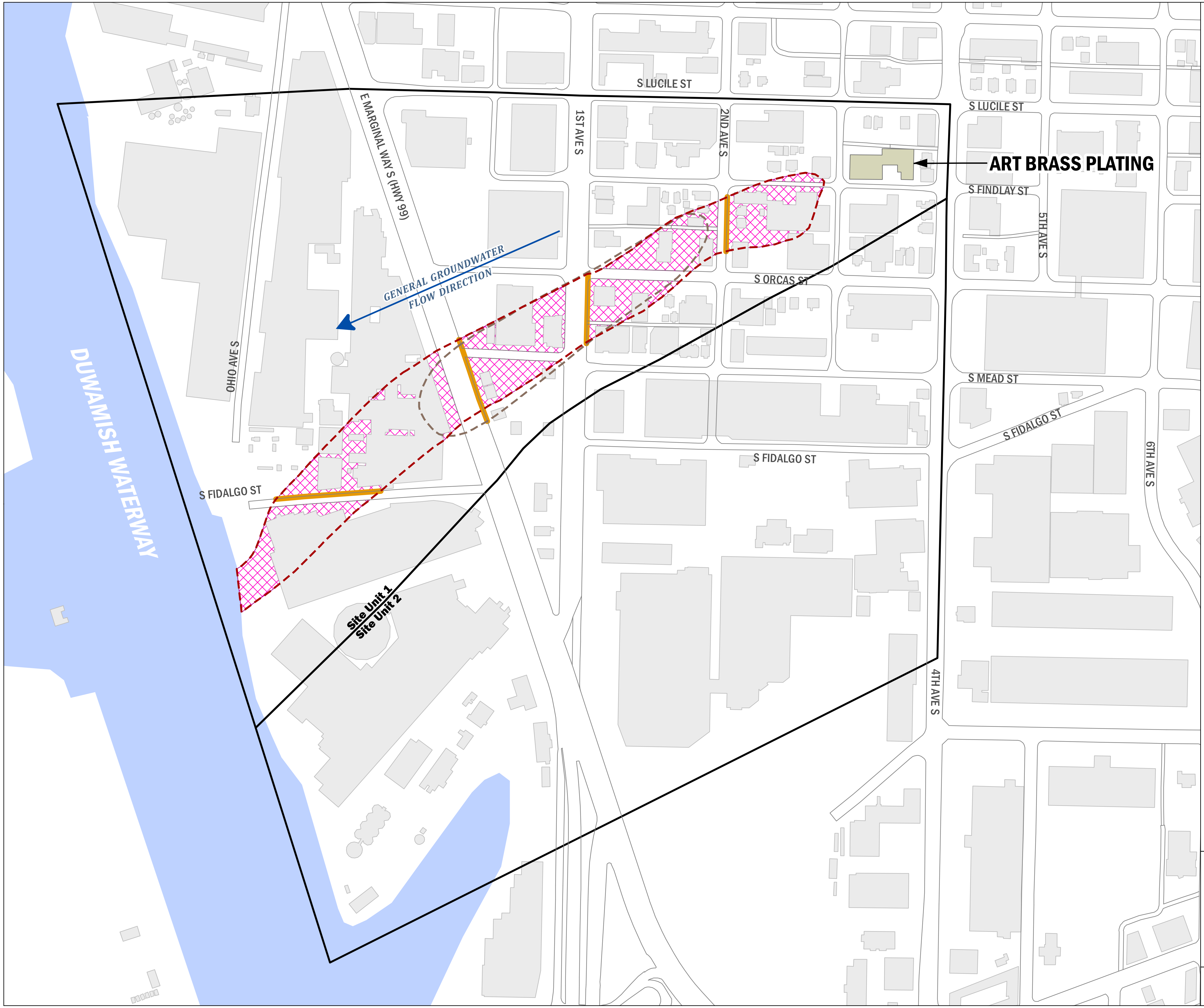
	Time to Meet Surface Water Remediation Levels at:					
Modeled Scenario	**ABP Facility**	**Second Avenue**	**First Avenue**	**East Marginal Way**	**Fidalgo Street**	**Shoreline Monitoring Wells[1]**
No Treatment, MNA only	Currently meets Remediation Levels	10 years	20 years	30 to 35 years	40 to 45 years	45 to 50 years
Treatment wall at Fidalgo	Currently meets Remediation Levels	10 years	20 years	30 to 35 years	40 to 45 years	40 to 45 years
Treatment walls at Fidalgo and East Marginal Way	Currently meets Remediation Levels	10 years	20 years	30 to 35 years	30 to 35 years	30 to 35 years
Treatment walls at areas exceeding remediation levels	Currently meets Remediation Levels	10 years	20 years	25 to 30 years	30 to 35 years	30 to 35 years
Treatment walls at areas exceeding cleanup levels and downgradient of ABP Facility	Currently meets Remediation Levels	10 years	15 years	25 to 30 years	30 to 35 years	30 to 35 years
Complete source removal/stabilization at ABP Facility, treatment walls at areas exceeding cleanup levels, and aerial treatment at accessible private property	Currently meets Remediation Levels	< 5 years	10 years	20 to 25 years	25 to 30 years	25 to 30 years
Source treatment at ABP Facility	Currently meets Remediation Levels	5 years	15 years	30 to 35 years	40 to 45 years	45 to 50 years
Source treatment at ABP Facility, adjacent rights-of-way, and 220 Findlay building	Currently meets Remediation Levels	< 5 years	15 years	25 to 30 years	40 to 45 years	45 to 50 years
Source treatment at ABP Facility, treatment wall at Fidalgo, sparge line at shoreline wells	Currently meets Remediation Levels	5 years	15 years	30 to 35 years	40 to 45 years	30 to 35 years

Table C-8 - Restoration Timeframe, Sensitivity to Treatment Effectiveness

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

Modeled Scenario	Treatment Locations	Treatment Effectiveness	Modeled Restoration Timeframe in Years
Treatment wall at Fidalgo	Fidalgo	80 percent 50 percent 90 percent	50 years 50 years 50 years
Treatment walls at Fidalgo and East Marginal Way	Fidalgo and East Marginal Way	80 percent 50 percent 90 percent	40 years 50 years 40 years
Treatment walls at areas exceeding remediation levels	Fidalgo, East Marginal Way, and First	80 percent 50 percent 90 percent	40 years 45 years 35 years
Treatment walls at areas exceeding cleanup levels and downgradient of ABP Facility	Fidalgo, East Marginal Way, First, and Second	80 percent 50 percent 90 percent	40 years 45 years 35 years
Source removal/stabilization at ABP Facility, treatment walls at areas exceeding cleanup levels, and aerial treatment at accessible private property	Fidalgo, East Marginal Way, First, and Second plus accessible private property	80 percent 50 percent 90 percent	40 years 45 years 35 years
Source treatment at ABP Facility	ABP Facility	80 percent 50 percent 90 percent	55 years 55 years 55 years
Source treatment at ABP Facility, adjacent rights-ofway, and 220 Findlay Building	ABP Facility, rights-of-way, 220 Findlay	80 percent 50 percent 90 percent	55 years 55 years 55 years
Source treatment at ABP Facility, treatment wall at Fidalgo, sparge line at shoreline wells	ABP Facility, Fidalgo, Shoreline Wells	80 percent 50 percent 90 percent	50 years 50 years 50 years

FIGURES



- TCE Isoconcentration Line at 18.0 µg/L Cleanup Level in Shallow Groundwater (for Protection of Surface Water)
- TCE Isoconcentration Line at 18.0 µg/L Cleanup Level in Intermediate Groundwater (for Protection of Surface Water)
- ▨ Areas Identified for Aerial Treatment on Accessible Private Property
- Modeled Linear Treatment Features (e.g., treatment walls)

Conceptual Layout of Treatment Areas for BIOCHLOR Modeling

W4 Group - Site Unit 1 FS
Seattle, Washington

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

GIS Path: T:\projects_8\Artbrass\FS\Delivered\W4Group_SiteUnit1FS\C-1 TCE Potential Treatment Areas.mxd || Coordinate System: NAD 1983 StatePlane Washington North FIPS 4601 Feet || Date Saved: 1/28/2016 || User: ecrumbaker || Print Date: 1/28/2016

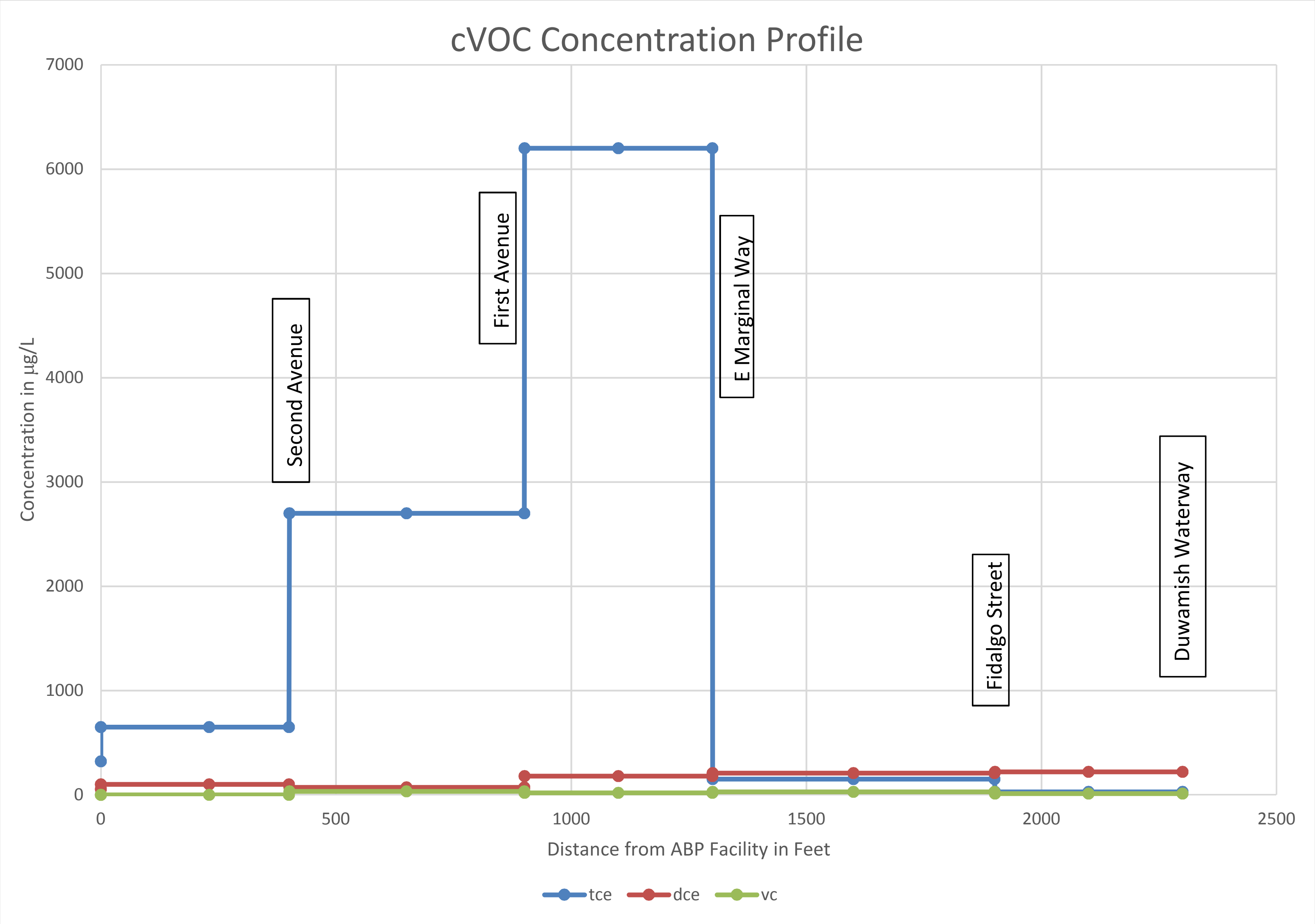


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Figure C-2
All Treatment Scenarios, T = 0 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

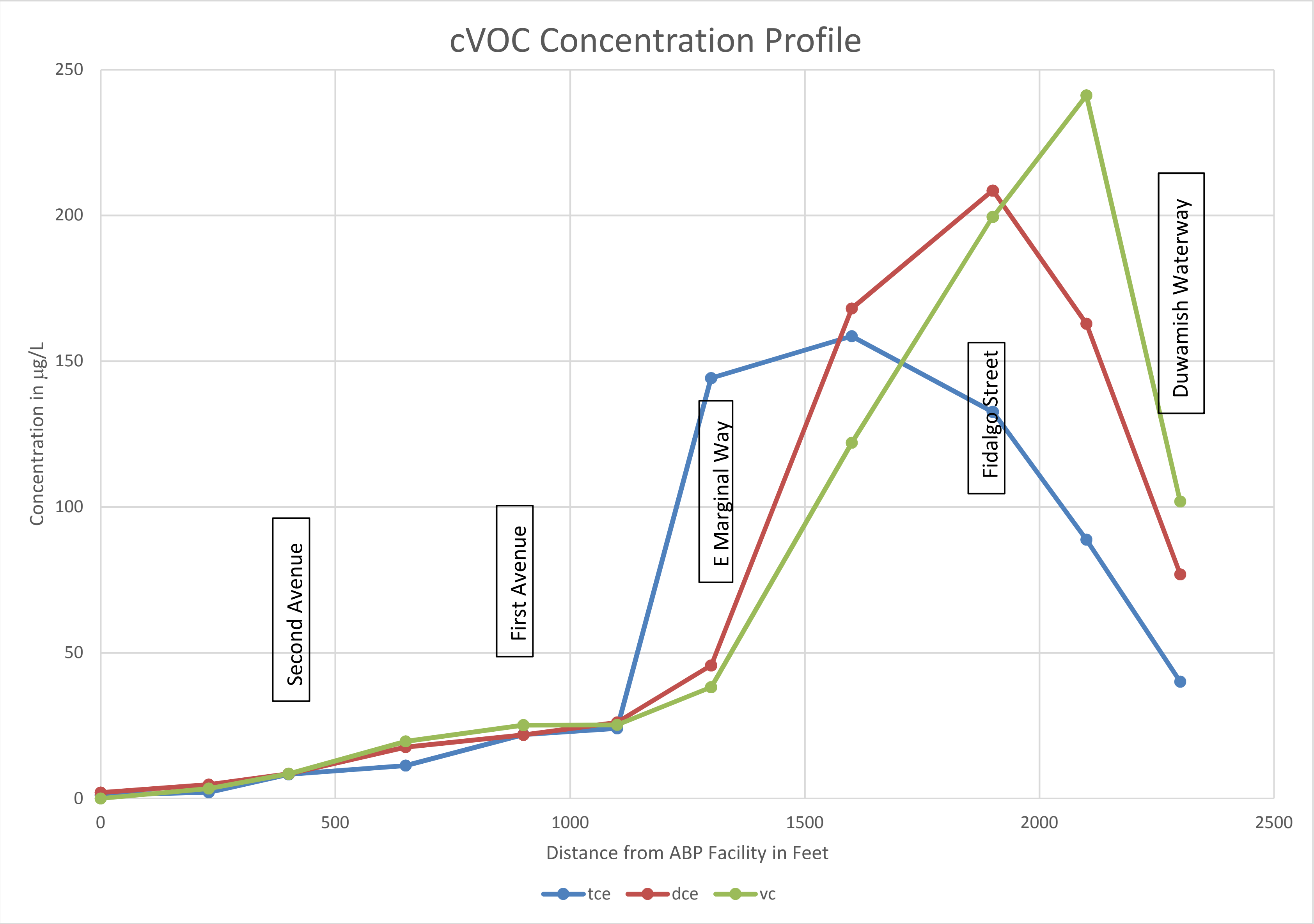

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Figure C-3
MNA Only, Time = 20 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

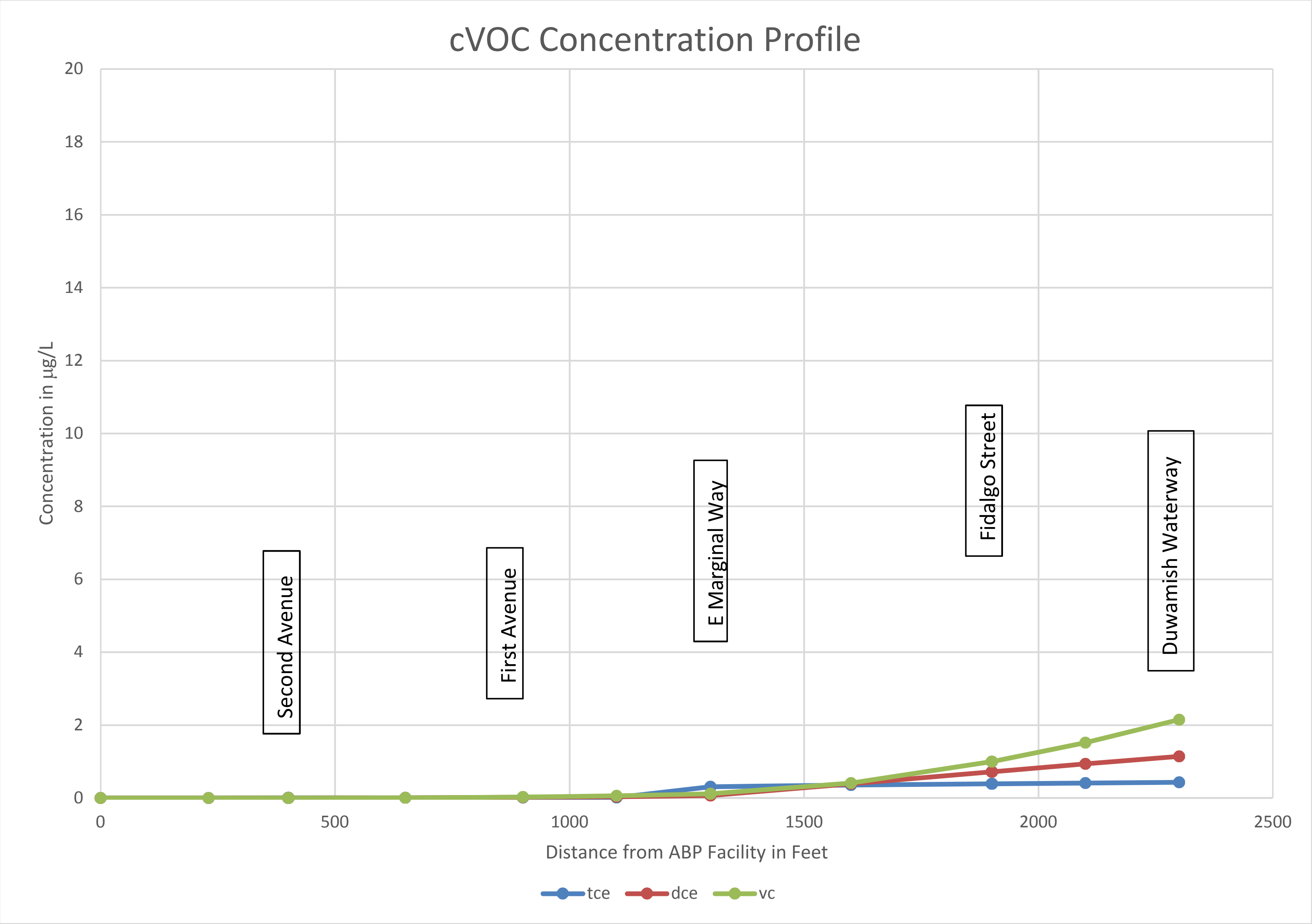

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Figure C-4
MNA Only, T = 50 Years
Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

