APPENDIX G
EPH MODEL

A1 Soil Cleanup Levels: Worksheet for Soil Data Entry: Refer to WAC 173-340-720, 740,745, 747, 750

1. Enter Site Information

Date:	10/05/11
Site Name:	MBTL
Sample Name:	SSA6-01-3-4

2. Enter Soil Concentration Measured

Chemical of Concern or Equivalent Carbon Group	Measured Soil Conc dry basis mg/kg	Composition Ratio %
Petroleum EC Fraction		
AL_EC >5-6	0	0.00%
AL_EC >6-8	0	0.00%
AL_EC >8-10	7	0.10%
AL_EC >10-12	47	0.67%
AL_EC >12-16	470	6.67%
AL_EC >16-21	2800	39.76%
AL_EC >21-34	3300	46.86%
AR_EC >8-10	7	0.10%
AR_EC >10-12	7	0.10%
AR_EC >12-16	54	0.77%
AR_EC >16-21	270	3.83%
AR_EC >21-34	80	1.14%
Benzene		0.00%
Toluene		0.00%
Ethylbenzene		0.00%
Total Xylenes		0.00%
Naphthalene		0.00%
1-Methyl Naphthalene		0.00%
2-Methyl Naphthalene		0.00%
n-Hexane		0.00%
MTBE		0.00%
Ethylene Dibromide (EDB)		0.00%
1,2 Dichloroethane (EDC)		0.00%
Benzo(a)anthracene		0.00%
Benzo(b)fluoranthene		0.00%
Benzo(k)fluoranthene		0.00%
Benzo(a)pyrene		0.00%
Chrysene		0.00%
Dibenz(a,h)anthracene		0.00%
Indeno(1,2,3-cd)pyrene		0.00%
Sum	7042	100.00%

3. Enter Site-Specific Hydrogeological Data

Total soil porosity:	0.43	Unitless
Volumetric water content:	0.3	Unitless
Volumetric air content:	0.13	Unitless
Soil bulk density measured:	1.5	kg/L
Fraction Organic Carbon:	0.001	Unitless
Dilution Factor:	1	Unitless

4. Target TPH Ground Water Concentation (if adjusted)

If you adjusted the target TPH ground water concentration, enter adjusted value here:	500	ug/L

Notes for Data Entry | **Set Default Hydrogeology**

Clear All Soil Concentration Data Entry Cells

Restore All Soil Concentration Data cleared previously

REMARK:
Enter site-specific information here……..

A2 Soil Cleanup Levels: Calculation and Summary of Results. Refer to WAC 173-340-720, 740, 745, 747, 750

Site Information

Date: 10/5/2011
Site Name: MBTL
Sample Name: SSA6-01-3-4
Measured Soil TPH Concentration, mg/kg: **7,042.000**

1. Summary of Calculation Results

Exposure Pathway	Method/Goal	Protective Soil TPH Conc, mg/kg	With Measured Soil Conc		Does Measured Soil Conc Pass or Fail?
			RISK @	HI @	
Protection of Soil Direct Contact: Human Health	Method B	12,050	0.00E+00	5.84E-01	Pass
	Method C	147,565	0.00E+00	4.77E-02	Pass
Protection of Method B Ground Water Quality (Leaching)	Potable GW: Human Health Protection	100% NAPL	0.00E+00	7.24E-01	Pass
	Target TPH GW Conc. @ 500 ug/L	100% NAPL	NA	NA	Pass

Warning! Check to determine if a simplified or site-specific Terrestrial Ecological Evaluation may be required (Refer to WAC 173-340-7490 through ~7494).

Warning! Check Residual Saturation (WAC340-747(10)).

2. Results for Protection of Soil Direct Contact Pathway: Human Health

	Method B: Unrestricted Land Use	Method C: Industrial Land Use
Protective Soil Concentration, TPH mg/kg	**12,050.39**	**147,565.29**
Most Stringent Criterion	**HI =1**	**HI =1**

Soil Criteria	Protective Soil Concentration @Method B				Protective Soil Concentration @Method C			
	Most Stringent?	TPH Conc, mg/kg	RISK @	HI @	Most Stringent?	TPH Conc, mg/kg	RISK @	HI @
HI =1	YES	1.21E+04	0.00E+00	1.00E+00	YES	1.48E+05	0.00E+00	1.00E+00
Total Risk=1E-5	NA	NA	NA	NA	NA	NA	NA	NA
Risk of Benzene= 1E-6	NA	NA	NA	NA	NA			
Risk of cPAHs mixture= 1E-6	NA	NA	NA	NA				
EDB	NA	NA	NA	NA				
EDC	NA	NA	NA	NA				

3. Results for Protection of Ground Water Quality (Leaching Pathway)

3.1. Protection of Potable Ground Water Quality (Method B): Human Health Protection

Most Stringent Criterion	**NA**
Protective Ground Water Concentration, ug/L	**NA**
Protective Soil Concentration, mg/kg	**Soil-to-Ground Water is not a critical pathway!**

Ground Water Criteria	Protective Potable Ground Water Concentration @Method B				Protective Soil Conc, mg/kg
	Most Stringent?	TPH Conc, ug/L	RISK @	HI @	
HI=1	YES	3.39E+02	0.00E+00	7.39E-01	100% NAPL
Total Risk = 1E-5	NA	NA	NA	NA	NA
Total Risk = 1E-6	NA	NA	NA	NA	NA
Risk of cPAHs mixture= 1E-5	NA	NA	NA	NA	NA
Benzene MCL = 5 ug/L	NA	NA	NA	NA	NA
MTBE = 20 ug/L	NA	NA	NA	NA	NA

Note: 100% NAPL is 69000 mg/kg TPH.

3.2 Protection of Ground Water Quality for TPH Ground Water Concentration previously adjusted and entered

Ground Water Criteria	Protective Ground Water Concentration			Protective Soil Conc, mg/kg
	TPH Conc, ug/L	Risk @	HI @	
Target TPH GW Conc = 500 ug/L	3.39E+02	0.00E+00	7.39E-01	**100% NAPL**

A1 Soil Cleanup Levels: Worksheet for Soil Data Entry: Refer to WAC 173-340-720, 740,745, 747, 750

1. Enter Site Information

Date: 10/05/11
Site Name: MBTL
Sample Name: SSA6-01-7-8

2. Enter Soil Concentration Measured

Chemical of Concern or Equivalent Carbon Group	Measured Soil Conc dry basis mg/kg	Composition Ratio %
Petroleum EC Fraction		
AL_EC >5-6	0	0.00%
AL_EC >6-8	0	0.00%
AL_EC >8-10	6.5	0.13%
AL_EC >10-12	6.5	0.13%
AL_EC >12-16	80	1.64%
AL_EC >16-21	2000	40.95%
AL_EC >21-34	2700	55.28%
AR_EC >8-10	6.5	0.13%
AR_EC >10-12	6.5	0.13%
AR_EC >12-16	6.5	0.13%
AR_EC >16-21	31	0.63%
AR_EC >21-34	41	0.84%
Benzene		0.00%
Toluene		0.00%
Ethylbenzene		0.00%
Total Xylenes		0.00%
Naphthalene		0.00%
1-Methyl Naphthalene		0.00%
2-Methyl Naphthalene		0.00%
n-Hexane		0.00%
MTBE		0.00%
Ethylene Dibromide (EDB)		0.00%
1,2 Dichloroethane (EDC)		0.00%
Benzo(a)anthracene		0.00%
Benzo(b)fluoranthene		0.00%
Benzo(k)fluoranthene		0.00%
Benzo(a)pyrene		0.00%
Chrysene		0.00%
Dibenz(a,h)anthracene		0.00%
Indeno(1,2,3-cd)pyrene		0.00%
Sum	4884.5	100.00%