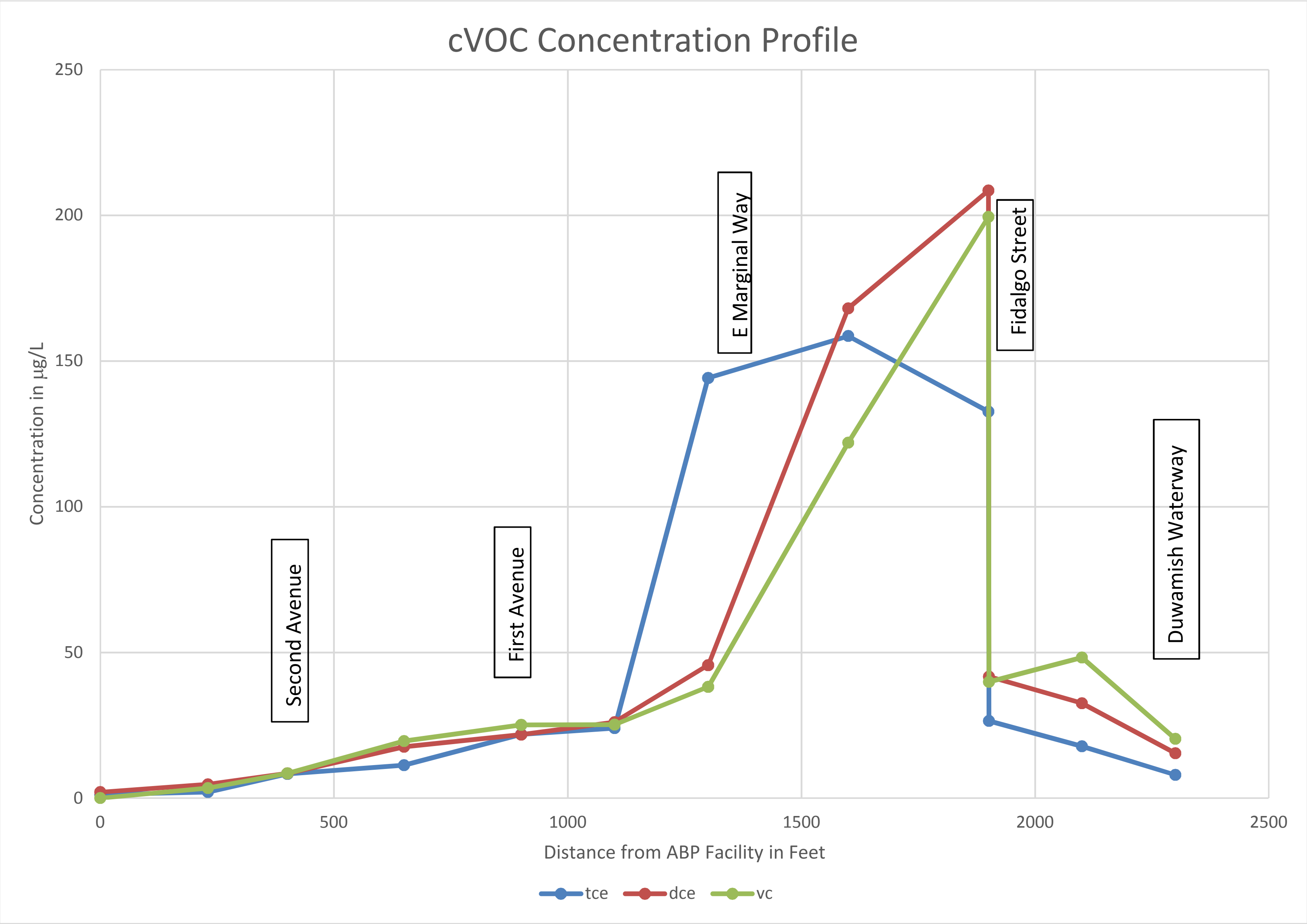

Figure C-5
Treatment at Fidalgo, T = 20 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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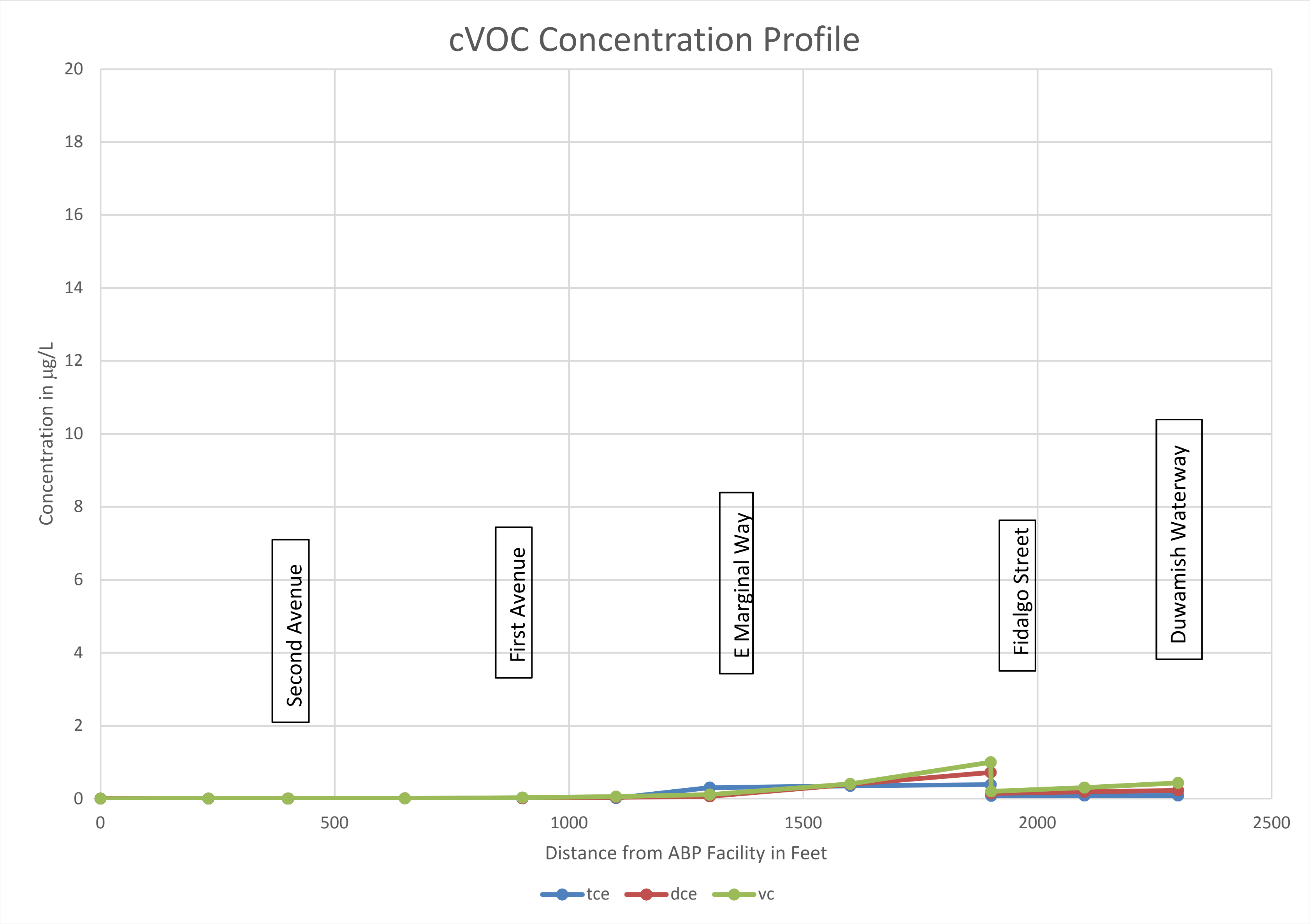

Figure C-6

Treatment at Fidalgo, T = 50 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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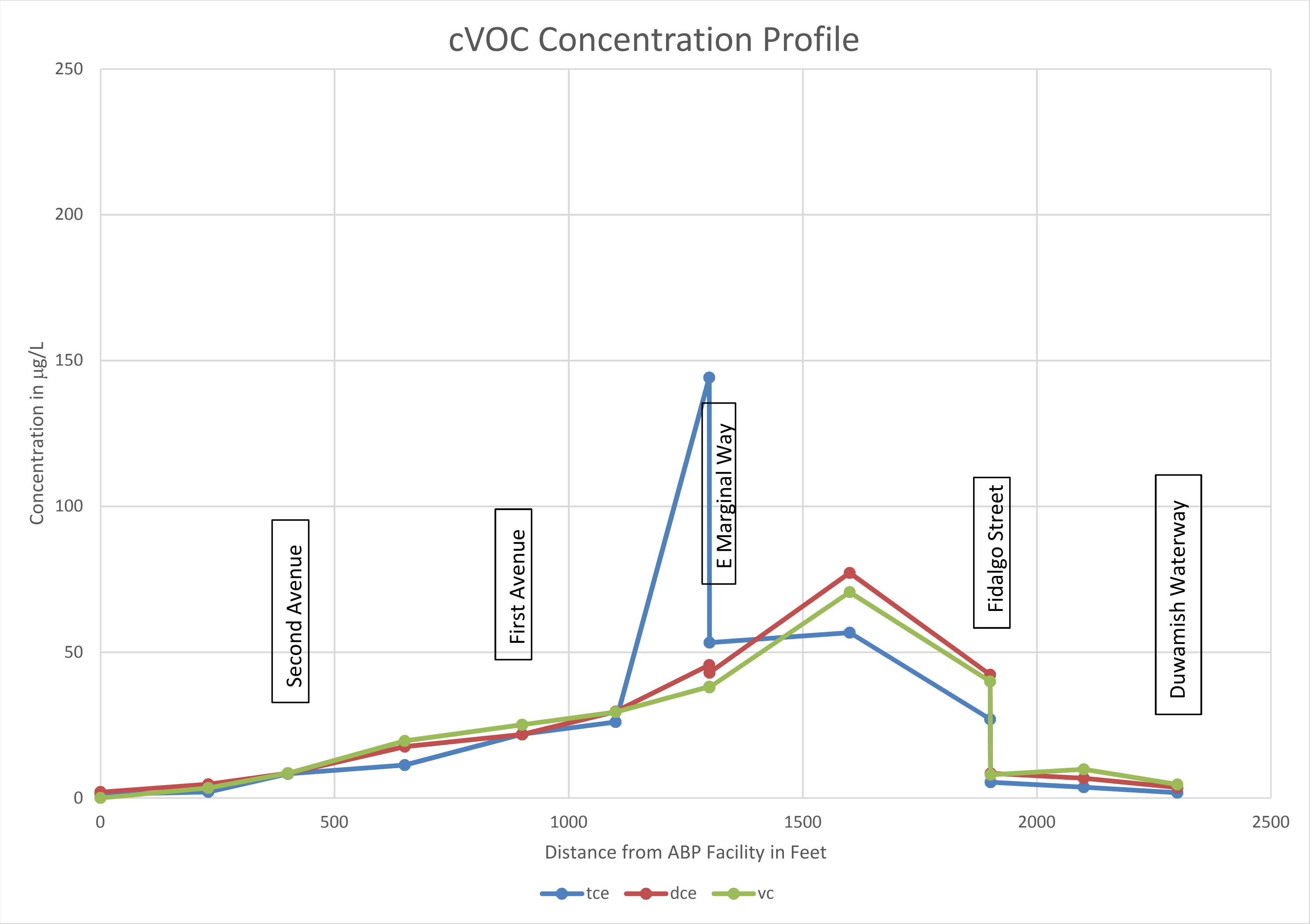

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Figure C-7
Treatment at Fidalgo EMW, T = 20 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

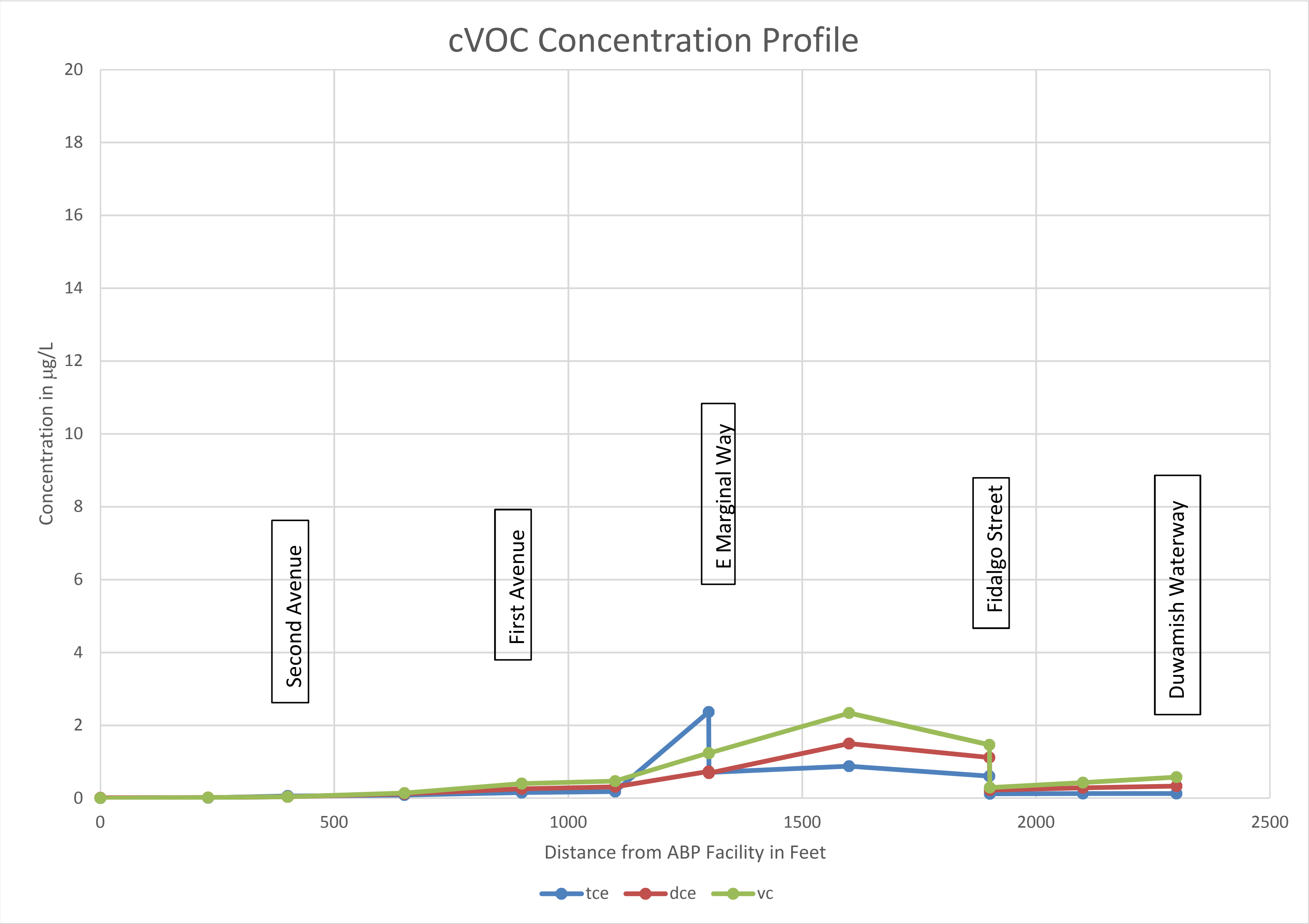

Figure C-8
Treatment at Fidalgo EMW, T = 40 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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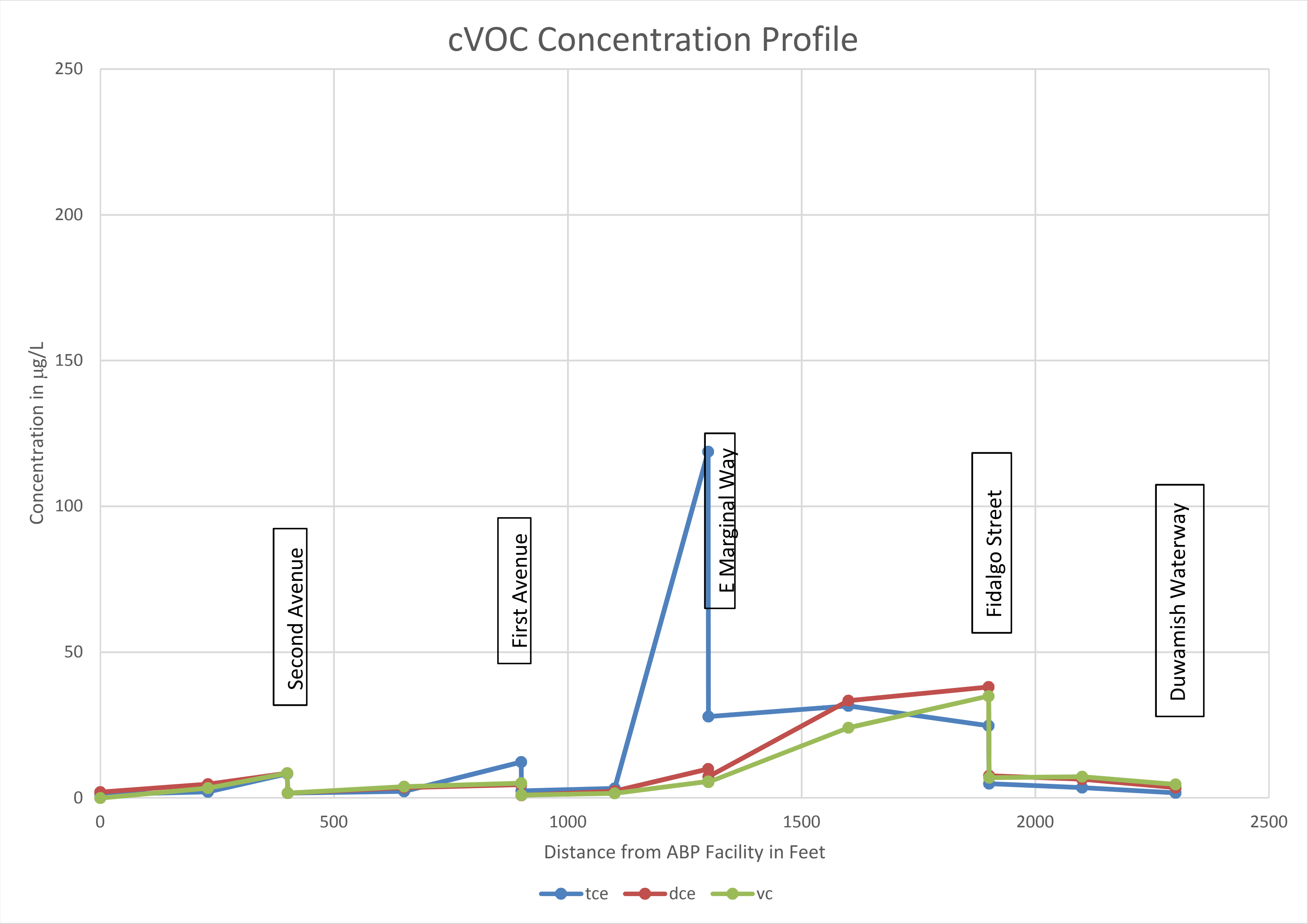

Figure C-9
Treatment at Fidalgo, EMW, 1st, T = 20 Years

Site Unit 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

Aspect Consulting
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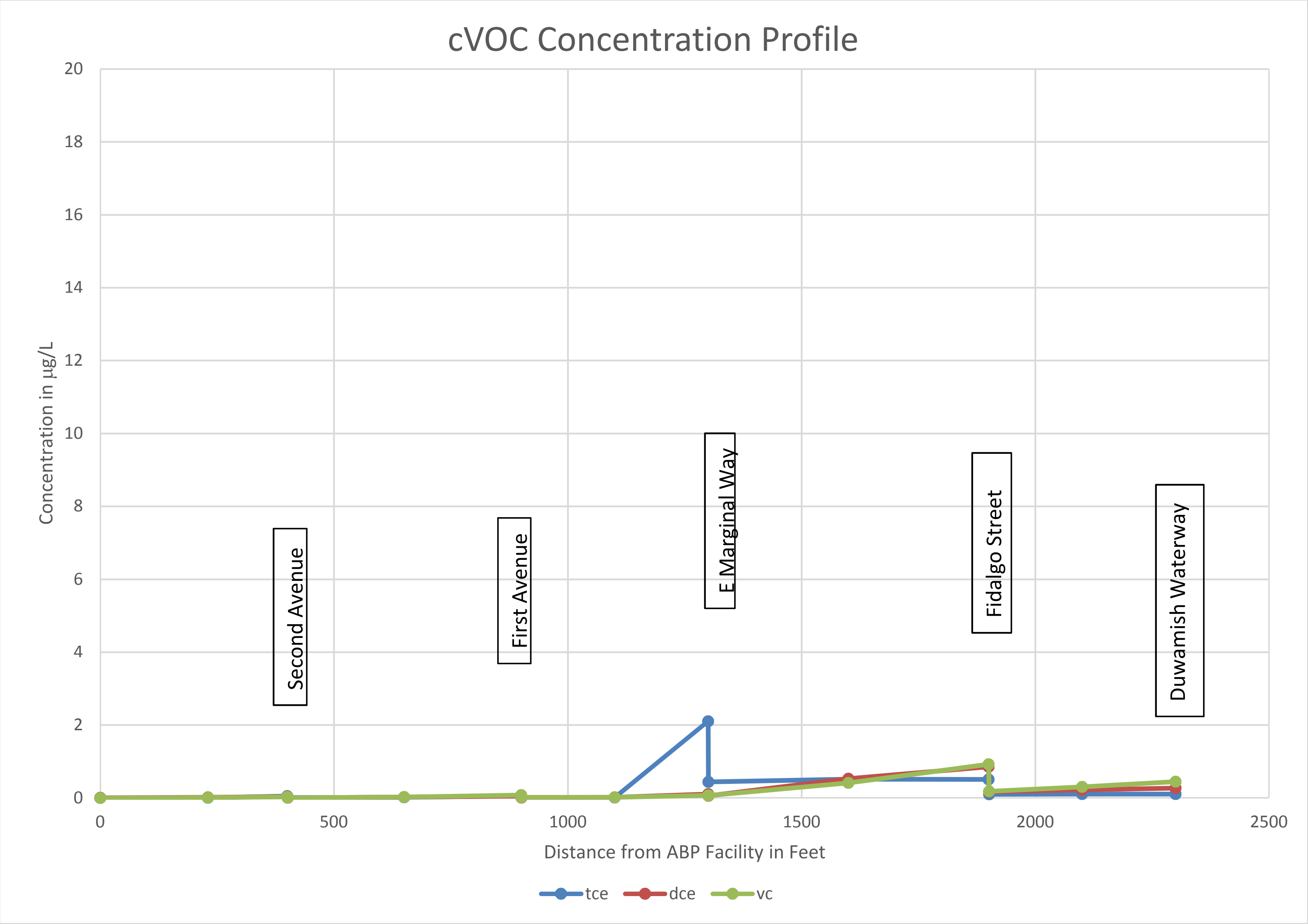

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Figure C-10
Treatment at Fidalgo, EMW, 1st, T = 40 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

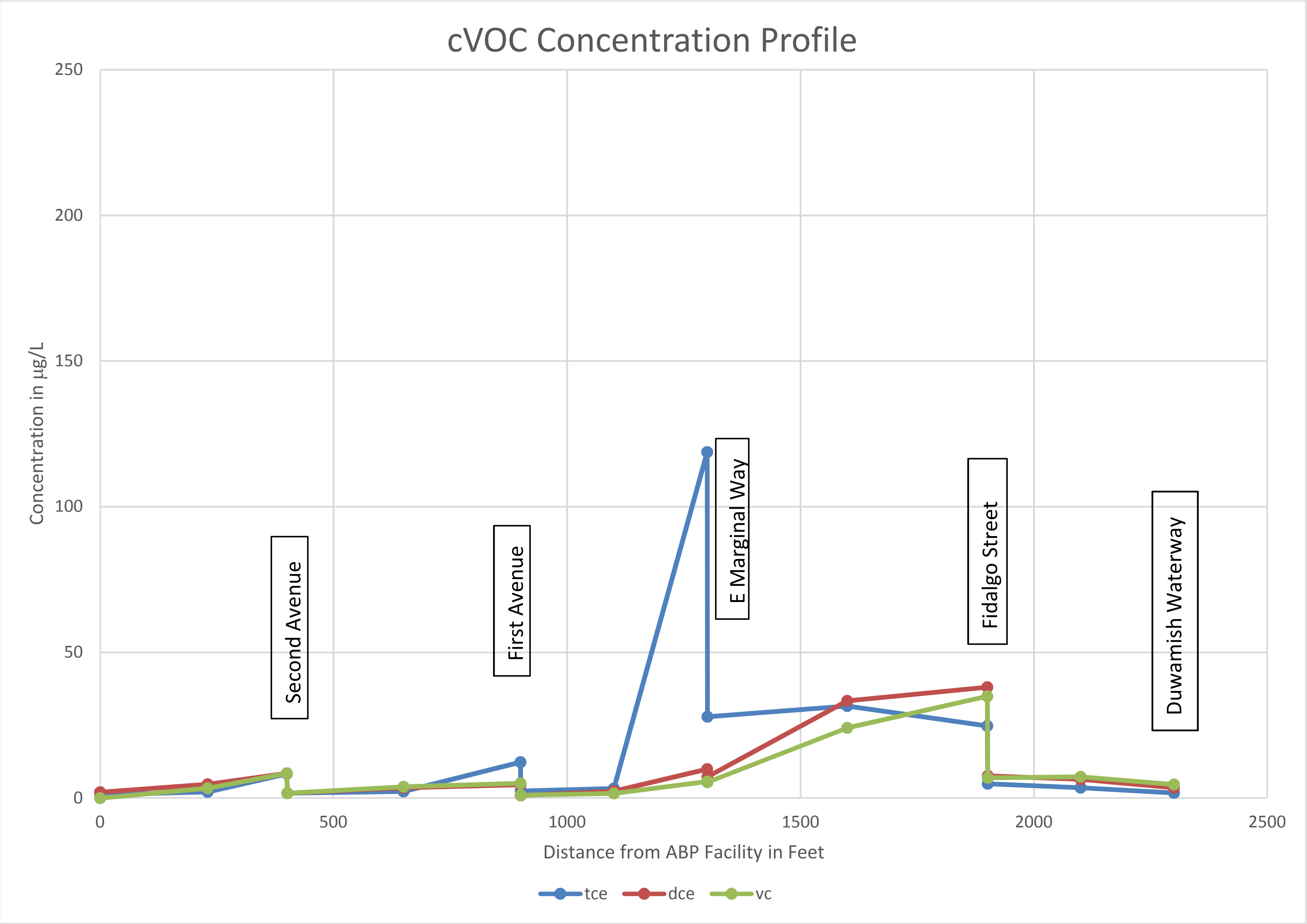

Figure C-11

Treatment at Fidalgo, EMW, 2ND, 1ST, T = 20 Years

SU 1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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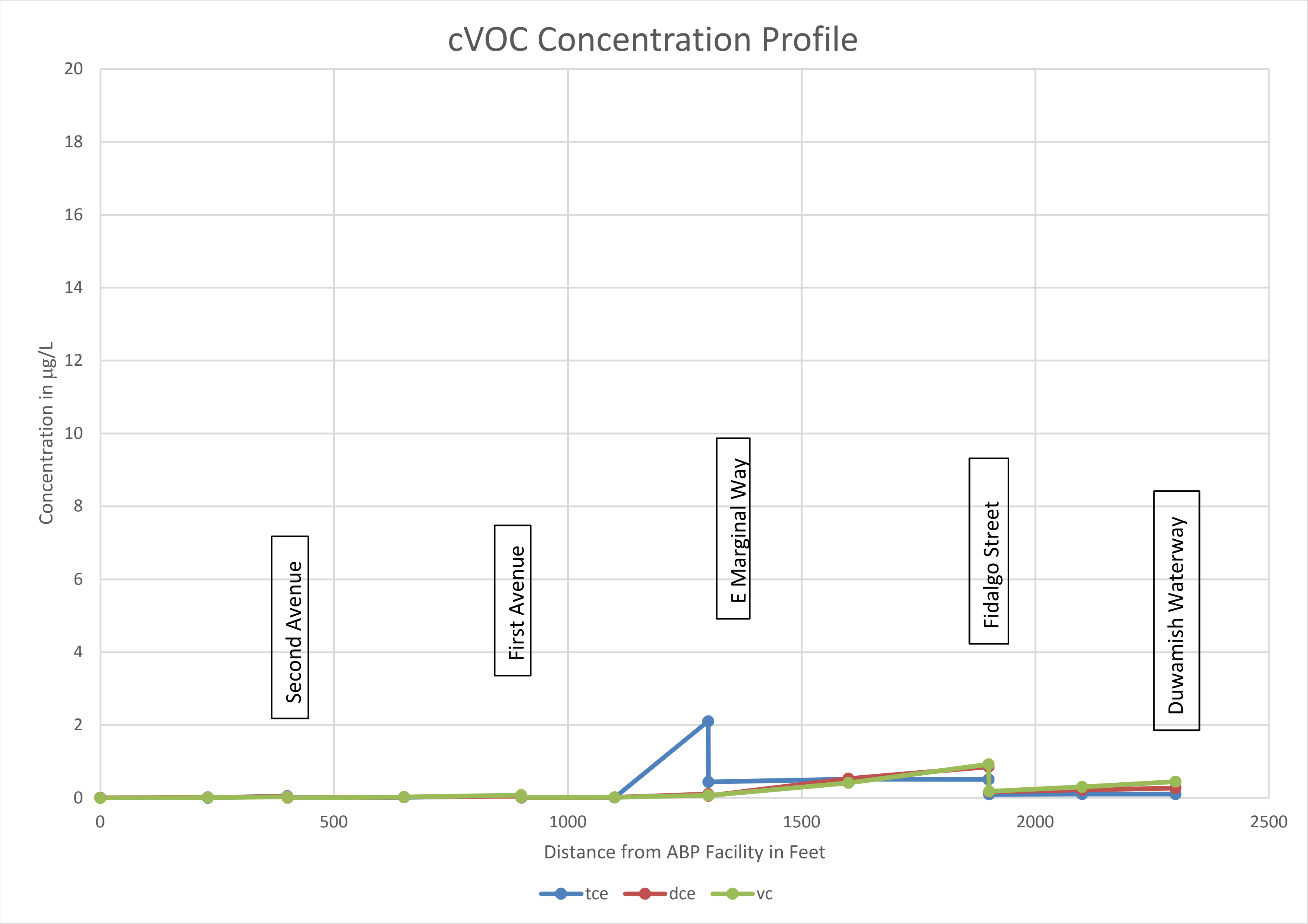

Figure C-12

Treatment at Fidalgo, EMW, 2ND, 1ST, T = 40 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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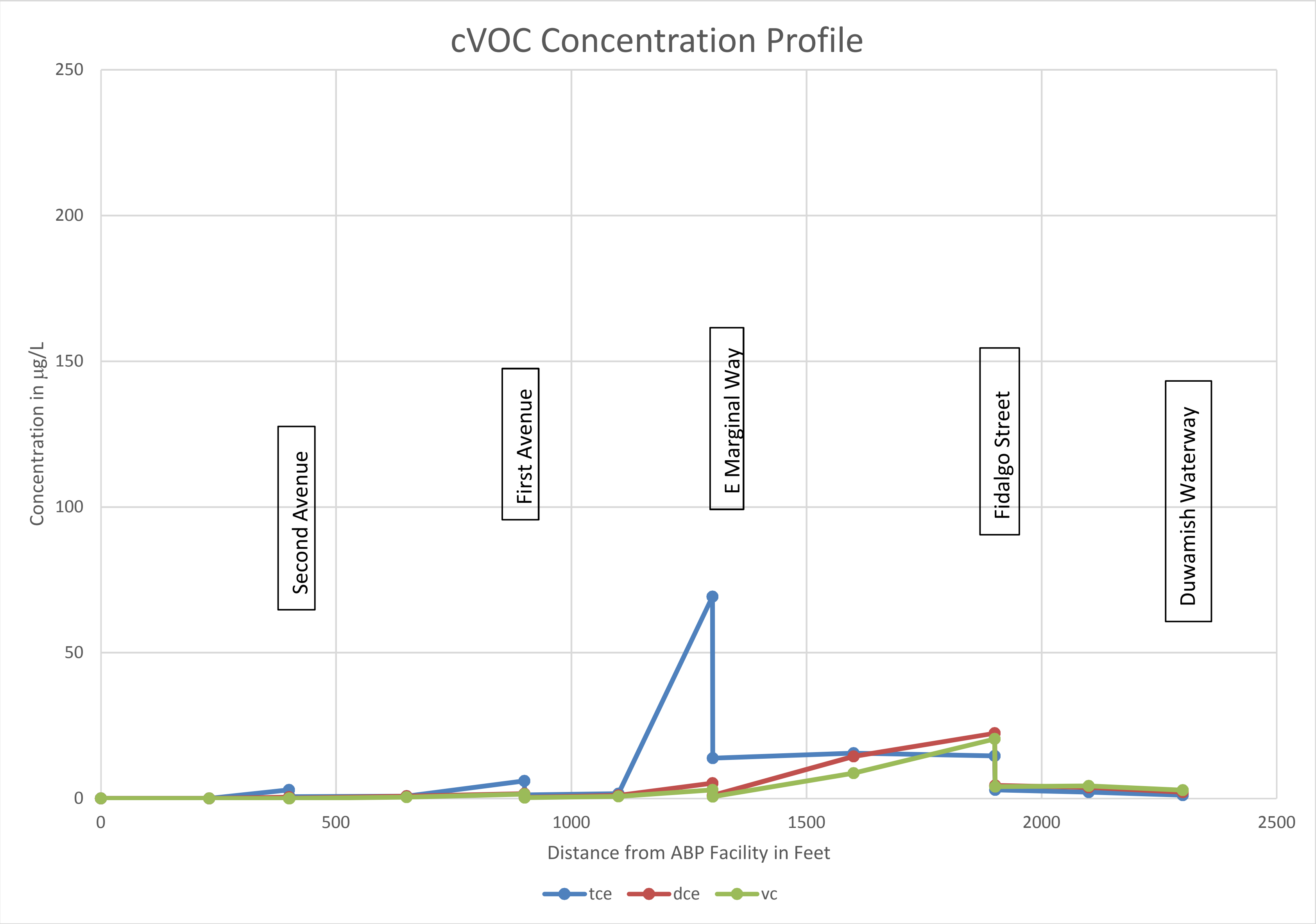

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Figure C-13
Treat All ROWs, ABP Source Removal, T = 20 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