3. Enter Site-Specific Hydrogeological Data

Total soil porosity:	0.43	Unitless
Volumetric water content:	0.3	Unitless
Volumetric air content:	0.13	Unitless
Soil bulk density measured:	1.5	kg/L
Fraction Organic Carbon:	0.001	Unitless
Dilution Factor:	1	Unitless

4. Target TPH Ground Water Concentation (if adjusted)

If you adjusted the target TPH ground water concentration, enter adjusted value here:	500	ug/L

Notes for Data Entry **Set Default Hydrogeology**

Clear All Soil Concentration Data Entry Cells

Restore All Soil Concentration Data cleared previously

REMARK:
Enter site-specific information here……..

A2 Soil Cleanup Levels: Calculation and Summary of Results. Refer to WAC 173-340-720, 740, 745, 747, 750

Site Information

Date: 10/5/2011
Site Name: MBTL
Sample Name: SSA6-01-7-8
Measured Soil TPH Concentration, mg/kg: **4,884.500**

1. Summary of Calculation Results

Exposure Pathway	Method/Goal	Protective Soil TPH Conc, mg/kg	With Measured Soil Conc		Does Measured Soil Conc Pass or Fail?
			RISK @	HI @	
Protection of Soil Direct Contact: Human Health	Method B	34,683	0.00E+00	1.41E-01	Pass
	Method C	429,462	0.00E+00	1.14E-02	Pass
Protection of Method B Ground Water Quality (Leaching)	Potable GW: Human Health Protection	100% NAPL	0.00E+00	8.12E-01	Pass
	Target TPH GW Conc. @ 500 ug/L	100% NAPL	NA	NA	Pass

Warning! Check to determine if a simplified or site-specific Terrestrial Ecological Evaluation may be required (Refer to WAC 173-340-7490 through ~7494).

Warning! Check Residual Saturation (WAC340-747(10)).

2. Results for Protection of Soil Direct Contact Pathway: Human Health

	Method B: Unrestricted Land Use	Method C: Industrial Land Use
Protective Soil Concentration, TPH mg/kg	**34,683.48**	**429,461.65**
Most Stringent Criterion	**HI =1**	**HI =1**

Soil Criteria	Protective Soil Concentration @Method B				Protective Soil Concentration @Method C			
	Most Stringent?	TPH Conc, mg/kg	RISK @	HI @	Most Stringent?	TPH Conc, mg/kg	RISK @	HI @
HI =1	YES	3.47E+04	0.00E+00	1.00E+00	YES	4.29E+05	0.00E+00	1.00E+00
Total Risk=1E-5	NA	NA	NA	NA	NA	NA	NA	NA
Risk of Benzene= 1E-6	NA	NA	NA	NA	NA			
Risk of cPAHs mixture= 1E-6	NA	NA	NA	NA				
EDB	NA	NA	NA	NA				
EDC	NA	NA	NA	NA				

3. Results for Protection of Ground Water Quality (Leaching Pathway)

3.1. Protection of Potable Ground Water Quality (Method B): Human Health Protection

Most Stringent Criterion	**NA**
Protective Ground Water Concentration, ug/L	**NA**
Protective Soil Concentration, mg/kg	**Soil-to-Ground Water is not a critical pathway!**

Ground Water Criteria	Protective Potable Ground Water Concentration @Method B				Protective Soil Conc, mg/kg
	Most Stringent?	TPH Conc, ug/L	RISK @	HI @	
HI=1	YES	3.38E+02	0.00E+00	8.44E-01	100% NAPL
Total Risk = 1E-5	NA	NA	NA	NA	NA
Total Risk = 1E-6	NA	NA	NA	NA	NA
Risk of cPAHs mixture= 1E-5	NA	NA	NA	NA	NA
Benzene MCL = 5 ug/L	NA	NA	NA	NA	NA
MTBE = 20 ug/L	NA	NA	NA	NA	NA

Note: 100% NAPL is 68000 mg/kg TPH.

3.2 Protection of Ground Water Quality for TPH Ground Water Concentration previously adjusted and entered

Ground Water Criteria	Protective Ground Water Concentration			Protective Soil Conc, mg/kg
	TPH Conc, ug/L	Risk @	HI @	
Target TPH GW Conc = 500 ug/L	3.38E+02	0.00E+00	8.44E-01	**100% NAPL**

A1 Soil Cleanup Levels: Worksheet for Soil Data Entry: Refer to WAC 173-340-720, 740,745, 747, 750

1. Enter Site Information

Date: 10/05/11
Site Name: MBTL
Sample Name: SSA6-03-3-4

Notes for Data Entry | Set Default Hydrogeology
Clear All Soil Concentration Data Entry Cells
Restore All Soil Concentration Data cleared previously

2. Enter Soil Concentration Measured

Chemical of Concern or Equivalent Carbon Group	Measured Soil Conc dry basis mg/kg	Composition Ratio %
Petroleum EC Fraction		
AL_EC >5-6	0	0.00%
AL_EC >6-8	0	0.00%
AL_EC >8-10	8	1.84%
AL_EC >10-12	8	1.84%
AL_EC >12-16	8	1.84%
AL_EC >16-21	130	29.95%
AL_EC >21-34	210	48.39%
AR_EC >8-10	8	1.84%
AR_EC >10-12	8	1.84%
AR_EC >12-16	8	1.84%
AR_EC >16-21	8	1.84%
AR_EC >21-34	38	8.76%
Benzene		0.00%
Toluene		0.00%
Ethylbenzene		0.00%
Total Xylenes		0.00%
Naphthalene		0.00%
1-Methyl Naphthalene		0.00%
2-Methyl Naphthalene		0.00%
n-Hexane		0.00%
MTBE		0.00%
Ethylene Dibromide (EDB)		0.00%
1,2 Dichloroethane (EDC)		0.00%
Benzo(a)anthracene		0.00%
Benzo(b)fluoranthene		0.00%
Benzo(k)fluoranthene		0.00%
Benzo(a)pyrene		0.00%
Chrysene		0.00%
Dibenz(a,h)anthracene		0.00%
Indeno(1,2,3-cd)pyrene		0.00%
Sum	434	100.00%

3. Enter Site-Specific Hydrogeological Data

Total soil porosity:	0.43	Unitless
Volumetric water content:	0.3	Unitless
Volumetric air content:	0.13	Unitless
Soil bulk density measured:	1.5	kg/L
Fraction Organic Carbon:	0.001	Unitless
Dilution Factor:	1	Unitless

4. Target TPH Ground Water Concentation (if adjusted)

If you adjusted the target TPH ground water concentration, enter adjusted value here:	500	ug/L

REMARK:
Enter site-specific information here……..