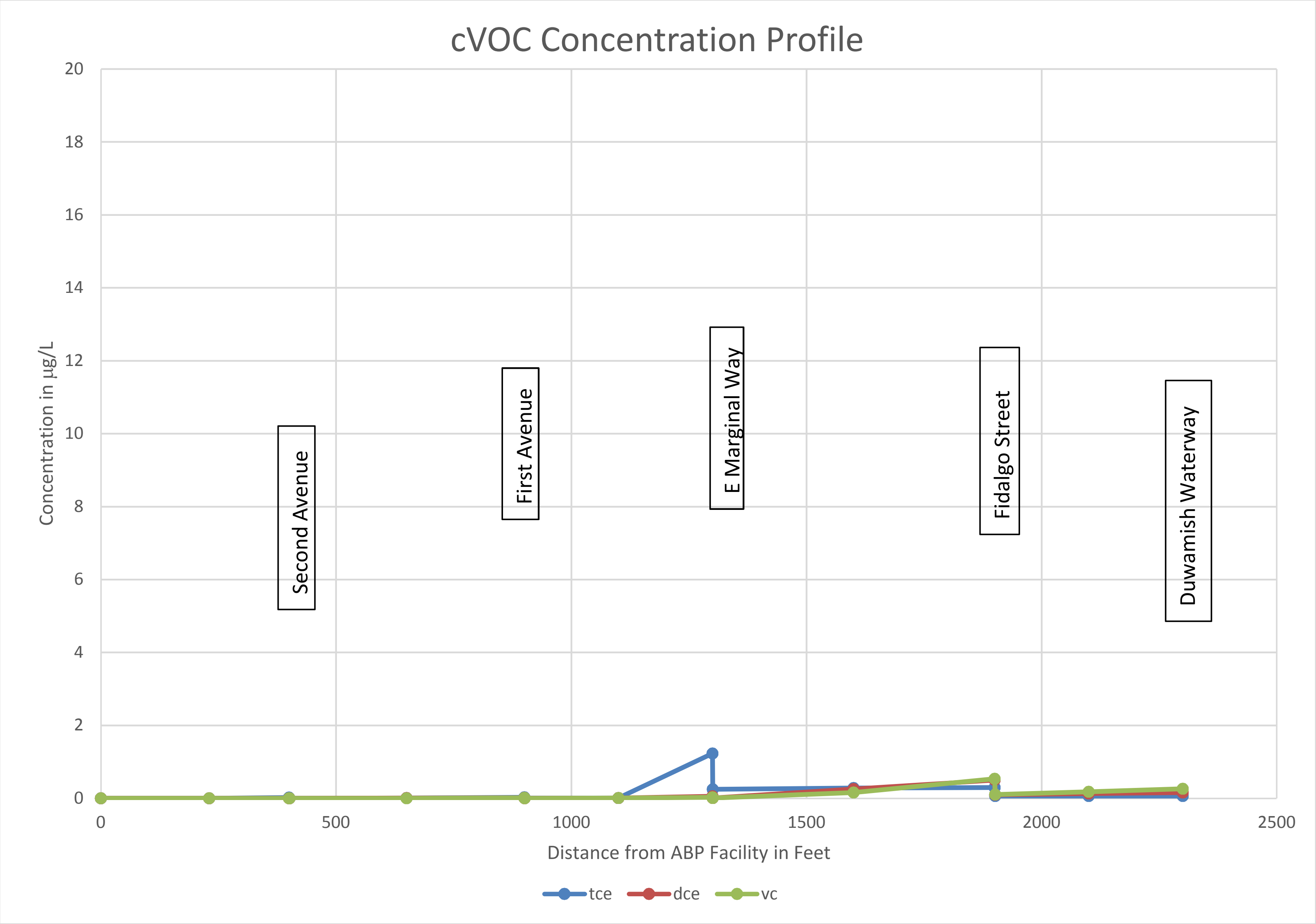

Figure C-14

Treat All ROWs, ABP Source Removal, T = 40 Years

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SU1 Feasibility Study

West of Fourth, Site Unit 1, Seattle, Washington

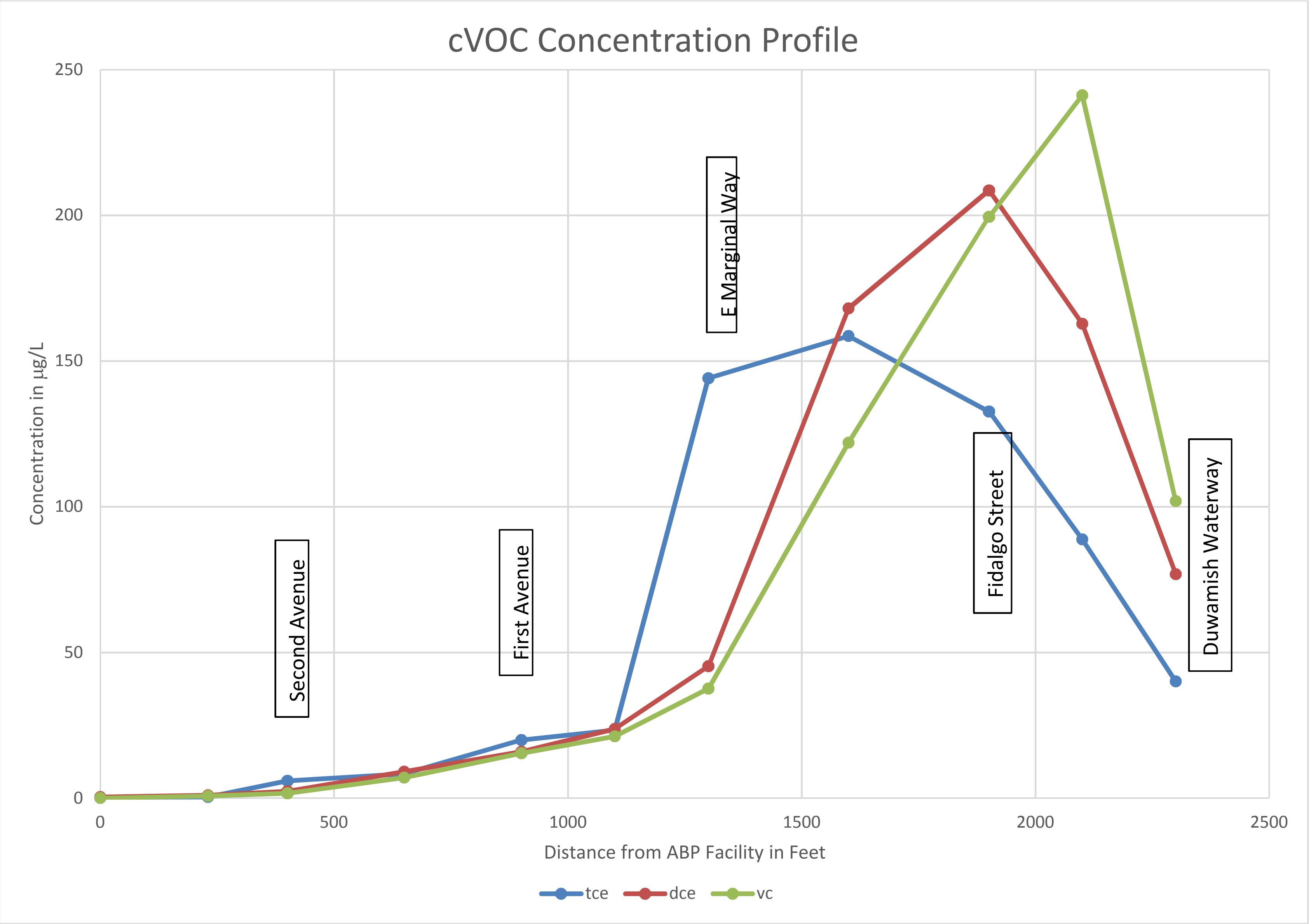

Figure C-15
Source Treatment at ABP Facility, T = 20 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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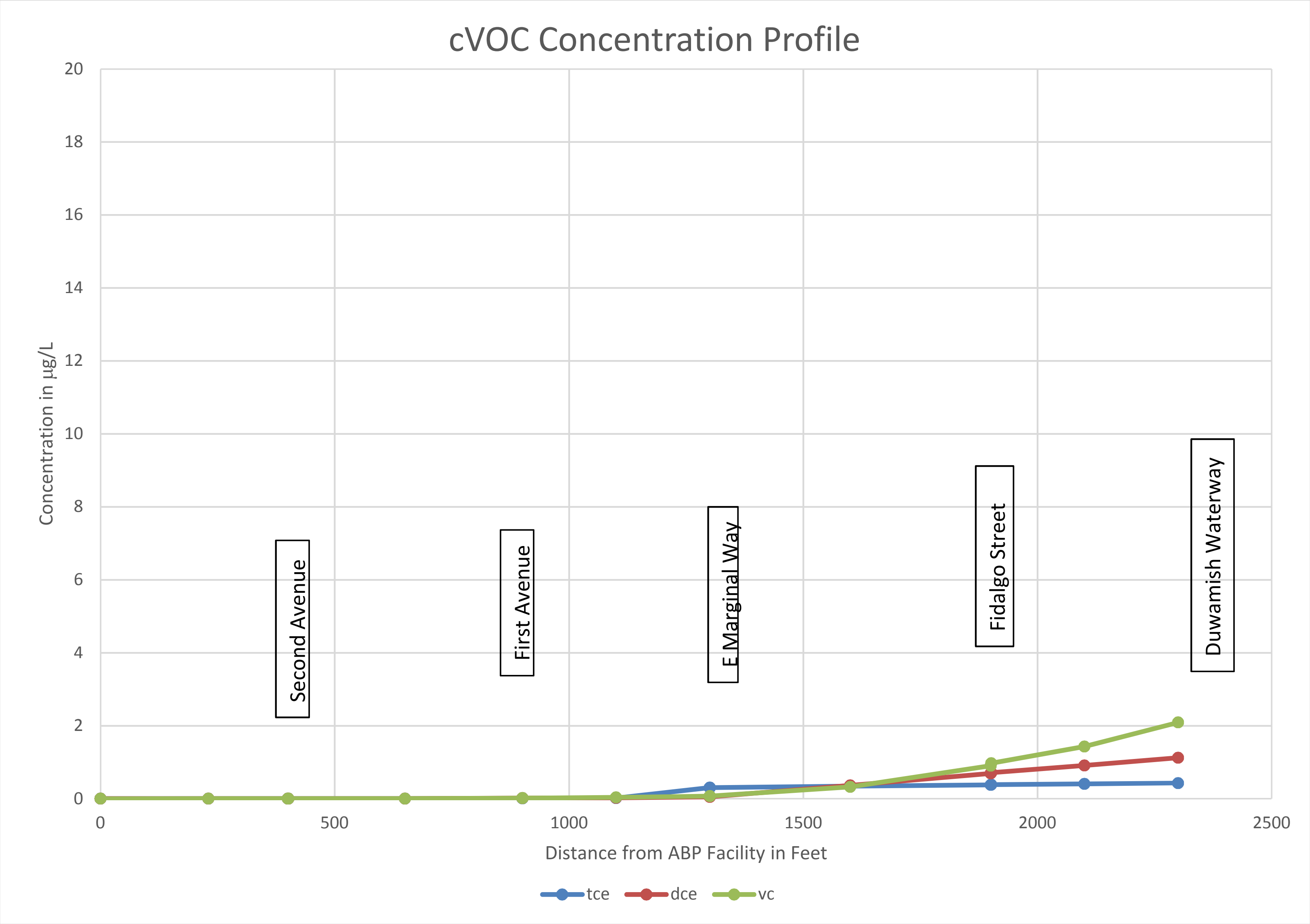

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Figure C-16
Source Treatment at ABP Facility, T = 50 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

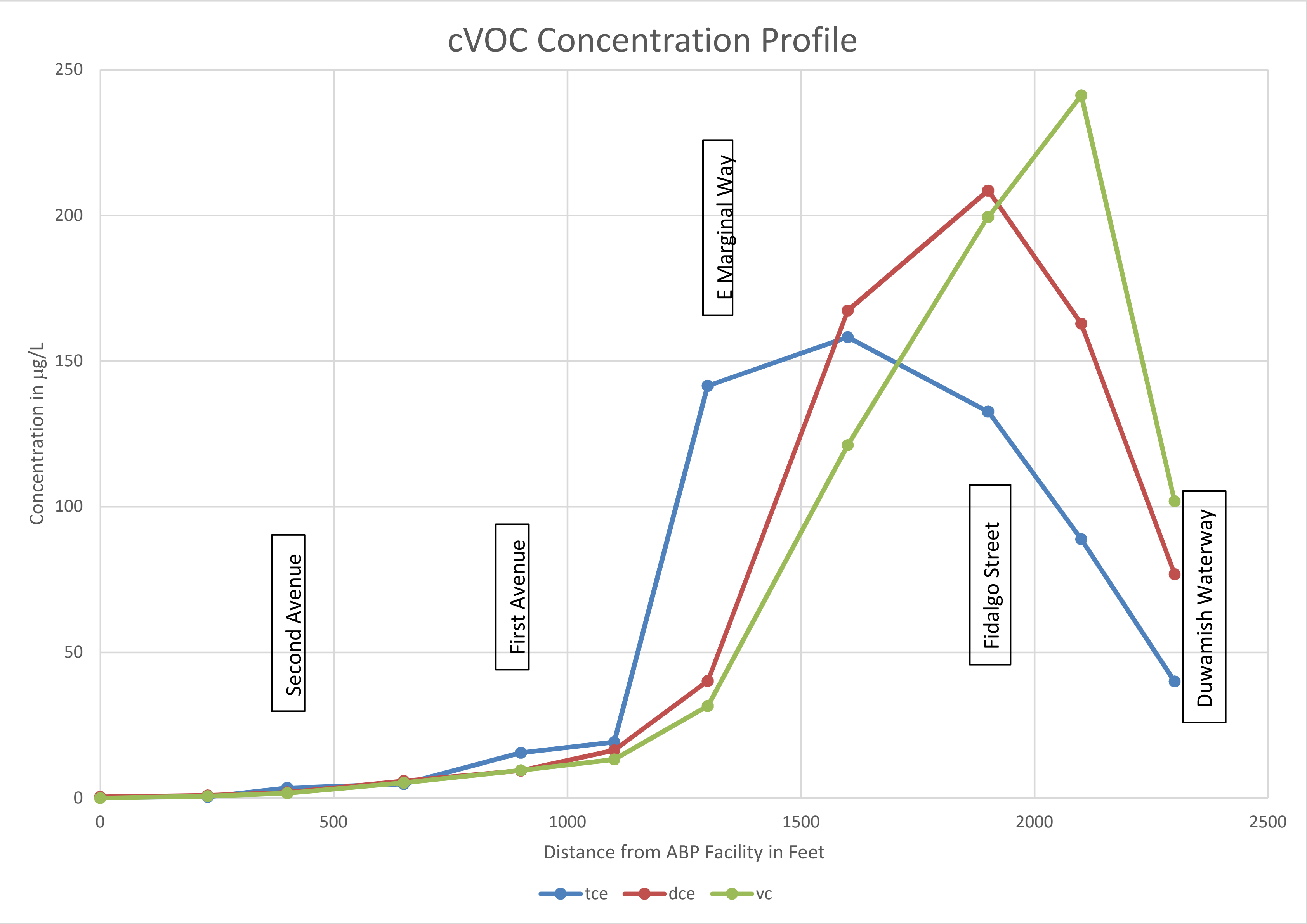

Figure C-17

Treat ABP Source ROWs, 220 Findlay, T = 20 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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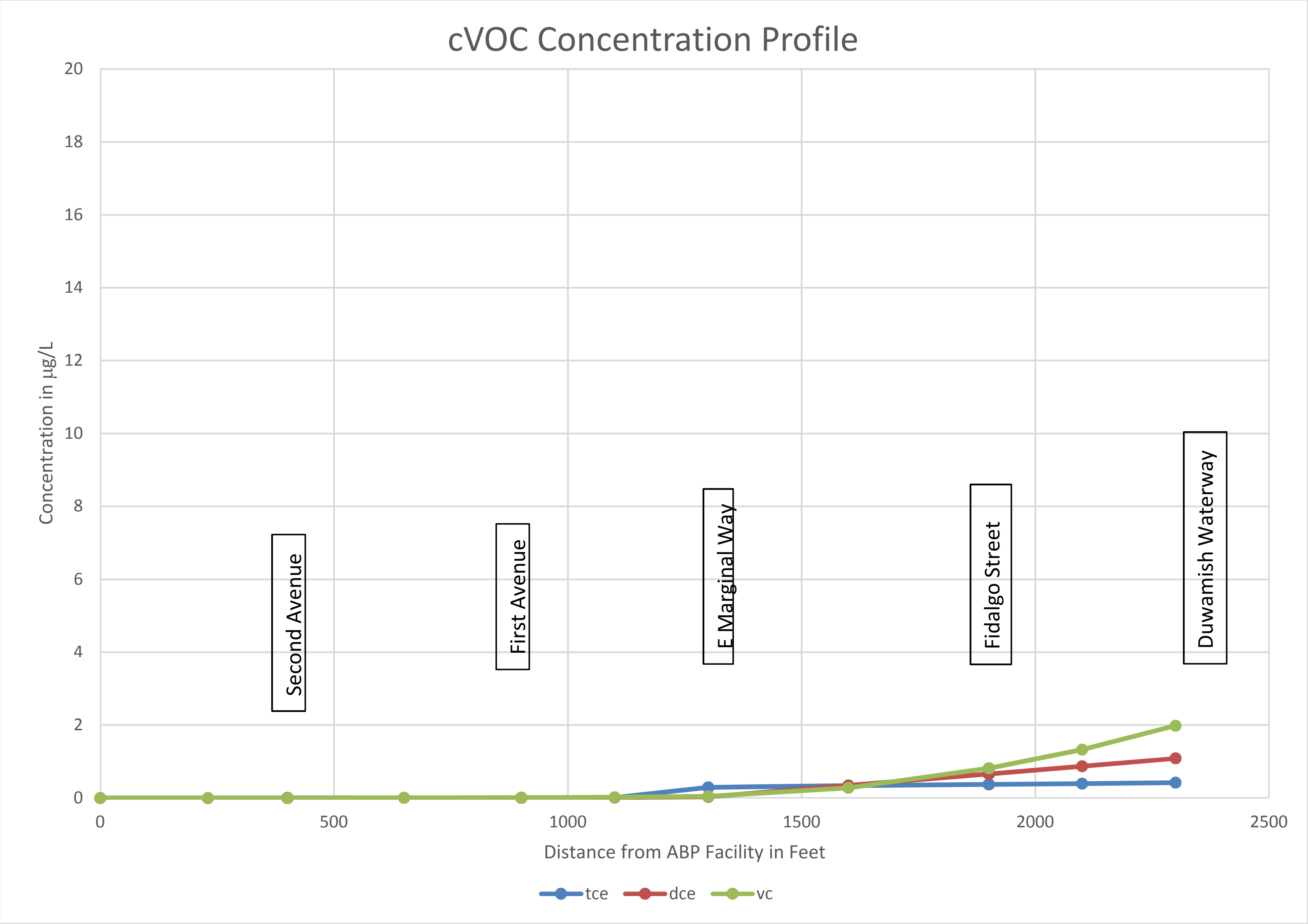

Figure C-18

Treat ABP Source ROWs, 220 Findlay, T = 50 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

Aspect Consulting
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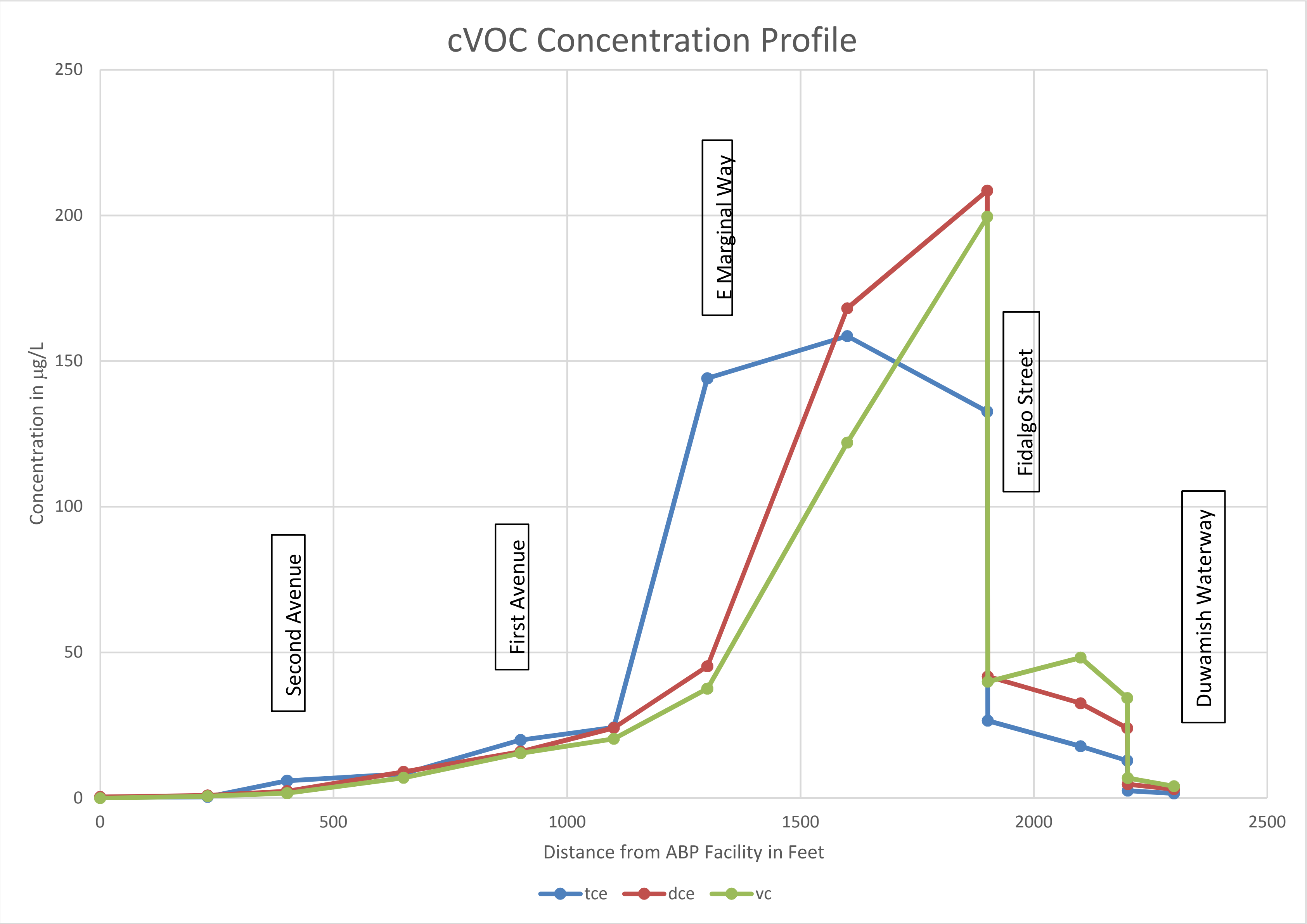

Figure C-19

ABP Source, Fidalgo, Shoreline Sparge, T = 20 Years

SU1 Feasibility Study

West of Fourth, Site Unit 1, Seattle, Washington

Aspect Consulting

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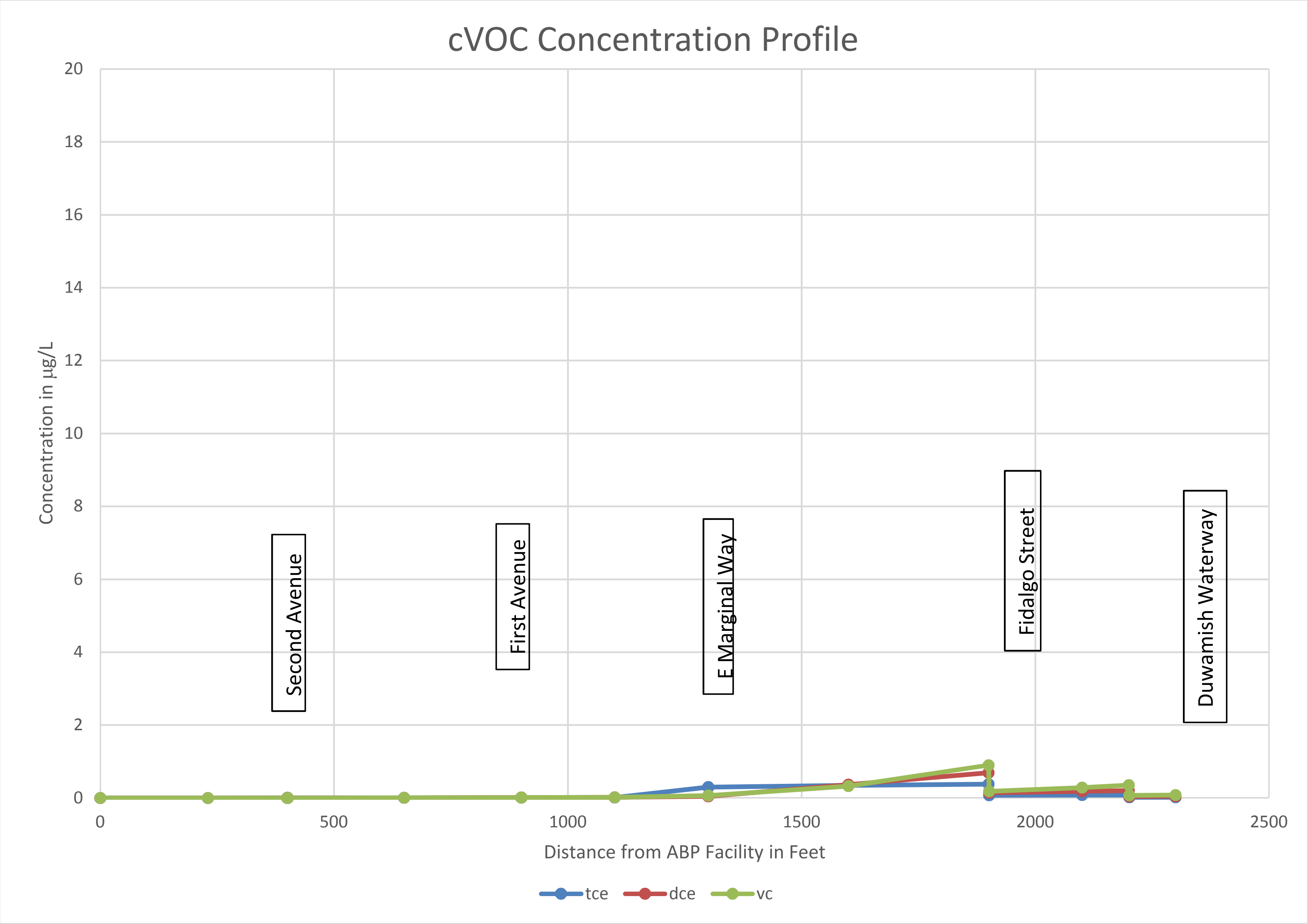

Figure C-20

ABP Source, Fidalgo, Shoreline Sparge, T = 50 Years

SU1 Feasibility Study
West of Fourth, Site Unit 1, Seattle, Washington

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APPENDIX D

Site Unit 1 Remediation Scenarios Modeling, Anchor QEA Memorandum

ANCHOR QEA

421 SW Sixth Avenue, Suite 750
Portland, Oregon 97204
Phone 503.688.5057
www.anchorqea.com

DRAFT MEMORANDUM

To:	Dana Cannon, Aspect Consulting	**Date:**	August 5, 2016
From:	Masa Kanematsu, Ph.D., and Dimitri Vlassopoulos, Ph.D., Anchor QEA, LLC	**Project:**	140204-01.01
Re:	Site Unit 1 Remediation Scenarios Modeling		

This memorandum presents the results of reactive transport modeling performed to evaluate the effectiveness and cleanup timeframes of selected remedial alternatives being considered to address the nickel plume originated from past release(s) of acidic metals plating solutions at the Art Brass Plating facility. The following two remediation scenarios were modeled: 1) source area pH neutralization; and 2) source area removal.