A2 Soil Cleanup Levels: Calculation and Summary of Results. Refer to WAC 173-340-720, 740, 745, 747, 750

Site Information

Date: 10/5/2011
Site Name: MBTL
Sample Name: SSA6-03-3-4
Measured Soil TPH Concentration, mg/kg: **434.000**

1. Summary of Calculation Results

Exposure Pathway	Method/Goal	Protective Soil TPH Conc, mg/kg	With Measured Soil Conc		Does Measured Soil Conc Pass or Fail?
			RISK @	HI @	
Protection of Soil Direct Contact: Human Health	Method B	9,363	0.00E+00	4.64E-02	Pass
	Method C	127,024	0.00E+00	3.42E-03	Pass
Protection of Method B Ground Water Quality (Leaching)	Potable GW: Human Health Protection	17	0.00E+00	7.37E+00	Fail
	Target TPH GW Conc. @ 500 ug/L	26	NA	NA	Fail

Warning! Check to determine if a simplified or site-specific Terrestrial Ecological Evaluation may be required (Refer to WAC 173-340-7490 through ~7494).

2. Results for Protection of Soil Direct Contact Pathway: Human Health

	Method B: Unrestricted Land Use	Method C: Industrial Land Use
Protective Soil Concentration, TPH mg/kg	**9,363.20**	**127,024.39**
Most Stringent Criterion	**HI =1**	**HI =1**

Soil Criteria	Protective Soil Concentration @Method B				Protective Soil Concentration @Method C			
	Most Stringent?	TPH Conc, mg/kg	RISK @	HI @	Most Stringent?	TPH Conc, mg/kg	RISK @	HI @
HI =1	YES	9.36E+03	0.00E+00	1.00E+00	YES	1.27E+05	0.00E+00	1.00E+00
Total Risk=1E-5	NA	NA	NA	NA	NA	NA	NA	NA
Risk of Benzene= 1E-6	NA	NA	NA	NA	NA			
Risk of cPAHs mixture= 1E-6	NA	NA	NA	NA				
EDB	NA	NA	NA	NA				
EDC	NA	NA	NA	NA				

3. Results for Protection of Ground Water Quality (Leaching Pathway)

3.1. Protection of Potable Ground Water Quality (Method B): Human Health Protection

Most Stringent Criterion	**HI=1**
Protective Ground Water Concentration, ug/L	**344.10**
Protective Soil Concentration, mg/kg	**17.14**

Ground Water Criteria	Protective Potable Ground Water Concentration @Method B				Protective Soil Conc, mg/kg
	Most Stringent?	TPH Conc, ug/L	RISK @	HI @	
HI=1	YES	3.44E+02	0.00E+00	1.00E+00	1.71E+01
Total Risk = 1E-5	NA	NA	NA	NA	NA
Total Risk = 1E-6	NA	NA	NA	NA	NA
Risk of cPAHs mixture= 1E-5	NA	NA	NA	NA	NA
Benzene MCL = 5 ug/L	NA	NA	NA	NA	NA
MTBE = 20 ug/L	NA	NA	NA	NA	NA

3.2 Protection of Ground Water Quality for TPH Ground Water Concentration previously adjusted and entered

Ground Water Criteria	Protective Ground Water Concentration			Protective Soil Conc, mg/kg
	TPH Conc, ug/L	Risk @	HI @	
Target TPH GW Conc = 500 ug/L	5.00E+02	0.00E+00	1.45E+00	**2.63E+01**

APPENDIX H
FLUORIDE FATE AND TRANSPORT EVALUATION

TABLE OF CONTENTS

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LIST OF ACRONYMS AND ABBREVIATIONS

2-D	two-dimensional
3-D	three-dimensional
AAO	acid ammonium oxalate
AEC	anion exchange capacity
Apex	Apex Laboratories, LLC
bgs	below ground surface
CDID	Consolidated Diking Improvement District
CEC	cation exchange capacity
CSM	conceptual site model
FS	Feasibility Study
GUI	graphical user interface
MSL	mean sea level
NPDES	National Pollutant Discharge Elimination System
NW	northwest
OHWL	ordinary high water line
REL	Remediation Level
Reynolds Facility	former Reynolds Metals Reduction Plant
RI/FS	Remedial Investigation
SI	saturation index
SEM	scanning electron microscopy
SPL	spent potliner
TAM	tidal attenuation modeling
TOC	total organic carbon
USGS	U.S. Geological Survey
WBZ	water bearing zone
XRD	X-ray diffraction

This appendix to the Remedial Investigation/Feasibility Study (RI/FS) report for the former Reynolds Metals Reduction Plant (Reynolds Facility) presents the data collected and the groundwater and geochemical reactive transport modeling conducted in support of the fate and transport evaluation of fluoride. Tidal attenuation modeling was also conducted as part of the fate and transport evaluation. Appendix H is divided into four sections: Geochemical Site Characterization, Groundwater Flow and Reactive Transport Modeling, Tidal Attenuation Modeling, and References. Section 1 discusses the characterization of, and presents the data collected from, soil borings advanced within the East Groundwater Area. Section 2 discusses the groundwater flow and geochemical reactive transport modeling that was conducted for the East and West Groundwater Areas, and presents the results of the fluoride fate and transport modeling. Section 3 discusses the tidal attenuation modeling that was conducted and the (physical) attenuation factor that was calculated for shallow groundwater proximal and discharging to the Columbia River.

1 GEOCHEMICAL SITE CHARACTERIZATION

Geochemical data were collected from four borings advanced within the East Groundwater Area and included solid media total fluoride and total organic carbon (TOC) concentration profiles; mineral identification by powder X-ray diffraction (XRD) and high-resolution scanning electron microscopy (SEM); determination of iron, aluminum, and manganese oxides by selective extraction; and determination of cation exchange capacity (CEC) and anion exchange capacity (AEC).

Results of geochemical speciation modeling for unsaturated zone porewater, groundwater (West and East Groundwater Areas), and surface water are summarized in this section (see Tables 5-10; 5-18a and 5-18b; 5-19a and 5-19b; and 5-20 in the RI/FS report, respectively).

Section 1 is divided into the following subsections:

- 1.1 – Soil Media Fluoride and Total Organic Carbon Data
- 1.2 – Powder X-ray Diffraction Results
- 1.3 – High-resolution Scanning Electron Microscopy Results
- 1.4 – Cation and Anion Exchange Data
- 1.5 – Extractable Iron, Aluminum, and Manganese Oxide Data
- 1.6 – Geochemical Speciation Modeling

1.1 Solid Media Fluoride and Total Organic Carbon Data

Four borings were advanced into the saturated zone along a southwest-northeast trending transect in the East Groundwater Area. Solid media samples were collected at 2.5-foot intervals to a total depth of 20 feet below ground surface (bgs). The 2.5-foot core sections were taken (on ice) from the site and brought to the Anchor QEA, LLC, Environmental Geochemistry Laboratory in Portland, Oregon, for processing. In the laboratory, each 2.5-foot core section was described, then homogenized and stored in the refrigerator until analysis. Table 1 summarizes sample locations, depth intervals, descriptions, and analyses performed on each sample.