MODELING METHODS

The reactive transport model was developed using the numerical groundwater flow and reactive transport simulator PHAST (Parkhurst et al. 2010). Detailed modeling methods and model configuration were described in the Site Unit 1 Geochemical Fate and Transport Evaluation Technical Memorandum (Anchor QEA 2016). Modeling approaches to simulate the two remediation scenarios are explained in the following sections.

For remedial alternative model simulations, it was assumed that air sparging was discontinued and redox conditions in the source area returned to ambient. Hydraulic effects from solidification of soil in the source area were also assumed to be insignificant. It should be noted that this simplifying assumption may affect the results (e.g., elevated concentrations could persist longer than predicted in areas downgradient of the solidified source zone where groundwater flushing may be reduced).

For VOCs, remedial approaches in the source area such as enhanced anaerobic bioremediation, in-situ chemical reduction using zero-valent iron, and in-situ chemical oxidation are being considered. Implementing any of these remedial actions for 10 to 20 years to address VOC contamination is unlikely to have a significant or lasting impact on the fate of the plating metals plume. Enhanced anaerobic bioremediation is expected to produce sulfide, which would drive the precipitation of sulfide solids of plating metals. Injected zero-valent iron will be quickly oxidized by reacting with VOCs and natural organic matter (NOM) and transform to iron oxides, which adsorb plating metals. Although in-situ chemical oxidation may mobilize plating metals by oxidizing metal sulfides in the source area, the metals in the oxidized groundwater in the source area are expected to attenuate downgradient due to dispersion and reactions with sulfide minerals and NOM.

The potential impact of pump-and-treat (P&T) on restoration time frame is limited. In the base case scenario (natural attenuation), nickel mass in the dissolved phase within the source area is about only about 1 percent of that in solid phase. Removing plating metals by groundwater extraction would be very inefficient and dissolved nickel concentrations would not be expected to decrease until nickel-bearing solid phases present in the aquifer are completely dissolved. Therefore, P&T would not be expected to significantly reduce the overall restoration time frame.

Source Area Removal

In the model scenarios presented in the Site Unit 1 Geochemical Fate and Transport Evaluation Technical Memorandum (Anchor QEA 2016), the source area is defined in the model as a zone 200 feet long by 25 feet deep along the groundwater flow path. For the source area removal alternative scenario, the portion of the source area accessible for removal was assumed to be 80 feet long by 25 feet deep, leaving a residual source zone 120 feet long by 25 feet deep (Figure 1). Removal of a portion of the source area is expected to reduce nickel concentrations downgradient. For this scenario, both adsorption and sulfate reduction reactions were included. Sulfate reduction kinetics were modeled using the Monod equation with a maximum rate $R_{max} = 1.6\times10^{-9}$ mol L^{-1} s^{-1}. This value is 10 times lower than the value reported by Amos et al. (2004). Except for the length of the source area, all other parameters remain unchanged.

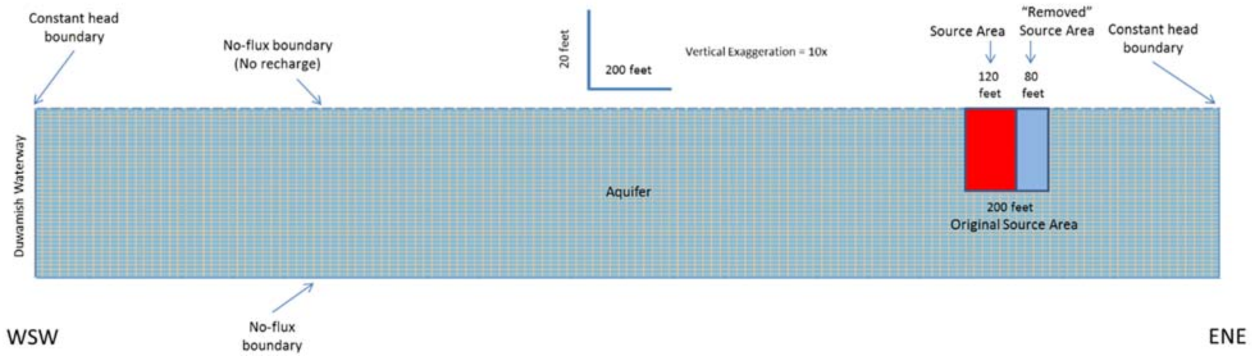

Figure 1. Model domain, initial and boundary conditions for the source area removal scenario.

Source Area pH Neutralization

For this scenario, a sodium hydroxide solution is injected into the source area to bring acidic pH (pH 4) to the background level (i.e., pH 7). The timescale for pH neutralization is assumed to be negligible compared to the simulation time (1,000 years). The equilibrium aqueous and solid phase chemistry resulting from the pH neutralization process was calculated using PHREEQC. According to the PHREEQC calculation, iron oxides (ferrihydrite, goethite, and magnetite) are supersaturated and precipitate from groundwater, adsorbing much of the dissolved nickel immediately following pH neutralization. For this scenario both adsorption and sulfide precipitation reactions were included, with the same sulfate reduction rate as in the source area removal scenario. Except for the solution chemistry in the source area, all other parameters remain unchanged.

MODEL RESULTS

Natural Attenuation

For comparison, results of the natural attenuation scenario (Anchor QEA 2016) are shown in Figure 2. The model-predicted dissolved nickel concentrations and extent of the plume exceeding the cleanup level of 0.0082 mg/L are shown for simulation times of 1, 10, 100, and 1,000 years. The nickel plume is attenuated by sulfide mineral (millerite) precipitation in addition to adsorption to iron oxides and, as a result, nickel transport in downgradient groundwater is very limited. The plume is predicted to remain essentially stationary and dissolved nickel concentrations decrease over time. Nickel concentrations are predicted to reach the cleanup level of 0.0082 mg/L off property within approximately 50 years.

However, onsite nickel concentrations are predicted to remain higher than the cleanup level for at least 1,000 years.

The minimum groundwater pH within the model domain is predicted to increase to 4.6, 6.2, 6.5, 6.6, and 6.7 after 1, 10, 20, 50, and 100 years, respectively. The simulation results indicate that the acid plume is effectively attenuated by dispersion and reaction with aquifer minerals. This is because the acid neutralizing capacity of aquifer soil, which is sufficient to attenuate the acidity of the entire plume within a few feet. Therefore, although hypothetical future releases of acidic solution could potentially remobilize plating metals near the source area, concentrations would be expected to be attenuated within a few feet downgradient.

Dissolved concentrations of zinc, copper, and cadmium, are also affected by acid neutralization, sorption onto metal oxides/hydroxides, and metal sulfide precipitation. Zinc, copper, and cadmium have a higher affinity for adsorption to iron oxides, and their sulfides are less soluble than nickel sulfide. Concentrations of these plating metals are therefore expected to decrease to an even greater extent than nickel due to sorption and precipitation reactions. Since the plating metal plume will be attenuated near the source area for the natural attenuation scenario as well as the remediation scenarios as discussed below, the plating metals will not exceed MCLs at the waterway.

Source Area Removal

The model-predicted dissolved nickel concentrations and extent of the plume exceeding 0.0082 mg/L are shown for simulation times of 0, 1, 10, 100, and 1,000 years in Figure 3. For the source removal scenario, the fate of the nickel plume is very similar to the natural attenuation scenario, and the dissolved nickel plume does not expand beyond the source area due to millerite precipitation. After 1,000 years, the maximum nickel concentration in the plume has decreased to 0.011 mg/L, just slightly above the cleanup level.

Source Area pH Neutralization

The model-predicted dissolved nickel concentrations and extent of the plume exceeding 0.0082 mg/L are shown for simulation times of 0, 1, 10, 100, and 1,000 years in Figures 4 and 5. For this scenario, a large portion of initially dissolved nickel present in the source area is adsorbed on iron oxides due to the increase in pH. The nickel plume is rapidly attenuated following pH neutralization. Nickel concentrations are predicted to not exceed the cleanup level of 0.0082 mg/L offsite shortly after application and reach the cleanup level onsite property in 280 years. Source area pH neutralization accelerates the reduction of nickel concentrations onsite and prevents further migration of nickel offsite.

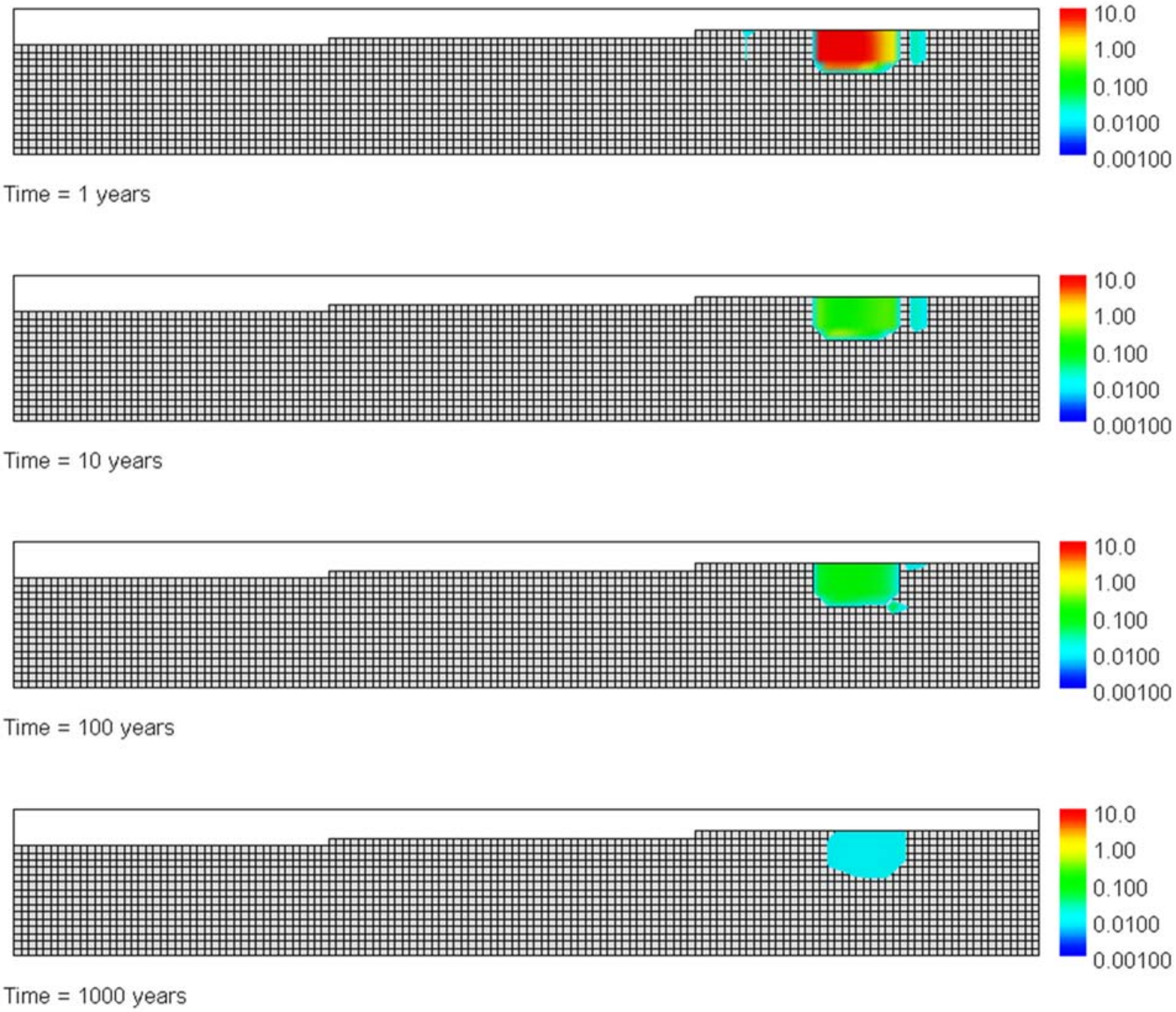

Figure 2. Modeled dissolved nickel plume at 1, 10, 100, and 1,000 years simulation time for the natural attenuation scenario. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

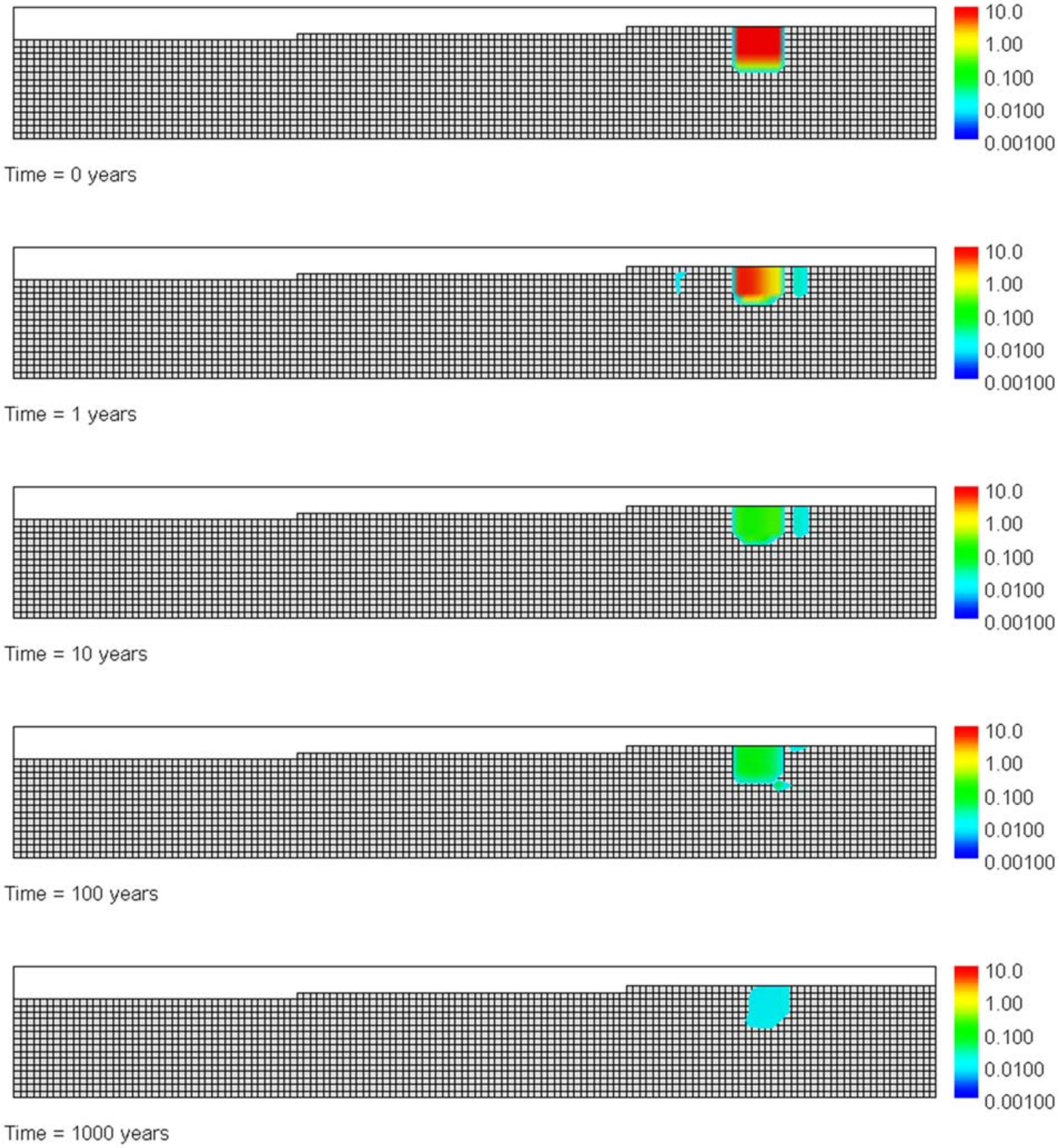

Figure 3. Modeled dissolved nickel plume for the source area removal scenario at 1, 10, 100, and 1,000 years simulation time. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

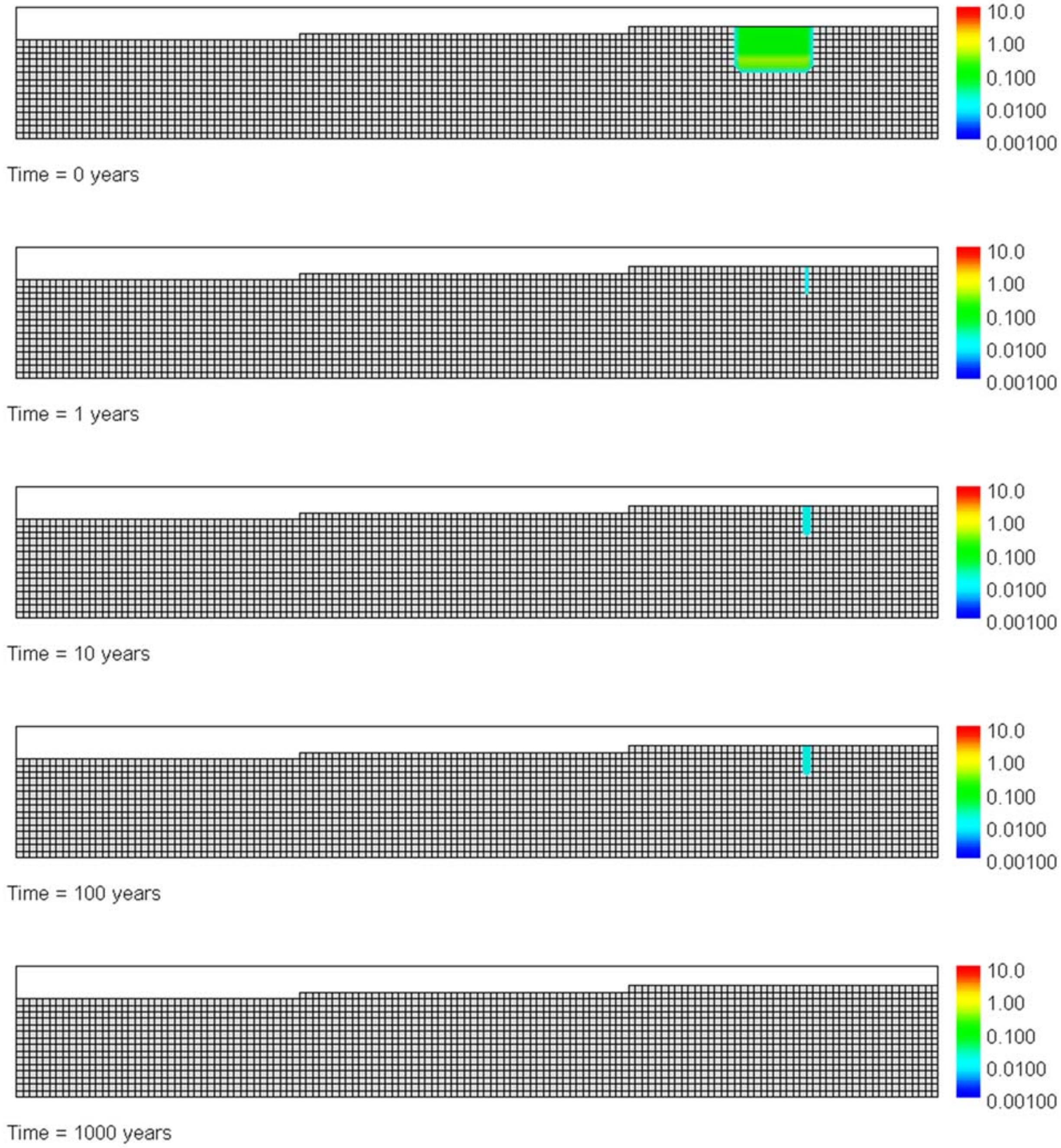

Figure 4. Modeled dissolved nickel plume for the pH neutralization scenario at simulation times of 0 (i.e. initial), 1, 10, 100, and 1,000 years. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth.