Table 1
Sample Summary and Analysis Matrix for Borings

Location	Depth (feet bgs)	Sample Description	F/ TOC	SEM	XRD	CEC/ AEC	Fe,Al,Mn Oxides
GC-SB-01	0 – 2.5	Sand, minor clay, and plant debris					
	2.5 – 5	Sand, minor clay, and cobbles	x				
Northing:	5 – 7.5	Stiff, wet clay (black)	x	x	x		
302765.97	7.5 – 10	Stiff, wet clay (black and red)	x				
Easting:	10 – 12.5	Stiff, wet clay	x		x	x	x
1008329	12.5 – 15	Sand	x				
Elevation:	15 – 17.5	Sand	x			x	x
14.08 feet	17.5 – 20	Sand					
GC-SB-02	0 – 2.5	Sand, minor black silt, and plant debris					
	2.5 – 5	Black silty clay	x	x	x		
Northing:	5 – 7.5	Black silty clay	x		x		
302889.11	7.5 – 10	Red-brown stiff clay, minor black silty clay	x	x	x	x	x
Easting:	10 – 12.5	Fine sand and clay	x		x	x	x
1008435.3	12.5 – 15	Fine sand and clay	x	x	x	x	x
Elevation:	15 – 17.5	Fine sand, minor clay	x			x	x
12.18 feet	17.5 – 20	Fine sand, minor clay					
GC-SB-03	0 – 2.5	Sand, black silty clay					
	2.5 – 5	Silt, black silty clay	x	x	x		
Northing:	5 – 7.5	Red-brown stiff clay, minor black silty clay	x	x	x		
303098.16	7.5 – 10	Red-brown stiff clay	x				
Easting:	10 – 12.5	Gray-brown stiff clay	x	x	x	x	x
1008623.9	12.5 – 15	Gray stiff clay, minor sand	x			x	x
Elevation:	15 – 17.5	Fine sand, gray					
10.33 feet	17.5 – 20	Gray silt					

Location	Depth (feet bgs)	Sample Description	F/ TOC	SEM	XRD	CEC/ AEC	Fe,Al,Mn Oxides
GC-SB-04 Northing: 303300.68 Easting: 1008802.96 Elevation: 7.416 feet	0 – 2.5	Sand with plant detritus					
	2.5 – 5	Gray-red clay, minor sand, and organic detritus	x				
	5 – 7.5	Organic-rich clay, minor gray clay	x				
	7.5 – 10	Gray clay, minor organic detritus	x		x	x	x
	10 – 12.5	Gray clay, organic detritus	x			x	x
	12.5 – 15	Brown-gray clay, peat layer, minor silty sand	x				
	15 – 17.5	Gray clay, minor silt, and organic detritus	x	x	x	x	x
	17.5 – 20	Brown-gray clay					

Notes:
AEC = anion exchange capacity
Al = aluminum
bgs = below ground surface
CEC = cation exchange capacity
F/TOC = fluoride and total organic carbon
Fe = iron
Mn = manganese
SEM = scanning electron microscopy
XRD = X-ray diffraction

Total fluoride and TOC concentrations were analyzed for all sample depths between 2.5 and 17.5 feet bgs in all four borings except one (GC-SB-03 was only analyzed to a maximum depth of 15 feet bgs). Analyses were performed by Apex Laboratories, LLC (Apex), in Portland, Oregon. Results for total fluoride and TOC are presented in Table 2. These results were used as a guide in selecting samples for more detailed mineralogical and geochemical analyses. The full laboratory report is included in Appendix F of the RI/FS report.

Table 2
Total Fluoride and Total Organic Carbon Concentration Profiles for East Groundwater Area Borings

Location	GC-SB-01		GC-SB-02		GC-SB-03		GC-SB-04	
Depth Interval (feet bgs)	Fluoride (mg/kg)	TOC (mg/kg)	Fluoride (mg/kg)	TOC (mg/kg)	Fluoride (mg/kg)	TOC (mg/kg)	Fluoride (mg/kg)	TOC (mg/kg)
2.5 – 5	1,610	38,000	11,350	320,000	54,000	360,000	703	30,000
5 – 7.5	46,400	57,000	12,600	47,000	10,900	220,000	525	36,000
7.5 – 10	2,610	3,300	2,550	2,400	3,380	28,000	321	4,000
10 – 12.5	956	1,300	1,230	890	407	7,700	298	49,000
12.5 – 15	630	700	616	720	325	9,000	267	22,000

Location	GC-SB-01		GC-SB-02		GC-SB-03		GC-SB-04	
Depth Interval (feet bgs)	Fluoride (mg/kg)	TOC (mg/kg)	Fluoride (mg/kg)	TOC (mg/kg)	Fluoride (mg/kg)	TOC (mg/kg)	Fluoride (mg/kg)	TOC (mg/kg)
15 – 17.5	309	310	414	310	--	--	163	11,000

Notes:
bgs = below ground surface
mg/kg = milligram per kilogram
TOC = total organic carbon

1.2 Powder X-ray Diffraction Results

Selected solid media samples were analyzed by powder XRD to identify major minerals and other crystalline phases. Sample selection included source area soils/solid media, as well as aquifer matrix in both impacted and background areas. XRD analyses were performed by Attard's Minerals, located in San Diego, California. Table 3 summarizes the XRD results, and the XRD report is presented in Attachment 1.

Table 3
Powder X-ray Diffraction Mineral Phase Identification for East Groundwater Area Borings

Location and Depth Interval (feet bgs)	Phase Identification			
	PDF No.	Score	Name	Chemical Formula
GC-SB-01 5 – 7.5	83-0539	46	Quartz	SiO_2
	87-0971	44	Calcium Fluoride	CaF_2
	29-0041	45	Gibbsite	$Al(OH)_3$
	75-1865	45	Aluminum Oxide	Al_2O_3
	21-1095	36	β-Sodium Aluminum Oxide	$NaAl_7O_{11}$
	83-1607	28	Albite	$NaAlSi_3O_8$
	11-0293	19	Brushite	$CaPO_3(OH){:}2H_2O$
	03-0015	9	Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2{:}nH_2O$
GC-SB-01 10 – 12.5	83-1417	76	Labradorite (Feldspar)	$(Ca_{0.64},Na_{0.31})(Al_{1.775}Si_{2.275})O_8$
	46-1045	70	Quartz	SiO_2
	19-1184	58	Albite	$NaAlSi_3O_8$
	13-0259	14	Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2{:}xH_2O$
GC-SB-02 2.5 – 5	33-0018	49	Gibbsite	$Al(OH)_3$
	10-0173	39	Corundum	Al_2O_3
	79-2288	38	Diaoyudaoite	$NaAl_{11}O_{17}$

Location and Depth Interval (feet bgs)	Phase Identification			
	PDF No.	Score	Name	Chemical Formula
	75-0097	27	Fluorite	CaF_2
	11-0293	17	Brushite	$CaPO_3(OH){:}2H_2O$
	82-0218	25	Cryolite	Na_3AlF_6
	29-0323	12	Calcium Monofluorophosphate Hydrate	$CaFPO_3{:}2H_2O$
	33-0284	24	Thadeuite	$CaMg(Mg,Fe,Mn)_3(PO_4)_2(OH,F)_2$
GC-SB-02 5 – 7.5	46-1045	60	Quartz	SiO_2
	71-1124	55	Corundum	Al_2O_3
	75-0097	45	Fluorite	CaF_2
	71-1151	39	Albite	$NaAlSi_3O_8$
	29-0041	36	Gibbsite	$Al(OH)_3$
	72-1406	15	Sodium Aluminum Oxide	$Na_2Al_{22}O_{34}$
	25-0772	37	Cryolite	Na_3AlF_6
GC-SB-02 7.5 – 10	46-1045	65	Quartz	SiO_2
	79-1148	56	Andesine (Feldspar)	$Na_{0.499}Ca_{0.491}Al_{1.488}Si_{2.506}O_8$
	71-1152	36	Albite	$NaAlSi_3O_8$
	12-0232	18	Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{16}(OH)_2{:}xH_2O$
GC-SB-02 10 – 12.5	46-1045	56	Quartz	SiO_2
	20-0548	34	Albite, calcian	$(Na,Ca)(Si,Al)_4O_8$
	71-1150	48	Albite	$NaAlSi_3O_8$
	41-1486	34	Anorthite (Feldspar)	$CaAl_2Si_2O_8$
	02-0037	12	Montmorillonite	$AlSi_2O_6(OH)_2$
GC-SB-02 12.5 – 15	79-1148	50	Andesine (Feldspar)	$Na_{0.499}Ca_{0.491}Al_{1.488}Si_{2.506}O_8$
	33-1161	54	Quartz	SiO_2
	83-1607	30	Albite	$NaAlSi_3O_8$
GC-SB-03 2.5 – 5	05-0712	62	α-Corundum	Al_2O_3
	35-0816	57	Fluorite	CaF_2
	12-0212	48	Graphite	C
	29-0041	41	Gibbsite	$Al(OH)_3$
	21-1096	38	Diaoyudaoite	$NaAl_{11}O_{17}$
	76-0717	27	Sodium Aluminum Silicate Hydroxide	$Na_4Si_3Al_3O_{12}(OH)$
	11-0293	28	Brushite	$CaPO_3(OH){:}2H_2O$
GC-SB-03 5 – 7.5	83-0539	59	Quartz	SiO_2
	71-1123	57	Corundum	Al_2O_3
	75-0097	50	Fluorite	CaF_2
	20-0548	37	Albite, calcian	$(Na,Ca)(Si,Al)_4O_8$
	07-0324	23	Gibbsite	$Al(OH)_3$
	11-0293	18	Brushite	$CaPO_3(OH){:}2H_2O$
	21-1095	23	β-Sodium Aluminum Oxide	$NaAl_7O_{11}$

Location and Depth Interval (feet bgs)	Phase Identification			
	PDF No.	Score	Name	Chemical Formula
	12-0232	9	Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_4O_{16}(OH)_2{:}xH_2O$
GC-SB-03 10 – 12.5	83-0539	60	Quartz	SiO_2
	79-1149	57	Andesine (Feldspar)	$Na_{0.499}Ca_{0.491}Al_{1.488}Si_{2.506}O_8$
	89-1455	26	Sanidine (Feldspar)	$K_{0.42}Na_{0.58}Ca_{0.03}AlSi_3O_8$
	12-0204	8	Montmorillonite	$Na_x(Al,Mg)_2Si_4O_{10}(OH)_2{:}zH_2O$
GC-SB-04 7.5 – 10	83-0539	41	Quartz	SiO_2
	79-1148	37	Andesine (Feldspar)	$Na_{0.499}Ca_{0.491}Al_{1.488}Si_{2.506}O_8$
	75-1631	23	Anorthoclase (Feldspar)	$Na_{0.667}K_{0.333}AlSi_3O_8$
	74-1393	18	Enstatite, ferroan	$Fe_{0.155}\ Mg_{0.845}SiO_3$
	38-0448	19	Opal-A	$SiO_2{:}xH_2O$
	07-0330	16	Illite-Montmorillonite	$K\text{-}Al_4(Si,Al)_8O_{20}(OH)_4{:}xH_2O$
GC-SB-04 15 – 17.5	83-0539	41	Quartz	SiO_2
	71-1151	39	Albite	$NaAlSi_3O_8$
	10-0357	23	Sanidine, K-rich (Feldspar)	$(Na,K)Si_3AlO_8$
	11-0500	15	Aluminum Phosphate	$AlPO_4$
	28-1065	15	Sodium Calcium Oxide Fluoride Phosphate (MFP Apatite)	$Ca_6Na_4(PO_3F)_6O_2$
	29-1499	10	Montmorillonite	$Na_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2{:}8H_2O$

Note:
bgs = below ground surface

1.3 High-resolution Scanning Electron Microscopy Results

High-resolution SEM imaging and microanalysis was used to supplement XRD mineral identifications and examine fluoride-mineral phase associations and distribution. High-resolution SEM work was performed by Anchor QEA personnel at the Center for Electron Microscopy and Nanofabrication at Portland State University. High-resolution SEM imaging and element mapping results are presented in Attachment 2.

1.4 Cation and Anion Exchange Data

CEC, AEC, and concentrations of exchangeable cations (calcium, magnesium, potassium, sodium, and aluminum) and fluoride were determined by the unbuffered salt extraction method, modified from Sumner and Miller (1996). Extractions were performed in Anchor QEA's Environmental Geochemistry Laboratory and solutions were submitted to

Apex for analysis. Results are summarized in Table 4. The full laboratory report is included in Appendix F of the RI/FS report.