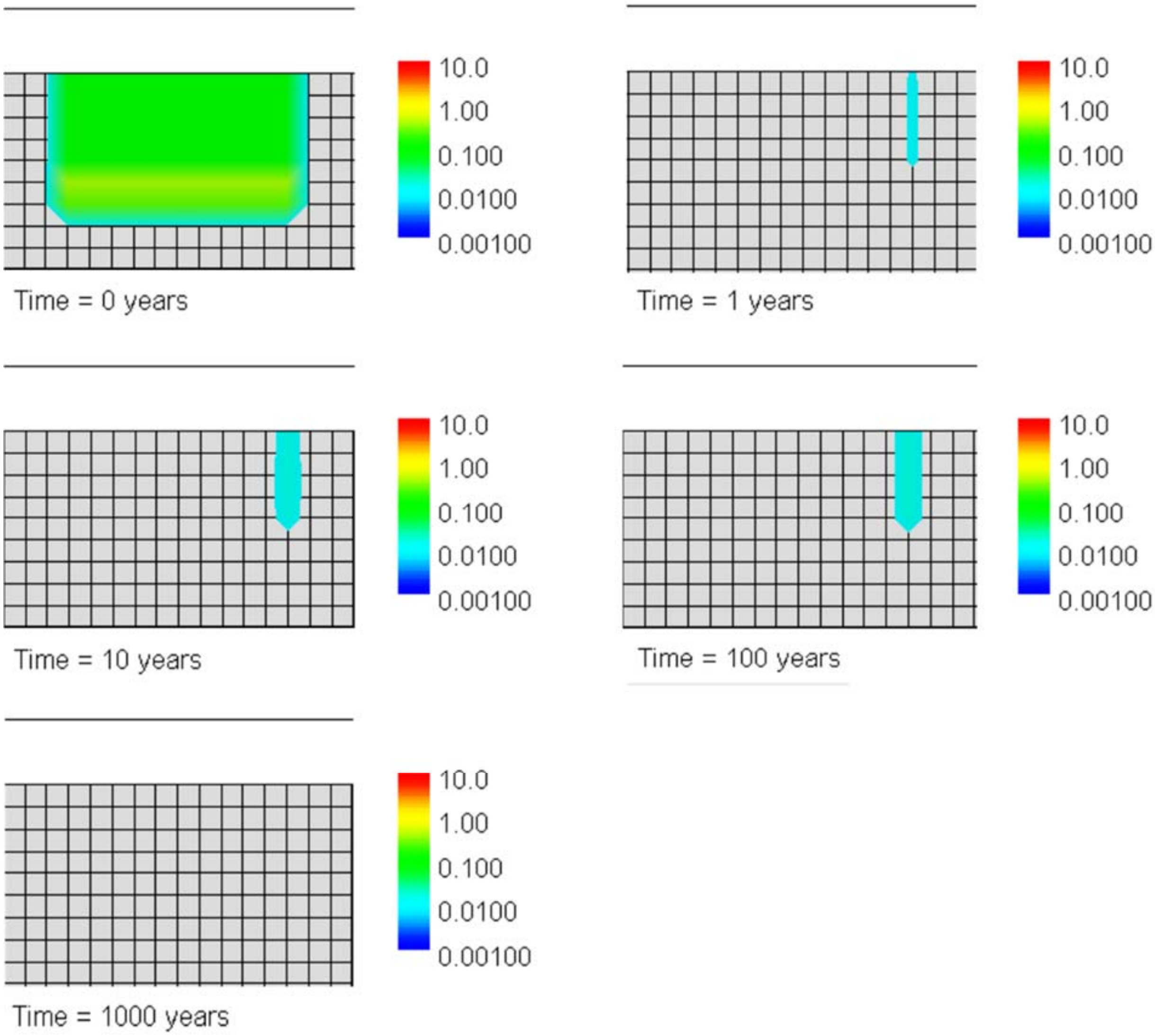

Figure 5. Detail view in the vicinity of the source area in Figure 4. Concentration scale is in mg/L. Plume boundary is defined by the 0.0082 mg/L isopleth. Nickel concentrations in the source area plume are predicted to be reduced below the cleanup level of 0.0082 mg/L wihtin 280 years.

REFERENCES

Amos, R.T., U.L. Mayer, D.W. Blowes, and C.J. Ptacek, 2004. Reactive transport modeling of column experiments for the remediation of acid mine drainage. *Environmental Science and Technology* 38(11):3131-3138.

Anchor QEA, 2016. Site Unit 1 Geochemical Fate and Transport Evaluation Technical Memorandum. January 25.

Parkhurst, D.L., K.L. Kipp, and S.R. Charlton, 2010. *PHAST Version 2—A Program for Simulating Groundwater Flow, Solute Transport, and Multicomponent Geochemical Reactions*: U.S. Geological Survey Techniques and Methods 6–A35, 235 p.

APPENDIX E

Alternatives 1-9 Detailed Cost Estimates

Table E-1 - Cost Estimate: Alternative 1 - Source pH neutralization, MNA, MNA

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

Site: Art Brass Plating
Remedial Action Description: Source pH neutralization, MNA, MNA
Cost Estimate Accuracy: Feasibility Level (+50/-30 percent)

Key Assumptions:
Future costs are adjusted to present value using a discount rate of 1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	10	yr	$ 9,000	$ 76,262	10 wells annually, years 6-15
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	45	yr	$ 9,000	$ 244,992	10 wells annually, years 11-55
Biannual long term groundwater monitoring (MNA) after year 10	22	yr	$ 18,000	$ 239,318	20 additional wells biannually, years 11-55
Confirmation groundwater sampling	1	ls	$ 108,000	$ 44,399	30 wells quarterly @ 56 years
Confirmation soil sampling	1	ls	$ 25,000	$ 10,278	vadose zone soil @ 56 years
Well decommissioning	125	ea	$ 500	$ 25,694	65 monitoring, 28 sparge, 5 sve, 24 pH @ 56 years
Subtotal				*$ 1,060,301*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	15	yr	$ 2,500	$ 33,106	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	25	yr	$ 2,500	$ 51,180	@ 220 Findlay and 218 Findlay
VI assessment program	25	yr	$ 2,500	$ 51,180	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 13,449	@ 25 years
Subtotal				*$ 201,576*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	8%		$ 1,806,045	$ 144,484	percentage of captial, O&M, and monitoring costs
Remedial design	15%		$ 625,971	$ 93,896	percentage of captial costs
Construction management	10%		$ 625,971	$ 62,597	percentage of captial costs
Subtotal				*$ 300,976*	
Subtotal				$ 2,107,021	
Tax	9.5%			$ 59,467	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 649,946	10% bid + 20% scope
Total Estimated Cost				**$ 2,800,000**	

Table E-2 - Cost Estimate: Alternative 2 - Source pH neutralization, MNA, Downgradient ISCR @ Fidalgo

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

Site:	Art Brass Plating
Remedial Action Description:	Source pH neutralization, MNA, Downgraident ISCR @ Fidalgo
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:
Future costs are adjusted to present value using a discount rate of 1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Downgradient Area ISCR Treatment - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 685,479	$ 34,274	percentage of captial costs below
ISCR direct push injection	15	days	$ 3,000	$ 167,955	300 foot treatment line, 30 points, 20-40 feet bgs, 2 points/day, repeats every 10 years for 40 years (4x) based on estimated time to meet RLs at Fidalgo (45 years)
ISCR amendment	1	ls	$ 138,660	$ 517,524	scaled up from vendor estimate, repeats every 10 years for 40 years
Subtotal				*$ 784,753*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	10	yr	$ 9,000	$ 76,262	10 wells annually, years 6-15
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	40	yr	$ 9,000	$ 244,219	10 wells annually, years 6-45
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	40	yr	$ 9,000	$ 225,585	10 wells annually, years 11-50
Biannual long term groundwater monitoring (MNA) after year 10	20	yr	$ 18,000	$ 223,795	20 additional wells biannually, years 11-50
Confirmation groundwater sampling	1	ls	$ 108,000	$ 48,067	30 wells quarterly @ 51 years
Confirmation soil sampling	1	ls	$ 25,000	$ 11,127	vadose zone soil @ 51 years
Well decommissioning	125	ea	$ 500	$ 27,816	65 monitoring, 28 sparge, 5 sve, 24 pH @ 51 years
Subtotal				*$ 1,447,901*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	15	yr	$ 2,500	$ 33,106	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	25	yr	$ 2,500	$ 51,180	@ 220 Findlay and 218 Findlay
VI assessment program	25	yr	$ 2,500	$ 51,180	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 13,449	@ 25 years
Subtotal				*$ 201,576*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	6%		$ 2,978,397	$ 178,704	percentage of captial, O&M, and monitoring costs
Remedial design	12%		$ 1,412,846	$ 169,542	percentage of captial costs
Construction management	8%		$ 1,412,846	$ 113,028	percentage of captial costs
Subtotal				*$ 461,273*	
Subtotal				$ 3,439,670	
Tax	9.5%			$ 134,220	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,072,167	10% bid + 20% scope
Total Estimated Cost				**$ 4,600,000**	

Table E-3 - Cost Estimate: Alternative 3 - Source pH neutralization+EAnB, Downgradient EAnB (PRB @ Fidalgo)

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

Site:	Art Brass Plating
Remedial Action Description:	Source pH neutralization+EAnB, Downgraident EAnB (PRB @ Fidalgo)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of 1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Source Area EAnB Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 325,673	$ 16,284	percentage of captial costs below
EAnB injection well installation	24	ea	$ 3,000	$ 72,000	4 inch wells, 20 feet deep
soil cuttings mgmt and disposal	48	drum	$ 100	$ 4,800	1 drum/10 feet of well, assumes contained it, bulk disposal
decon and development water disposal	12	drum	$ 250	$ 3,000	0.5 drum/well, assume F-listed waste
EAnB amendments	1	ls	$ 173,873	$ 173,873	Based on Regenesis estimate, incl. 3DMe/culture/plumestop
Application cost	1	ls	$ 72,000	$ 72,000	Based on Regenesis estimate
Annual application of commodity electron donor	15	year	$ 10,000	$ 132,423	engineers estimate, based on time to meet cleanup levels at ABP facility
Subtotal				*$ 539,379*	
Downgradient Area EAnB Treatment - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 991,586	$ 900	percentage of captial costs below
EAnB injection well installation	16	ea	$ 4,000	$ 64,000	4 inch wells, 40 feet deep, 20 feet on-center, 300 foot length
soil cuttings mgmt and disposal	64	drum	$ 100	$ 6,400	1 drum/10 feet of well, assumes contained it, bulk disposal
decon and development water disposal	16	drum	$ 250	$ 4,000	1 drum/well, assume F-listed waste
EAnB amendments (year 1)	1	ls	$ 250,534	$ 250,534	Based on Regenesis estimate, incl. plumestop/HRC/culture
Application cost (year 1)	1	ls	$ 103,000	$ 103,000	Based on Regenesis estimate
EAnB amendments (year 21)	1	ls	$ 167,910	$ 120,312	Based on Regenesis estimate, incl. plumestop/HRC/culture
Application cost (year 21)	1	ls	$ 61,000	$ 43,708	Based on Regenesis estimate
EAnB amendments (year 41)	1	ls	$ 112,500	$ 58,683	Based on Regenesis estimate, incl. plumestop/HRC/culture
Application cost (year 41)	1	ls	$ 42,000	$ 21,908	Based on Regenesis estimate
Annual application of commodity electron donor	45	year	$ 10,000	$ 319,041	engineers estimate, based on estimated time to meet RLs at Fidalgo (45 years)
Subtotal				*$ 1,057,486*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	5	yr	$ 9,000	$ 39,644	10 wells annually, years 6-10
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	40	yr	$ 9,000	$ 244,219	10 wells annually, years 6-45
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	40	yr	$ 9,000	$ 225,585	10 wells annually, years 11-50
Biannual long term groundwater monitoring (MNA) after year 10	20	yr	$ 18,000	$ 223,795	20 additional wells biannually, years 11-50
Confirmation groundwater sampling	1	ls	$ 108,000	$ 48,067	30 wells quarterly @ 51 years
Confirmation soil sampling	1	ls	$ 25,000	$ 11,127	vadose zone soil @ 51 years
Well decommissioning	165	ea	$ 500	$ 36,718	65 monitoring, 28 sparge, 5 sve, 24 pH, 43 EAnB @ 51 years
Subtotal				*$ 1,420,183*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	10	yr	$ 2,500	$ 22,934	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 14,560	@ 20 years
Subtotal				*$ 175,158*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	6%		$ 3,736,373	$ 224,182	percentage of captial, O&M, and monitoring costs
Remedial design	12%		$ 2,234,971	$ 268,197	percentage of captial costs
Construction management	8%		$ 2,234,971	$ 178,798	percentage of captial costs
Subtotal				*$ 671,177*	
Subtotal				$ 4,407,550	
Tax	9.5%			$ 212,322	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,385,962	10% bid + 20% scope
Total Estimated Cost				**$ 6,000,000**	

Table E-4 - Cost Estimate: Alternative 4 - Source pH neutralization+ISCR, Downgradient ISCR (PRB @ Fidalgo)

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

Site:	Art Brass Plating
Remedial Action Description:	Source pH neutralization+ISCR, Downgraident ISCR (PRB @ Fidalgo)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)
Key Assumptions:	
Future costs are adjusted to present value using a discount rate of	1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Source Area ISCR Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 268,243	$ 13,412	percentage of captial costs below
ISCR direct push injection	38	days	$ 3,000	$ 114,000	112 points, 5-20 feet bgs, 3 points/day
ISCR amendment	1	ls	$ 154,243	$ 154,243	scaled from vendor estimate
Subtotal				*$ 346,655*	
Downgradient Area ISCR Treatment - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 685,479	$ 34,274	percentage of captial costs below
ISCR direct push injection	15	days	$ 3,000	$ 167,955	300 foot treatment line, 30 points, 20-40 feet bgs, 2 points/day, repeats every 10 years for 40 years (4x) based on estimated time to meet RLs at Fidalgo (45 years)
ISCR amendment	1	ls	$ 138,660	$ 517,524	scaled up from vendor estimate, repeats every 10 years for 40 years
Subtotal				*$ 784,753*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	5	yr	$ 9,000	$ 39,644	10 wells annually, years 6-10
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	40	yr	$ 9,000	$ 244,219	10 wells annually, years 6-45
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	40	yr	$ 9,000	$ 225,585	10 wells annually, years 11-50
Biannual long term groundwater monitoring (MNA) after year 10	20	yr	$ 18,000	$ 223,795	20 additional wells biannually, years 11-50
Confirmation groundwater sampling	1	ls	$ 108,000	$ 48,067	30 wells quarterly @ 51 years
Confirmation soil sampling	1	ls	$ 25,000	$ 11,127	vadose zone soil @ 51 years
Well decommissioning	125	ea	$ 500	$ 27,816	65 monitoring, 28 sparge, 5 sve, 24 pH @ 51 years
Subtotal				*$ 1,411,282*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	10	yr	$ 2,500	$ 22,934	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 14,560	@ 20 years
Subtotal				*$ 175,158*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	6%		$ 3,262,014	$ 195,721	percentage of captial, O&M, and monitoring costs
Remedial design	12%		$ 1,760,612	$ 211,273	percentage of captial costs
Construction management	8%		$ 1,760,612	$ 140,849	percentage of captial costs
Subtotal				*$ 547,843*	
Subtotal				$ 3,809,857	
Tax	9.5%			$ 167,258	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,193,135	10% bid + 20% scope
Total Estimated Cost				**$ 5,200,000**	

Table E-5 - Cost Estimate: Alternative 5 - Source pH neutralization+ISCR, Downgradient EAnB (PRB @ Fidalgo)