Table 4
Cation and Anion Exchange Data

Location	Depth Interval (feet bgs)	Cation Exchange Capacity (meq/kg)	Exchangeable Cations (mmol/kg)					Anion Exchange Capacity (meq/kg)	Exchangeable Fluoride (mmol/kg)
			Ca	Mg	K	Na	Al		
GC-SB-01	10 – 12.5	99.7	11.8	2.57	3.84	176	0.023	5.89	10.4
	15 – 17.5	84.3	5.74	0.99	1.50	50.2	0.155	11.0	9.45
GC-SB-02	7.5 – 10	204	2.35	1.50	2.38	274	0.795	28.7	38.2
	10 – 12.5	143	8.28	2.71	3.08	235	0.173	12.3	32.9
	12.5 – 15	86.9	12.6	1.76	2.03	122	0.060	21.6	18.6
		105.5	12.3	1.71	1.99	122	0.062	28.4	17.7
	15 – 17.5	52.2	40.5	1.16	0.99	73.3	0.023	16.9	17.2
GC-SB-03	10 – 12.5	144	21.7	12.0	1.99	79.8	0.023	19.8	7.18
	12.5 – 15	135	22.7	12.3	2.29	68.9	0.023	8.53	5.66
GC-SB-04	7.5 – 10	140	27.2	12.8	1.53	35.9	0.921	14.9	2.66
	10 – 12.5	171	38.5	16.4	1.36	27.2	0.402	25.1	1.01
	15 – 17.5	150	30.4	13.9	1.09	4.65	0.072	11.1	0.13

Notes:
Al = aluminum
bgs = below ground surface
Ca = calcium
K = potassium
meq/kg = milliequivalents per kilogram
Mg = magnesium
mmol/kg = millimoles per kilogram
Na = sodium

1.5 Extractable Iron, Aluminum, and Manganese Oxide Data

Iron, aluminum, and manganese oxide contents of solid media were determined by selective extraction using the acid ammonium oxalate (AAO) method, modified from Loeppert and Inskeep (1996). Extractions were performed in Anchor QEA's Environmental Geochemistry Laboratory and solutions were submitted to Apex for analysis. Results are summarized in Table 5. The full laboratory report is included in Appendix F of the RI/FS report.

Table 5
Extractable Oxide Concentrations

Location	Depth Interval (feet bgs)	Extractable (Amorphous) Oxides (mmol/kg)		
		Aluminum	Iron	Manganese
GC-SB-01	10 – 12.5	73.2	226	6.48
	15 – 17.5	25.8	193	1.29
GC-SB-02	7.5 – 10	92.8	127	3.83
	10 – 12.5	81.8	157	2.77
	12.5 – 15	45.0	146	1.13
		42.2	139	1.09
	15 – 17.5	18.8	35.5	0.38
GC-SB-03	10 – 12.5	36.7	71.4	1.16
	12.5 – 15	37.0	103	1.08
GC-SB-04	7.5 – 10	62.3	191	4.81
	10 – 12.5	33.8	87.6	1.52
	15 – 17.5	38.5	157	2.17

Notes:
bgs = below ground surface
mmol/kg = millimoles per kilogram

1.6 Geochemical Speciation Modeling

Geochemical speciation modeling was performed to evaluate reactivity and potential solubility controls on porewater, groundwater, surface water, and ditch water as part of the conceptual site model (CSM) development and as a preliminary step to reactive transport modeling. The geochemical modeling software PHREEQC (Parkhurst and Appelo 1999) was used for speciation modeling. Chemical analyses of site groundwater, surface water, and ditch water collected in 2011 and porewater collected from lysimeters in 2012 were used to define solution compositions (data are presented in Section 5 of the RI/FS report). Model input parameters also included water temperature, pH, and redox potential. Saturation index (SI) calculations for selected minerals in each water sample are summarized in Tables 6 (porewater), 7 (groundwater), and 8 (surface and ditch water). The SI is defined as follows:

$$SI_i = log_{10}\left(\frac{IAP}{K_{sp}}\right)_i \quad (1\text{-}1)$$

where:

IAP	=	the ion activity product for the solubility reaction of mineral *i* in the water sample
K_{sp}	=	the solubility product of mineral *i* (ion activity product in a solution in equilibrium with the mineral)

A negative value indicates under-saturation and a tendency for the mineral to dissolve into the solution, while a positive value indicates super-saturation and a tendency for the mineral to precipitate from the solution. Values close to 0 indicate a water chemistry that is close to equilibrium with respect to the mineral.

Table 6
Geochemical Speciation Results for Unsaturated Zone Porewater

Name	Chemical Formula	GC-LY-01	GC-LY-02	GC-LY-03	GC-LY-04	GC-LY-05	GC-LY-06	GC-LY-07	GC-LY-08
Cryolite	Na_3AlF_6	-7.41	-11.81	-4.72	-3.79	-2.72	-3.46	-3.72	-4.27
Chiolite	$Na_5Al_3F_{14}$	-12.96	-25.88	-1.75	-0.69	-1.23	0.24	-1.01	-1.55
Villiaumite	NaF	-4.26	-4.32	-5.04	-4.61	-3.67	-4.60	-4.47	-4.76
Aluminum Fluoride	AlF_3	-8.64	-12.85	-3.59	-3.96	-5.73	-3.68	-4.32	-4.02
Corundum	Al_2O_3	1.14	0.27	-2.22	-1.43	-1.44	-2.52	-2.12	-1.94
β-alumina	$NaAl_9O_{14}$	12.49	10.22	-5.80	-1.73	0.66	-6.73	-3.75	-3.55
β''-alumina	$Na_2Al_{12}O_{19}$	10.70	8.47	-15.71	-9.82	-5.61	-16.67	-12.41	-12.39
Fluorite	CaF_2	0.48	0.28	1.42	0.97	1.72	1.12	1.12	0.90
Fluorapatite	$Ca_5(PO_4)_3F$	6.05	8.13	6.36	4.01	6.06	5.39	5.08	2.58
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	-4.72	-1.40	-6.64	-8.73	-6.15	-7.63	-7.71	-10.27
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	-17.94	-23.31	-6.31	-9.49	-9.33	-5.03	-7.45	-12.13
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	2.16	5.58	1.61	-2.65	2.53	-0.82	-0.34	-6.38
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	-5.75	-2.06	-6.05	-10.38	-5.19	-8.38	-8.14	-13.70
Brushite	$CaHPO_4{:}2H_2O$	-18.33	-18.76	-16.62	-17.35	-17.75	-16.71	-17.10	-17.71
Calcium Monfluorophosphate	$CaPO_3F{:}2H_2O$	-11.23	-12.93	-7.27	-8.26	-9.26	-7.34	-8.03	-8.57
Calcite	$CaCO_3$	0.50	0.43	-0.31	-0.47	0.53	-0.83	-0.23	-1.42
Chalcedony	SiO_2	-0.12	-0.95	0.90	0.85	0.34	0.83	0.82	0.69
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-1.26	-1.50	-6.10	-5.35	-4.52	-6.91	-6.01	-6.43
Albite (Na- Feldspar)	$NaAlSi_3O_8$	3.22	1.49	1.57	2.50	2.49	1.62	2.20	1.56
K-Feldspar	$KAlSi_3O_8$	3.98	2.47	2.72	3.15	3.11	2.55	2.91	2.59
Goethite	$FeO(OH)$	4.96	3.58	3.42	4.58	6.11	2.12	4.26	3.75
Iron (III) Hydroxide	$Fe(OH)_3$	-0.38	-1.77	-1.91	-0.75	0.76	-3.22	-1.09	-1.59
Gibbsite	$Al(OH)_3$	2.23	1.80	0.55	0.94	0.95	0.39	0.61	0.70

Name	Chemical Formula	GC-LY-01	GC-LY-02	GC-LY-03	GC-LY-04	GC-LY-05	GC-LY-06	GC-LY-07	GC-LY-08
Kaolinite	$Al_2Si_2O_5(OH)_4$	5.36	2.84	4.04	4.72	3.71	3.58	3.99	3.91
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	5.46	2.28	4.87	5.52	4.36	4.22	4.92	4.30
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	5.76	2.59	4.76	5.61	4.65	4.30	5.05	4.37

Table 7
Geochemical Speciation Results for East and West Groundwater Areas

		East Groundwater Area											
Name	**Chemical Formula**	**G1-D-072511**	**G1-D-101111**	**G1-S-072511**	**G1-S-101111**	**G2-D-072511**	**G2-D-101111**	**G2-S-072511**	**G2-S-101111**	**G3-D-072811**	**G3-D-101111**	**G3-S-072811**	**G3-S-101111**
Cryolite	Na_3AlF_6	-13.70	-	-7.47	-8.26	-11.91	-	-5.38	-	-10.09	-	-5.61	-5.07
Chiolite	$Na_5Al_3F_{14}$	-21.46	-	-7.43	-8.94	-18.81	-	-5.39	-	-14.12	-	-5.58	-4.39
Villiaumite	NaF	-6.85	-6.45	-5.68	-5.90	-6.17	-6.16	-4.63	-4.70	-5.98	-5.90	-4.75	-4.64
Aluminum Fluoride	AlF_3	-7.05	-	-4.33	-4.46	-7.32	-	-5.40	-	-6.03	-	-5.23	-5.04
Corundum	Al_2O_3	-2.31	-	-2.69	-1.36	0.62	-	-3.48	-	-5.53	-	-5.57	-4.65
Sodium Aluminate	$Na_2Al_2O_4{:}2.5H_2O$	-0.19	-	-0.04	1.31	5.48	-	1.62	-	-3.63	-	-1.68	-0.20
β-alumina	$NaAl_9O_{14}$	-10.71	-	-11.70	-5.95	4.54	-	-14.41	-	-25.96	-	-24.90	-19.96
β''-alumina	$Na_2Al_{12}O_{19}$	-22.77	-	-23.95	-16.27	-1.59	-	-26.72	-	-43.12	-	-41.06	-34.34
Fluorite	CaF_2	-1.96	-1.72	0.70	0.22	-2.24	-2.18	1.02	0.83	-0.07	0.02	1.12	1.18
Fluorapatite	$Ca_5(PO_4)_3F$	8.01	9.15	7.18	9.34	10.25	10.51	12.82	13.33	7.36	8.78	12.19	12.44
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	-3.62	-2.37	-5.46	-3.01	-0.85	-0.80	0.44	1.01	-5.11	-3.60	-0.56	-0.27
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	-5.63	-3.05	-5.34	-2.03	-2.01	-0.12	6.90	8.15	-4.04	-2.21	7.95	7.92
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	3.18	5.46	2.06	5.59	7.89	8.13	13.19	13.80	2.02	4.70	11.09	11.69
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	-5.74	-3.49	-5.70	-2.32	-1.34	-1.06	5.04	5.60	-6.11	-3.45	3.21	3.83
Brushite	$CaHPO_4{:}2H_2O$	-14.97	-14.79	-16.05	-15.28	-14.61	-14.36	-14.60	-14.34	-15.57	-15.27	-14.48	-14.53
Calcium Monofluorophosphate	$CaPO_3F{:}2H_2O$	-6.64	-6.49	-6.74	-6.21	-6.90	-6.46	-5.54	-5.29	-6.36	-6.19	-5.01	-5.16
Calcite	$CaCO_3$	-0.40	-0.05	-0.60	-0.58	0.22	0.06	0.60	0.53	-0.57	-0.41	-0.05	0.01
Quartz	SiO_2	1.41	1.31	0.97	0.92	1.31	1.30	1.20	1.18	1.19	1.18	1.19	1.21
Chalcedony	SiO_2	1.13	1.03	0.69	0.64	1.03	1.02	0.92	0.90	0.91	0.90	0.91	0.93
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-6.65	-	-7.21	-5.90	-3.07	-	-6.75	-	-10.12	-	-9.52	-8.37
Albite (Na-Feldspar)	$NaAlSi_3O_8$	1.50	-	0.20	0.77	3.94	-	1.77	-	-0.78	-	0.17	0.88
K-Feldspar	$KAlSi_3O_8$	2.44	-	2.51	3.13	4.62	-	2.85	-	0.92	-	0.85	1.57
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	4.84	-	4.54	6.49	9.97	-	4.08	-	0.08	-	-0.02	1.63
Goethite	FeO(OH)	-1.32	0.29	0.27	1.05	-2.84	0.19	-0.80	0.26	-0.01	0.93	-0.66	0.40
Iron (III) Hydroxide	$Fe(OH)_3$	-6.59	-4.95	-5.00	-4.22	-8.12	-5.10	-6.06	-4.99	-5.25	-4.33	-5.92	-4.86
Gibbsite	$Al(OH)_3$	0.42	-	0.24	0.90	1.90	-	-0.16	-	-1.20	-	-1.22	-0.75
Kaolinite	$Al_2Si_2O_5(OH)_4$	4.28	-	3.04	4.27	7.04	-	2.70	-	0.60	-	0.58	1.55
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	5.25	-	3.54	4.48	7.76	-	4.23	-	1.77	-	2.08	3.04
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	5.06	-	3.31	4.25	7.85	-	4.29	-	1.55	-	2.07	3.07