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

Site:	Art Brass Plating
Remedial Action Description:	Source pH neutralization+ISCR, Downgraident EAnB (PRB @ Fidalgo)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of	1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Source Area ISCR Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 268,243	$ 13,412	percentage of captial costs below
ISCR direct push injection	38	days	$ 3,000	$ 114,000	112 points, 5-20 feet bgs, 3 points/day
ISCR amendment	1	ls	$ 154,243	$ 154,243	scaled from vendor estimate
Subtotal				*$ 346,655*	
Downgradient Area EAnB Treament - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 759,052	$ 37,953	percentage of captial costs below
EAnB injection well installation	16	ea	$ 4,000	$ 64,000	4 inch wells, 40 feet deep, 20 feet on-center, 300 foot length
soil cuttings mgmt and disposal	64	drum	$ 100	$ 6,400	1 drum/10 feet of well, assumes contained it, bulk disposal
decon and development water disposal	16	drum	$ 250	$ 4,000	1 drum/well, assume F-listed waste
EAnB amendments (year 1)	1	ls	$ 250,534	$ 18,000	Based on Regenesis estimate, incl. plumestop/HRC/culture
Application cost (year 1)	1	ls	$ 103,000	$ 103,000	Based on Regenesis estimate
EAnB amendments (year 21)	1	ls	$ 167,910	$ 120,312	Based on Regenesis estimate, incl. plumestop/HRC/culture
Application cost (year 21)	1	ls	$ 61,000	$ 43,708	Based on Regenesis estimate
EAnB amendments (year 41)	1	ls	$ 112,500	$ 58,683	Based on Regenesis estimate, incl. plumestop/HRC/culture
Application cost (year 41)	1	ls	$ 42,000	$ 21,908	Based on Regenesis estimate
Periodic application of commodity electron donor	45	year	$ 10,000	$ 319,041	engineers estimate, based on estimated time to meet RLs at Fidalgo (45 years)
Subtotal				*$ 862,005*	
Sparge Curtain at Waterway					
Pilot testing for sparge well design	1	ls	$ 25,000	$ 25,000	
mobilization/demobilization	5%		$ 166,975	$ 8,349	
AS wells	10	day	$ 2,500	$ 25,000	20 x 3/4 inch wells, 40 feet deep, direct push (2 wells/day)
soil cuttings mgmt and disposal	4	drum	$ 200	$ 800	0.2 drum/AS well
decon water and disposal	4	drum	$ 250	$ 1,000	2 drums decon, 2 drums development and purge
well parts	20	ea	$ 750	$ 15,000	valves, gauges, fittings
asphalt cutting	600	lf	$ 2	$ 1,200	rsmeans, 300 ft x 2
trenching for pipe runs	100	bcy	$ 10	$ 1,000	rsmeans, 300 ft trench x 3 ft x 3 ft
trench spoils mgmt and disposal	63	cy	$ 80	$ 5,000	
Perforated SVE piping	300	lf	$ 5	$ 1,500	4 inch perforated piping for vapor containment
AS piping	3,150	lf	$ 1.50	$ 4,725	3/4 inch HDPE pipe
backfill for pipe runs	50	lcy	$ 45	$ 2,250	pea gravel
asphalt replacement	900	sf	$ 5	$ 4,500	rsmeans, 300 ft trench x 3 ft
equipment	1	ls	$ 60,000	$ 60,000	compressor, blower, enclosure, controls, condensate collection
building	1	ls	$ 20,000	$ 20,000	
mechanical/electrical work	1	ls	$ 25,000	$ 25,000	plumbing, power drop, and controls
Subtotal				*$ 200,324*	
Annual Operation and Maintenace of Sparge Curtain					
O&M, incl. monitoring for protectiveness and performance	35	yr	$ 50,000	$ 1,332,041	monitoring/maintenance, condensate disposal, electricity
Lease space for equipment/building	35	yr	$ 7,300	$ 194,478	2 parking spaces @ $10/day
Decommisioning	1	ls	$ 25,000	$ 14,118	@ 36 years
Subtotal				*$ 1,540,637*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	5	yr	$ 9,000	$ 39,644	10 wells annually, years 6-10
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	40	yr	$ 9,000	$ 244,219	10 wells annually, years 6-45
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	40	yr	$ 9,000	$ 225,585	10 wells annually, years 11-50
Biannual long term groundwater monitoring (MNA) after year 10	20	yr	$ 18,000	$ 223,795	20 additional wells biannually, years 11-50
Confirmation groundwater sampling	1	ls	$ 108,000	$ 48,067	30 wells quarterly @ 51 years
Confirmation soil sampling	1	ls	$ 25,000	$ 11,127	vadose zone soil @ 51 years
Well decommissioning	161	ea	$ 500	$ 35,828	65 monitoring, 28 sparge, 5 sve, 24 pH, 16 EAnB, 20 sparge curtain @ 51 years
Subtotal				*$ 1,419,293*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	10	yr	$ 2,500	$ 22,934	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 14,560	@ 20 years
Subtotal				*$ 175,158*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	6%		$ 5,088,238	$ 305,294	percentage of captial, O&M, and monitoring costs
Remedial design	12%		$ 2,060,317	$ 247,238	percentage of captial costs
Construction management	8%		$ 2,060,317	$ 164,825	percentage of captial costs
Subtotal				*$ 717,358*	
Subtotal				$ 5,805,596	
Tax	9.5%			$ 195,730	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,800,398	10% bid + 20% scope
Total Estimated Cost				**$ 7,800,000**	

Table E-6 - Cost Estimate: Alternative 6 - Source pH neutralization+ISCR, Downgradient ISCR (PRBs @ Fidalgo and EMW)

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

Site:	Art Brass Plating
Remedial Action Description:	Source pH neutralization+ISCR, Downgraident ISCR (PRBs @ Fidalgo and EMW)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of	1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Source Area ISCR Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 268,243	$ 13,412	percentage of captial costs below
ISCR direct push injection	38	days	$ 3,000	$ 114,000	112 points, 5-20 feet bgs, 3 points/day
ISCR amendment	1	ls	$ 154,243	$ 154,243	scaled from vendor estimate
Subtotal				*$ 346,655*	
Downgradient Area PRB - E Marginal Way					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 1,872,512	$ 93,626	percentage of captial costs below
ISCR direct push injection	45	days	$ 3,750	$ 540,397	probe rig with injection equipment, 25% applied to standard rate for work in arterial/highway, 450 foot treatment line, 45 injection points, 20-60 feet bgs, 1 points per day, repeats every 10 years for 30 years (3x) based on estimated time to meet RLs at EMW (35 years)
ISCR amendment	1	ls	$ 415,980	$ 1,332,115	scaled up from vendor estimate, repeats every 10 years for 30 years
Subtotal				*$ 2,031,138*	
Downgradient Area ISCR Treatment - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 588,144	$ 29,407	percentage of captial costs below
ISCR direct push injection	15	days	$ 3,000	$ 144,106	300 foot treatment line, 30 points, 20-40 feet bgs, 2 points/day, repeats every 10 years for 30 years (3x) based on estimated time to meet RLs at Fidalgo (35 years)
ISCR amendment	1	ls	$ 138,660	$ 444,038	scaled up from vendor estimate, repeats every 10 years for 30 years
Subtotal				*$ 682,551*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	5	yr	$ 9,000	$ 39,644	10 wells annually, years 6-10
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	30	yr	$ 9,000	$ 196,849	10 wells annually, years 6-35
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	30	yr	$ 9,000	$ 181,830	10 wells annually, years 11-40
Biannual long term groundwater monitoring (MNA) after year 10	15	yr	$ 18,000	$ 180,387	20 additional wells biannually, years 11-40
Confirmation groundwater sampling	1	ls	$ 108,000	$ 56,335	30 wells quarterly @ 41 years
Confirmation soil sampling	1	ls	$ 25,000	$ 13,041	vadose zone soil @ 41 years
Well decommissioning	125	ea	$ 500	$ 32,602	65 monitoring, 28 sparge, 5 sve, 24 pH @ 41 years
Subtotal				*$ 1,291,717*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	10	yr	$ 2,500	$ 22,934	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 14,560	@ 20 years
Subtotal				*$ 175,158*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	5%		$ 5,071,386	$ 253,569	percentage of captial, O&M, and monitoring costs
Remedial design	8%		$ 3,694,334	$ 295,547	percentage of captial costs
Construction management	6%		$ 3,694,334	$ 221,660	percentage of captial costs
Subtotal				*$ 770,776*	
Subtotal				$ 5,842,162	
Tax	9.5%			$ 347,865	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,857,008	10% bid + 20% scope
Total Estimated Cost				**$ 8,000,000**	

Table E-7 - Cost Estimate: Alternative 7 - Source pH neutralization+ISCR, Downgradient ISCR (PRBs @ Fidalgo, EMW, and 1st Ave)

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

Site:	Art Brass Plating
Remedial Action Description:	Source pH neutralization+ISCR, Downgraident ISCR (PRBs @ Fidalgo, EMW, and 1st Ave)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:
Future costs are adjusted to present value using a discount rate of 1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area pH Neutralization					
Pre-design investigation	1	ls	$ 10,000	$ 10,000	engineers estimate
Lab-scale treatablity testing	1	ls	$ 20,000	$ 20,000	engineers estimate
Field-scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
Mobilization/demobilization	5%		$ 432,540	$ 21,627	percentage of captial costs below
Injection well installation	27	ea	$ 3,000	$ 81,000	4 inch wells, 20 feet deep
Soil cuttings mgmt and disposal	54	drum	$ 100	$ 5,400	1 drum/10 feet of well, assumes contained it, bulk disposal
Decon and development water disposal	14	drum	$ 250	$ 3,500	0.5 drum/well, assume F-listed waste
Sodium bicarbonate amendment	1	ls	$ 70,000	$ 70,000	vendor estimate for 38,000 lbs of Nubuff
Injection system and application	1	ls	$ 143,750	$ 143,750	engineers estimate
Secondary application	1	ls	$ 128,890	$ 128,890	engineers estimate
Subtotal				*$ 534,167*	
Source Area ISCR Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 268,243	$ 13,412	percentage of captial costs below
ISCR direct push injection	38	days	$ 3,000	$ 114,000	112 points, 5-20 feet bgs, 3 points/day
ISCR amendment	1	ls	$ 154,243	$ 154,243	scaled from vendor estimate
Subtotal				*$ 346,655*	
Downgradient Area PRB - 1st Avenue S					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 722,424	$ 36,121	percentage of captial costs below
ISCR direct push injection	30	days	$ 3,750	$ 208,488	probe rig with injection equipment, 25% factor applied to standard rate for work in arterial, 300 foot treatment line, 30 injection points, 20-60 feet bgs, 1 points per day, repeats at 10 years (1x) based on estimated time to meet RLs at 1st Ave (15 years)
ISCR amendment	1	ls	$ 277,320	$ 513,936	scaled up from vendor estimate, repeats at 10 years
Subtotal				*$ 823,545*	
Downgradient Area PRB - E Marginal Way					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 1,151,402	$ 57,570	percentage of captial costs below
ISCR direct push injection	45	days	$ 3,750	$ 435,580	probe rig with injection equipment, 25% applied to standard rate for work in arterial/highway, 450 foot treatment line, 45 injection points, 20 60 feet bgs, 1 points per day, repeats at 10 and 20 years (2x) based on estimated time to meet RLs at EMW (30 years)
ISCR amendment	1	ls	$ 277,320	$ 715,822	scaled up from vendor estimate, repeats at 10 and 20 years
Subtotal				*$ 1,273,972*	
Downgradient Area ISCR Treatment - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 588,144	$ 29,407	percentage of captial costs below
ISCR direct push injection	15	days	$ 3,000	$ 144,106	300 foot treatment line, 30 points, 20-40 feet bgs, 2 points/day, repeats every 10 years for 30 years (3x) based on estimated time to meet RLs at Fidalgo (35 years)
ISCR amendment	1	ls	$ 138,660	$ 444,038	scaled up from vendor estimate, repeats every 10 years for 30 years
Subtotal				*$ 682,551*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	5	yr	$ 9,000	$ 39,644	10 wells annually, years 5-10
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	30	yr	$ 9,000	$ 196,849	10 wells annually, years 5-35
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	30	yr	$ 9,000	$ 181,830	10 wells annually, years 11-40
Biannual long term groundwater monitoring (MNA) after year 10	15	yr	$ 18,000	$ 180,387	20 additional wells biannually, years 11-40
Confirmation groundwater sampling	1	ls	$ 108,000	$ 56,335	30 wells quarterly @ 41 years
Confirmation soil sampling	1	ls	$ 25,000	$ 13,041	vadose zone soil @ 41 years
Well decommissioning	125	ea	$ 500	$ 32,602	65 monitoring, 28 sparge, 5 sve, 24 pH @ 41 years
Subtotal				*$ 1,291,717*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	10	yr	$ 2,500	$ 22,934	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 14,560	@ 20 years
Subtotal				*$ 175,158*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	5%		$ 5,137,766	$ 256,888	percentage of captial, O&M, and monitoring costs
Remedial design	8%		$ 3,760,713	$ 300,857	percentage of captial costs
Construction management	6%		$ 3,760,713	$ 225,643	percentage of captial costs
Subtotal				*$ 783,388*	
Subtotal				$ 5,921,154	
Tax	9.5%			$ 357,268	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,883,526	10% bid + 20% scope
Total Estimated Cost				**$ 8,200,000**	

Table E-8 - Cost Estimate: Alternative 8 - Source ISCO+ Groundwater Pump-and-Treat, Downgradient ISCR (PRB @ Fidalgo)

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

Site:	Art Brass Plating
Remedial Action Description:	Source ISCO+Groundwater Pump-and-Treat, Downgradient ISCR (PRB @ Fidalgo)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of 1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area ISCO Recirculation System					
mobilization/demobilization	5%		$ 1,876,866	$ 93,843	percentage of captial costs below
ISCO injection/extraction well installation	4	ea	$ 5,000	$ 20,000	4 inch wells, 25 feet deep
soil cuttings mgmt and disposal	10	drum	$ 100	$ 1,000	1 drum/10 feet of well, assumes contained it, bulk disposal
decon and development water disposal	2	drum	$ 250	$ 500	0.5 drum/well, assume F-listed waste
Permanganate mixing and injection system	1	ls	$ 50,000	$ 50,000	engineers estimate
Groundwater extraction, treatment, and reinjection systsem	1	ls	$ 200,000	$ 200,000	engineers estimate
Chemical and power consumption	10	yr	$ 100,000	$ 917,352	engineers estimate, incl. oxidant and pH buffer
Annual operation and maintenance	10	yr	$ 75,000	$ 688,014	engineers estimate
Subtotal				*$ 1,970,709*	
Downgradient Area ISCR Treatment - Fidalgo Street					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	5%		$ 685,479	$ 34,274	percentage of captial costs below
ISCR direct push injection	15	days	$ 3,000	$ 167,955	300 foot treatment line, 30 points, 20-40 feet bgs, 2 points/day, repeats every 10 years for 40 years (4x) based on estimated time to meet RLs at Fidalgo (45 years)
ISCR amendment	1	ls	$ 138,660	$ 517,524	scaled up from vendor estimate, repeats every 10 years for 40 years
Subtotal				*$ 784,753*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual source area performance monitoring	5	yr	$ 9,000	$ 39,644	10 wells annually, years 6-10
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	40	yr	$ 9,000	$ 244,219	10 wells annually, years 6-45
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	40	yr	$ 9,000	$ 225,585	10 wells annually, years 11-50
Biannual long term groundwater monitoring (MNA) after year 10	20	yr	$ 18,000	$ 223,795	20 additional wells biannually, years 11-50
Confirmation groundwater sampling	1	ls	$ 108,000	$ 48,067	30 wells quarterly @ 51 years
Confirmation soil sampling	1	ls	$ 25,000	$ 11,127	vadose zone soil @ 51 years
Well decommissioning	102	ea	$ 500	$ 22,698	65 monitoring, 28 sparge, 5 sve, 4 ISCO @ 51 years
Subtotal				*$ 1,406,164*	
Vapor Mitigation					
Convert SVE to vapor mitigation system	1	ls	$ 10,000	$ 10,000	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	10	yr	$ 2,500	$ 22,934	@ Art Brass Plating
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 50,000	$ 42,661	once @ 10 years
Decommisioning	1	ls	$ 20,000	$ 14,560	@ 20 years
Subtotal				*$ 175,158*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	6%		$ 4,346,783	$ 260,807	percentage of captial, O&M, and monitoring costs
Remedial design	12%		$ 2,157,367	$ 258,884	percentage of captial costs
Construction management	8%		$ 2,157,367	$ 172,589	percentage of captial costs
Subtotal				*$ 692,280*	
Subtotal				$ 5,039,063	
Tax	9.5%			$ 204,950	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 1,573,204	10% bid + 20% scope
Total Estimated Cost				**$ 6,800,000**	

Table E-9 - Cost Estimate: Alternative 9 - Source Excavation+ISS, Downgradient ISCR (Areal Coverage)

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

Site:	Art Brass Plating
Remedial Action Description:	Source Excavation+ISS, Downgradient ISCR (Areal Coverage)
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of 1.6%

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area Excavation and In-Situ Soil Stabilization					
mobilization/demobilization	5%		$ 3,437,497	$ 171,875	percentage of captial costs below
Well decomissioning	19	ea	$ 1,200	$ 22,800	engineers estimate
Relocation of equipment and materials inside building	1	ls	$ 75,000	$ 75,000	engineers estimate
Utility protection/relocation/replacement	1	ls	$ 2,500	$ 2,500	replace side sewer
Slab removal and micropile support	1	ls	$ 70,000	$ 70,000	reference from other project FS costs (Mill Creek)
Excavation	5809	bcy	$ 12	$ 69,702	reference from other project FS costs (Mill Creek)
Soil handling, loading	5809	bcy	$ 7	$ 40,660	reference from other project FS costs (Mill Creek)
Hazardous soil transport and disposal	9874	ton	$ 154	$ 1,520,670	Assumes soil meets treatment standards
Analytical Sampling	100	ea	$ 300	$ 30,000	reference from other project FS costs (Mill Creek)
In-Situ Soil Stablization	9874	ton	$ 100	$ 987,448	engineers estimate
Import, Place, Compact Structural Fill	10292	ton	$ 30	$ 308,759	gravel borrow @ 2835 lbs/ton
Replace concrete slab	15683	sf	$ 26	$ 407,758	reference from other project FS costs (Mill Creek)
Replace equipment and materials inside building	1	ls	$ 75,000	$ 75,000	engineers estimate
Subtotal				*$ 3,782,172*	
Downgradient Area ISCR Treatment - Areal					
Lab scale bench testing	1	ls	$ 15,000	$ 15,000	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 50,000	engineers estimate
mobilization/demobilization	2%		$ 6,689,911	$ 133,798	percentage of captial costs below
ISCR direct push injection - shallow interval	193	days	$ 3,000	$ 579,000	385 injection points, 20-40 feet bgs, 2 points per day/rig
ISCR amendment - shallow interval	1	ls	$ 3,111,042	$ 3,111,042	scaled up from vendor estimate for source area
ISCR direct push injection - intermediate interval	345	days	$ 3,000	$ 1,035,000	690 injection points, 40-60 feet bgs, 2 points per day/rig
ISCR amendment- intermediate interval	1	ls	$ 1,964,869	$ 1,964,869	scaled up from vendor estimate for source area
Subtotal				*$ 6,888,709*	
Compliance Monitoring					
Quarterly source area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Quarterly downgradient area performance monitoring	5	yr	$ 36,000	$ 171,673	10 wells quarterly, years 1-5
Annual downgradient area performance monitoring	25	yr	$ 9,000	$ 170,191	10 wells annually, years 6-30
Annual long term groundwater monitoring (MNA) for 10 years	10	yr	$ 27,000	$ 247,685	30 wells annually, years 1-10
Annual long term groundwater monitoring (MNA) after year 10	30	yr	$ 9,000	$ 181,830	10 wells annually, years 11-40
Biannual long term groundwater monitoring (MNA) after year 10	15	yr	$ 18,000	$ 180,387	20 additional wells biannually, years 11-40
Confirmation groundwater sampling	1	ls	$ 108,000	$ 56,335	30 wells quarterly @ 41 years
Confirmation soil sampling	1	ls	$ 25,000	$ 13,041	vadose zone soil @ 41 years
Well decommissioning	98	ea	$ 500	$ 25,560	65 monitoring, 28 sparge, 5 sve @ 41 years
Subtotal				*$ 1,218,374*	
Vapor Mitigation					
O&M, incl. performance and protectiveness monitoing	20	yr	$ 2,500	$ 42,501	@ 220 Findlay and 218 Findlay
VI assessment program	20	yr	$ 2,500	$ 42,501	
Equipment replacement	1	ls	$ 25,000	$ 21,331	once @ 10 years
Decommisioning	1	ls	$ 15,000	$ 10,920	@ 20 years
Subtotal				*$ 117,253*	
Environmental Covenant					
Record Environmental Covenant	1	ls	$ 10,000	$ 10,000	
Subtotal				*$ 10,000*	
Professional Services					
Project management	2%		$ 12,016,508	$ 240,330	percentage of captial, O&M, and monitoring costs
Remedial design	3%		$ 10,728,691	$ 321,861	percentage of captial costs
Construction management	3%		$ 10,728,691	$ 321,861	percentage of captial costs
Subtotal				*$ 884,052*	
Subtotal				$ 12,900,560	
Tax	9.5%			$ 1,019,226	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 4,175,936	10% bid + 20% scope
Total Estimated Cost				**$ 18,100,000**	

Table E-10 - Cost Estimate: Source Area ISCR Contingency

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

Site:	Art Brass Plating
Remedial Action Description:	Source Area ISCR Contigency
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of	1.6%
Contigency action starts at year 15.	
Same assumptions as ISCR treatment for source area under Alternative 4.	

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Source Area ISCR Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 11,822	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 39,406	engineers estimate
mobilization/demobilization	5%		$ 211,408	$ 8,331	percentage of captial costs below
ISCR direct push injection	38	days	$ 3,000	$ 89,846	112 points, 5-20 feet bgs, 4 points/day
ISCR amendment	1	ls	$ 154,243	$ 121,562	scaled from vendor estimate
Subtotal				*$ 270,967*	
Professional Services					
Project management	8%		$ 270,967	$ 21,677	percentage of captial, O&M, and monitoring costs
Remedial design	15%		$ 270,967	$ 40,645	percentage of captial costs
Construction management	10%		$ 270,967	$ 27,097	percentage of captial costs
Subtotal				*$ 89,419*	
Subtotal				$ 360,386	
Tax	9.5%			$ 25,742	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 115,839	10% bid + 20% scope
Total Estimated Cost				**$ 500,000**	

Table E-11 - Cost Estimate: Sparge Curtain Contingency Action

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

Site:	Art Brass Plating
Remedial Action Description:	Sparge Curtain at the Waterway
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

Future costs are adjusted to present value using a discount rate of 1.6%
Contigency action starts at year 15 and lasts for 20 years.
300-foot-long sparge curtain.
No off-gas treatment required.
Sparge wells spaced 15 feet on center.
Assumes no additional compliance monitoring outside of primary remedial alternatives.

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Sparge Curtain					
Pilot testing for sparge well design	1	ls	$ 25,000	$ 19,703	
mobilization/demobilization	5%		$ 127,873	$ 5,039	
AS wells	10	day	$ 2,500	$ 19,703	20 x 3/4 inch wells, 40 feet deep, direct push (2 wells/day)
soil cuttings mgmt and disposal	4	drum	$ 200	$ 630	0.2 drum/AS well
decon water and disposal	4	drum	$ 250	$ 788	2 drums decon, 2 drums development and purge
well parts	20	ea	$ 750	$ 11,822	valves, gauges, fittings
asphalt cutting	600	lf	$ 2	$ 946	rsmeans, 300 ft x 2
trenching for pipe runs	100	bcy	$ 10	$ 788	rsmeans, 300 ft trench x 3 ft x 3 ft
trench spoils mgmt and disposal	63	cy	$ 80	$ 3,941	
Perforated SVE piping	300	lf	$ 5	$ 1,182	4 inch perforated piping for vapor containment
AS piping	0	lf	$ 1.50	$ -	3/4 inch HDPE pipe
backfill for pipe runs	50	lcy	$ 45	$ 1,773	pea gravel
asphalt replacement	900	sf	$ 5	$ 3,547	rsmeans, 300 ft trench x 3 ft
equipment	1	ls	$ 60,000	$ 47,287	compressor, blower, enclosure, controls, condensate collection
building	1	ls	$ 20,000	$ 15,762	
mechanical/electrical work	1	ls	$ 25,000	$ 19,703	plumbing, power drop, and controls
Subtotal				*$ 152,615*	
Annual Operation and Maintenace					
O&M, incl. monitoring for protectiveness and	20	yr	$ 50,000	$ 669,928	monitoring/maintenance, condensate disposal, electricity
Lease space for equipment/building	20	yr	$ 7,300	$ 97,809	2 parking spaces @ $10/day
Decommisioning	1	ls	$ 25,000	$ 14,344	@ 35 years
Subtotal				*$ 782,081*	
Professional Services					
Project management	8%		$ 934,696	$ 74,776	percentage of captial and O&M costs
Remedial design	15%		$ 166,959	$ 25,044	percentage of captial costs
Construction management	10%		$ 166,959	$ 16,696	percentage of captial costs
Subtotal				*$ 116,515*	
Subtotal				$ 1,051,212	
Tax	9.5%			$ 15,861	Washington Sales Tax (applied to capital costs)
Contingency	25%			$ 266,768	10% bid + 15% scope
Total Estimated Cost				**$ 1,300,000**	

Table E-12 - Cost Estimate: Containment Contingency Action

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

Site:	Art Brass Plating
Remedial Action Description:	Slurry/Cutoff Wall with Groundwater Pump and Treat for Containment at the Waterway
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

- Future costs are adjusted to present value using a discount rate of 1.6%
- Contigency action starts at year 15 and lasts for 20 years.
- 300-foot-long soil bentonite slurry wall.
- No costs included specifically for removal/replacement of utilities if necessary.
- Assumes no additional compliance monitoring outside of primary remedial alternatives.

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
Slurry/Cutoff Wall					
mobilization/demobilization	1	ls	$ 80,000	$ 63,050	for dewind trenching machine
support equipment	1	ls	$ 40,000	$ 31,525	loader and excavator for handling materials
mixing slurry wall materials for placement	444	cy	$ 10	$ 3,503	300' long x 20' thick x 2' wide
one-pass trenching	1	ls	$ 250,000	$ 197,031	300' long x 40' deep x 2' wide (per dewind trenching)
bentonite	444	cy	$ 330	$ 115,591	assumes 50% bentonite mix, 300x20x2
soil mgmt and disposal	444	cy	$ 80	$ 28,022	rsmeans, assumes contained in, 300x20x2
asphalt replacement	6,000	sf	$ 5	$ 23,644	rsmeans, 300 ft trench x 20 ft
Subtotal				*$ 462,366*	
Groundwater Pump and Treat					
mobilization/demobilization	5%		$ 126,691	$ 4,992	
Extraction well installation	2	ea	$ 5,000	$ 7,881	4 inch wells, 40 feet deep
soil cuttings mgmt and disposal	5	drum	$ 100	$ 394	1 drum/10 feet of well, assumes contained it, bulk disposal
decon and development water disposal	1	drum	$ 250	$ 197	0.5 drum/well, assume F-listed waste
Groundwater extraction and treatment syste	1	ls	$ 150,000	$ 118,219	collection tank, air stripping tray, discharge to sewer
Subtotal				*$ 131,683*	
Annual Operation and Maintenace					
O&M, incl. monitoring for protectiveness anc	20	yr	$ 75,000	$ 1,004,892	monitoring/maintenance, condensate disposal, electricity
Lease space for equipment/building	20	yr	$ 29,200	$ 391,238	8 parking spaces @ $10/day
Decommisioning	1	ls	$ 25,000	$ 14,344	@ 35 years
Subtotal				*$ 1,410,474*	
Professional Services					
Project management	8%		$ 2,004,523	$ 160,362	percentage of captial and O&M costs
Remedial design	15%		$ 594,049	$ 89,107	percentage of captial costs
Construction management	10%		$ 594,049	$ 59,405	percentage of captial costs
Subtotal				*$ 308,874*	
Subtotal				$ 2,313,397	
Tax	9.5%			$ 146,505	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 599,261	10% bid + 20% scope
Total Estimated Cost				**$ 3,100,000**	

Table E-13 - Cost Estimate: Enhanced Aerobic Biodegradation Contigency

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

Site:	Art Brass Plating
Remedial Action Description:	Enhanced Aerobic Biodegradation
Cost Estimate Accuracy:	Feasibility Level (+50/-30 percent)

Key Assumptions:

- Future costs are adjusted to present value using a discount rate of 1.6%
- Contigency action starts at year 15 and lasts for 20 years.
- Oxygen release compound will require reapplication annually for the duration of the contingency.
- 300-foot-long treatment zone.
- Injection points spaced 10 feet on center.
- Assumes no additional compliance monitoring outside of primary remedial alternatives.

Item	Quantity	Unit	Unit Cost	Total Cost	Notes
EAB Treatment					
Lab scale bench testing	1	ls	$ 15,000	$ 11,822	engineers estimate
Field scale pilot testing	1	ls	$ 50,000	$ 39,406	engineers estimate
mobilization/demobilization	5%		$ 106,397	$ 4,193	percentage of captial costs below
ORC direct push injection	15	days	$ 3,000	$ 35,466	probe rig with injection equipment, 30 injection points, 20-40 feet bgs, 2 points per day
ORC amendment	9000	lb	$ 10	$ 70,931	Assumes 300 lbs ORC per injection point, actual requirement unknown
Annual application cost	20	yr	$ 110,589	$ 1,880,084	Annual application for years 16 to 35
Subtotal				*$ 2,041,901*	
Professional Services					
Project management	8%		$ 2,041,901	$ 163,352	percentage of captial costs
Remedial design	15%		$ 2,041,901	$ 306,285	percentage of captial costs
Construction management	10%		$ 2,041,901	$ 204,190	percentage of captial costs
Subtotal				*$ 673,827*	
Subtotal				$ 2,715,729	
Tax	9.5%			$ 193,981	Washington Sales Tax (applied to capital costs)
Contingency	30%			$ 2,909,709	10% bid + 20% scope
Total Estimated Cost				**$ 5,800,000**	

APPENDIX F

Beneficial Use Evaluation of Groundwater as a Drinking Water Source

PACIFIC groundwater GROUP

Technical Memorandum

To: Ed Jones, Department of Ecology, NWRO

From: Pacific Groundwater Group

Cc: Blaser Die-Casting, Inc.
Burlington Environmental, LLC and Pacific Crest Consulting, LLC
Capital Industries, Inc. and Farallon Consulting, LLC
Art Brass Plating, Inc. and Aspect Consulting, LLC

Re: **West of 4th Site Agreed Order No. DE 10402**
Beneficial Use Evaluation of Groundwater as a Drinking Water Source

Date: July 22, 2016

Pacific Groundwater Group (PGG) has prepared this Technical Memorandum on behalf of Art Brass Plating, Inc.; Blaser Die Casting Co.; Capital Industries, Inc.; and PSC Environmental Services, LLC (PSC) (collectively referred to herein as the West of 4th Group) in accordance with the requirements of Agreed Order No. DE 10402 entered into by the West of 4th Group and the Washington State Department of Ecology (Ecology) in April 2014 (Agreed Order), and the Washington State Model Toxics Control Act Cleanup Regulation (MTCA), as established in Chapter 173-340 of the Washington Administrative Code (WAC 173-340).

This Technical Memorandum is applicable to the West of 4th Site (herein referred to as the Site), which consists of Site Unit 1 (SU1) and Site Unit 2 (SU2), as depicted on Exhibit A of the Agreed Order. The purpose of this Technical Memorandum is to provide a beneficial use evaluation of groundwater as a drinking water source per WAC 173-340-720(2).

1.0 DRINKING WATER BENEIFICAL USE DEFINED

According to WAC 173-340-720 groundwater cleanup levels shall be based on estimates of the highest beneficial use, which Ecology determined to be drinking water, unless the groundwater at the facility meets the non-potability criteria listed in WAC 173-340-720(2)(a) through (c):

Groundwater shall be classified as potable to protect drinking water beneficial uses unless the following can be demonstrated:

(a) The groundwater does not serve as a current source of drinking water;
(b) The groundwater is not a potential future source of drinking water for any of the following reasons:

  (i) The groundwater is present in insufficient quantity to yield greater than 0.5 gallon per minute on a sustainable basis to a well constructed in compliance with chapter 173-160

WAC and in accordance with normal domestic water well construction practices for the area in which the site is located;

(ii) The groundwater contains natural background concentrations of organic or inorganic constituents that make use of the water as a drinking water source not practicable. Groundwater containing total dissolved solids at concentrations greater than 10,000 mg/l shall normally be considered to have fulfilled this requirement; (NOTE: The total dissolved solids concentration provided here is an example. There may be other situations where high natural background levels also meet this requirement.) or

(iii) The groundwater is situated at a great depth or location that makes recovery of water for drinking water purposes technically impossible; and

(c) The department determines it is unlikely that hazardous substances will be transported from the contaminated groundwater to groundwater that is a current or potential future source of drinking water, as defined in (a) and (b) of this subsection, at concentrations which exceed groundwater quality criteria published in chapter 173-200 WAC.

In making a determination under this provision, the department shall consider site-specific factors including:

(i) The extent of affected groundwater;
(ii) The distance to existing water supply wells;
(iii) The likelihood of interconnection between the contaminated groundwater and groundwater that is a current or potential future source of drinking water due to well construction practices in the area of the state where the site is located;
(iv) The physical and chemical characteristics of the hazardous substance;
(v) The hydrogeologic characteristics of the site;
(vi) The presence of discontinuities in the affected geologic stratum; and
(vii) The degree of confidence in any predictive modeling performed.

(d) Even if groundwater is classified as a potential future source of drinking water under (b) of this subsection, the department recognizes that there may be sites where there is an extremely low probability that the groundwater will be used for that purpose because of the site's proximity to surface water that is not suitable as a domestic water supply. An example of this situation would be shallow groundwaters in close proximity to marine waters such as on Harbor Island in Seattle. At such sites, the department may allow groundwater to be classified as nonpotable for the purposes of this section if each of the following conditions can be demonstrated. These determinations must be for reasons other than that the groundwater or surface water has been contaminated by a release of a hazardous substance at the site.

(i) The conditions specified in (a) and (c) of this subsection are met;
(ii) There are known or projected points of entry of the groundwater into the surface water;
(iii) The surface water is not classified as a suitable domestic water supply source under chapter 173-201A WAC; and
(iv) The groundwater is sufficiently hydraulically connected to the surface water that the groundwater is not practicable to use as a drinking water source.

2.0 ENVIRONMENTAL SETTING

The hydrogeologic units encountered in borings completed at the Site include a 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 from the Site Conceptual Model Technical Memorandum (Aspect, 2014).

- **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 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 Duwamish Waterway (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 (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. The following is a standardized nomenclature for groundwater monitoring and sampling intervals which are:

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

These zones are hydraulically interconnected, with no confining unit separating the zones. The zones are considered here as a single aquifer for the purposes of beneficial use evaluation.

3.0 DRINKING WATER BENEFICIAL USE ANALYSIS

3.1 WAC 173-340-720(2)a - CURRENT SOURCE OF DRINKING WATER

The groundwater does not serve as a current source of drinking water. According to Amec (2014), there are no water supply wells within one-mile down or cross-gradient of their Georgetown facility; this search area covers the Site and the findings are applicable to the Site.

The Site is served by the Seattle Public Utilities water system, which is supplied by the Cedar and Tolt River Watersheds located in the Cascade Mountains (SPU, 2012). Amec (2014) identified the Highline Well field 5 miles to the south as the nearest groundwater source of drinking water from an aquifer not hydraulically connected to the Site aquifers.

A review of the Washington Department of Health SENTRY database (accessed July 19, 2016) finds there are no water supply systems within more than a ½ mile radius of the Site (T24, R4E, Sections 29, 28, 33, 20, and 19).

3.2 WAC 173-340-720(2)b - FUTURE SOURCE OF DRINKING WATER

3.2.1 Groundwater Yield

The groundwater is present in sufficient quantity to yield greater than 0.5 gallon per minute on a sustainable basis to a well constructed in compliance with chapter 173-160 WAC. According to Amec (2014), based on pumping test data, the aquifer can yield more than 0.5 gpm.

3.2.2 Groundwater Natural Background

The groundwater contains natural background concentrations of organic or inorganic constituents that make use of the water as a drinking water source not practicable[1]. Natural background at this Site is likely the same as found the upgradient and cross-gradient of the Georgetown Facility site, which is upgradient of the Site. According to PSC (2003) and Amec (2014), the following constituents exceeded the primary and secondary drinking water standards:

- Shallow/Intermediate Intervals
    - primary standards- turbidity and coliform.
    - secondary standards- iron, manganese, total dissolved solids, and color.

PSC (2003) and Amec (2014) found that the Shallow/Intermediate Interval would require treatment for naturally occurring constituents to be used as a source of drinking water and that

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[1] The Model Toxics Control Act (MTCA) defines "practicable" as "capable of being designed, constructed and implemented in a reliable and effective manner, including consideration of cost. When considering cost under this analysis, an alternative shall not be considered practicable if the incremental cost of the alternative is disproportionate to the incremental degree of benefits provided by the alternative over other lower-cost alternatives" (WAC 173-340-200).

the costs associated with treatment compared to obtaining water from SPU renders the groundwater impracticable as a source of drinking water.

3.2.3 Groundwater Depth

The groundwater is situated at a depth and location that makes recovery of water for drinking water purposes technically possible.

3.3 WAC 173-340-720(2)c – CONTAMINANT TRANSPORT TO SOURCE OF DRINKING WATER

As discussed in sections 3.1 and 3.2 above, Site groundwater is not a current or future potential source of drinking water. Also, the downgradient surface water body, the Duwamish Waterway, is not a current or future source of suitable domestic drinking water per WAC 173-201A.

3.4 WAC 173-340-720(2)d – GROUNDWATER PROXIMITY TO SURFACE WATER THAT IS NOT SUITABLE AS A DOMESTIC WATER SUPPLY

3.4.1 Conditions of WAC 173-204-720 a-c

Conditions of WAC 173-204-720 a-c have been met that Site groundwater is not a current or future source of drinking water.

3.4.2 Groundwater Discharge to Surface Water

The groundwater at the Site flows to the west and southwest toward the Duwamish Waterway (Aspect, 2014).

3.4.3 Surface Water is not a Suitable Domestic Drinking Water Source

The Duwamish Waterway is not designated as a suitable domestic drinking water source per WAC 173-201.

3.4.4 Groundwater is Sufficiently Hydraulically Connected to Surface Water

Site groundwater is influenced by Duwamish Waterway surface water. According to Amec (2014), groundwater located up to 1,000 feet from the Duwamish Waterway “is sufficiently hydraulically connected to the surface water that the groundwater is not practicable to use as a drinking water source.” Furthermore, a pumping well or well field could enhance the intermixing or extend the mixing zone.

4.0 OTHER CONSIDERATIONS FOR GROUNDWATER BENEFICIAL USE

4.1 LOCAL REGULATIONS AND WELL CONSTRUCTION PRACTICES

According to Amec (2014), local regulations and well construction practices currently preclude the completion and use of groundwater as a drink water source at or near the Site. The Amec (2014) list includes requirements to connect to existing supplies (e.g SPU), setbacks (e.g. from roads, sewers, surface water), minimum lot size for private wells, and water rights for domestic supply unlikely, which severely limit the likelihood that there are acceptable drinking water points of withdrawal.

4.2 GROUNDWATER BENEFICIAL USE DESIGNATIONS IN THE DUWAMISH VALLEY

According to the Stericycle Georgetown Facility Remedial Investigation (PSC, 2003), a site located upgradient of SU1 and SU2, there are several other sites in the Duwamish Valley where groundwater has been either designated as non-potable or where protection of surface water protection is the highest beneficial use. These sites include, but are not limited to: Harbor Island, Holnam Markey, Great Western Chemical, Fostoria Business Park, Spencer Industries, former All City Wrecking, and Myrtle Street (shown on Figure 6-5 of PSC, 2003). To our knowledge, there are no neighboring sites in the Duwamish Valley that have met the potability requirements for the alluvial aquifer.

5.0 SUMMARY AND CONCLUSIONS OF GROUNDWATER BENEFICIAL USE ANALYSIS

Drinking water is not the highest beneficial use of groundwater at the Site for the following reasons:

- The groundwater at the Site does not serve as a current source of drinking water per WAC 173-340-720(2)a.
- The groundwater at the Site is not a potential future source of groundwater per WAC 173-340-720(2)b.
- The groundwater at the Site is not hydraulically connected to a surface water body (i.e. Duwamish Waterway) or groundwater aquifer that is a current or future source of drinking water per WAC 173-340-720(2)d.
- Various state and local regulations prohibit the installation and use of drinking water wells at the Site and vicinity.
- Other sites in the Duwamish Valley have been designated as having non-potable groundwater and/or where discharge to surface water is the highest beneficial use of groundwater.

6.0 REFERENCES

AMEC, 2014. Potability Determination Five-Year Review Stericycle Georgetown Facility, Seattle Washington. December 30, 2014.

Aspect Consulting, 2014. Site Conceptual Model Technical Memorandum (Revised), W4 Joint Deliverable. December 15, 2014.

Booth and Herman, 1998, Duwamish Basin Groundwater Pathways Conceptual Model Report, Duwamish Industrial Area Hydrogeologic Pathways Project, Prepared for City of Seattle Office of Economic Development and King County Office of Budget and Strategic Planning, University of Washington and Hart Crowser, Seattle, Washington.

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