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Name	Chemical Formula	East Groundwater Area											
		G4-D-072811	G4-D-101111	G4-S-072611	G4-S-101011	PZ-1S-072611	PZ-1S-100711	PZ-2D-072611	PZ-2D-100711	PZ-3-072711	PZ-3-100711	PZ-4-072711	PZ-4-101011
Cryolite	Na_3AlF_6	-16.71	-	-	-	-4.18	-4.61	-1.54	-2.28	-2.76	-2.43	-0.44	0.36
Chiolite	$Na_5Al_3F_{14}$	-27.23	-	-	-	-5.83	-7.16	-0.96	-2.98	-1.10	-0.82	0.32	2.48
Villiaumite	NaF	-7.67	-7.67	-	-8.03	-3.61	-3.60	-2.85	-2.90	-3.74	-3.56	-2.35	-2.29
Aluminum Fluoride	AlF_3	-7.64	-	-	-	-7.17	-7.67	-6.82	-7.46	-5.43	-5.61	-7.28	-6.65
Corundum	Al_2O_3	-0.16	-	-	-	-0.18	-0.15	-1.09	-1.52	-0.71	-0.25	-1.10	-0.98
Sodium Aluminate	$Na_2Al_2O_4{:}2.5H_2O$	1.73	-	-	-	8.67	9.41	8.76	9.00	6.96	7.70	10.49	10.35
β-alumina	$NaAl_9O_{14}$	-0.22	-	-	-	0.53	2.12	-3.01	-3.03	-1.16	-0.06	-0.83	-0.38
β''-alumina	$Na_2Al_{12}O_{19}$	-8.94	-	-	-	-5.40	-3.14	-9.79	-9.73	-8.15	-6.50	-6.42	-5.91
Fluorite	CaF_2	-2.51	-2.39	-	-2.59	1.38	1.42	1.48	1.48	1.47	1.50	2.02	2.17
Fluorapatite	$Ca_5(PO_4)_3F$	10.68	6.98	-	8.48	15.02	15.68	12.09	12.55	13.01	13.52	14.88	15.07
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	-0.47	-4.37	-3.76	-2.93	3.91	4.66	0.70	1.19	1.13	1.86	3.54	3.54
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	-5.83	-12.16	-	-9.29	4.77	4.57	3.70	3.26	5.24	5.81	7.91	9.40
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	8.07	1.73	-	3.62	16.89	18.32	12.02	13.03	13.53	14.59	17.36	17.70
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	-1.13	-7.41	-	-5.45	9.18	10.60	4.29	5.31	5.73	6.74	9.78	10.15
Brushite	$CaHPO_4{:}2H_2O$	-14.26	-15.37	-14.91	-14.67	-15.27	-15.24	-16.04	-16.02	-15.32	-15.31	-15.62	-15.47
Calcium Monofluorophosphate	$CaPO_3F{:}2H_2O$	-6.52	-7.44	-	-6.68	-7.30	-7.47	-7.81	-7.97	-6.72	-6.81	-7.57	-7.24
Calcite	$CaCO_3$	-0.14	-0.24	-0.68	-0.64	0.78	0.89	0.77	0.77	0.62	0.88	1.03	1.03
Quartz	SiO_2	1.33	1.31	1.40	1.36	0.52	0.62	0.52	0.50	0.81	0.79	0.24	0.30
Chalcedony	SiO_2	1.04	1.03	1.12	1.08	0.24	0.34	0.24	0.22	0.53	0.51	-0.04	0.02
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-4.17	-	-	-	-2.05	-1.50	-3.41	-3.70	-3.35	-2.55	-3.21	-3.21
Albite (Na-Feldspar)	$NaAlSi_3O_8$	2.06	-	-	-	3.51	4.03	3.54	3.38	3.33	3.81	3.39	3.47
K-Feldspar	$KAlSi_3O_8$	3.98	-	-	-	3.74	4.34	3.84	3.75	3.85	4.27	3.57	3.64
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	8.56	-	-	-	8.21	8.88	7.40	6.93	7.83	8.68	7.17	7.36
Goethite	FeO(OH)	-1.59	-0.28	-1.08	-0.20	2.00	4.33	1.70	5.38	0.36	2.55	2.13	4.25
Iron (III) Hydroxide	$Fe(OH)_3$	-6.87	-5.56	-6.36	-5.48	-3.23	-0.92	-3.53	0.12	-4.89	-2.68	-3.12	-1.01
Gibbsite	$Al(OH)_3$	1.52	-	-	-	1.45	1.49	0.99	0.81	1.21	1.41	1.02	1.08
Kaolinite	$Al_2Si_2O_5(OH)_4$	6.29	-	-	-	4.57	4.84	3.66	3.24	4.65	5.04	3.15	3.37
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	6.99	-	-	-	5.30	5.92	4.57	4.27	5.58	6.06	3.90	4.08
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	6.63	-	-	-	5.62	6.24	5.12	4.82	5.85	6.38	4.54	4.72

(page 2 of 5)

Name	Chemical Formula	East Groundwater Area								West Groundwater Area			
		PZ-5-072511	PZ-5-101011	R-1D-100511	R-1S-100511	R-2-100511	R-3-100511	R-4D-100511	R-4S-100511	G5-D-072811	G5-D-100711	G5-S-072811	G5-S-100711
Cryolite	Na_3AlF_6	-0.20	-	-	-7.41	-	-	-	-	-19.57	-	-20.02	-
Chiolite	$Na_5Al_3F_{14}$	-1.12	-	-	-8.23	-	-	-	-	-32.01	-	-33.67	-
Villiaumite	NaF	-1.81	-1.85	-6.95	-5.44	-7.68	-1.85	-6.63	-5.31	-8.61	-8.55	-8.54	-8.51
Aluminum Fluoride	AlF_3	-8.66	-	-	-4.98	-	-	-	-	-7.64	-	-8.35	-
Corundum	Al_2O_3	-3.01	-	-	-2.74	-	-	-	-	-3.85	-	0.10	-
Sodium Aluminate	$Na_2Al_2O_4{:}2.5H_2O$	10.01	-	-	0.66	-	-	-	-	-5.23	-	0.96	-
β-alumina	$NaAl_9O_{14}$	-8.43	-	-	-12.07	-	-	-	-	-18.92	-	0.97	-
β''-alumina	$Na_2Al_{12}O_{19}$	-16.10	-	-	-24.15	-	-	-	-	-34.92	-	-7.75	-
Fluorite	CaF_2	2.02	-	-1.83	0.92	-2.44	1.94	-1.11	0.51	-3.15	-3.02	-3.23	-3.12
Fluorapatite	$Ca_5(PO_4)_3F$	11.62	-	9.54	10.51	7.93	11.60	9.47	11.76	3.74	6.28	7.89	6.33
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	0.41	-	-2.00	-1.88	-3.50	0.13	-2.38	-0.67	-7.99	-5.10	-3.01	-4.56
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	2.37	-3.45	-4.85	-0.46	-9.76	4.11	-4.02	4.34	-15.98	-14.60	-14.29	-17.81
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	11.18	1.19	6.25	7.59	1.92	11.37	5.88	10.60	-6.19	-1.12	2.41	-0.14
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	3.90	-6.14	-2.72	-0.04	-6.78	3.94	-2.70	2.43	-15.03	-10.03	-6.76	-9.26
Brushite	$CaHPO_4{:}2H_2O$	-16.85	-	-14.70	-15.29	-14.97	-16.60	-14.88	-14.58	-15.53	-15.18	-14.98	-15.58
Calcium Monofluorophosphate	$CaPO_3F{:}2H_2O$	-8.96	-9.92	-6.58	-6.21	-7.01	-8.52	-6.43	-5.50	-7.16	-7.27	-7.55	-8.16
Calcite	$CaCO_3$	0.50	-	-0.14	-0.55	-1.22	0.60	-0.38	0.09	-1.81	-1.36	-0.78	-0.76
Quartz	SiO_2	0.02	-0.26	1.33	1.23	1.35	0.16	1.36	1.26	1.36	1.39	1.34	1.35
Chalcedony	SiO_2	-0.26	-0.54	1.04	0.95	1.07	-0.12	1.08	0.98	1.08	1.10	1.06	1.07
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-5.29	-	-	-6.07	-	-	-	-	-9.62	-	-4.06	-
Albite (Na-Feldspar)	$NaAlSi_3O_8$	2.45	-	-	1.40	-	-	-	-	-1.23	-	1.66	-
K-Feldspar	$KAlSi_3O_8$	2.69	-	-	2.95	-	-	-	-	1.25	-	4.09	-
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	4.39	-	-	4.92	-	-	-	-	2.13	-	8.95	-
Goethite	$FeO(OH)$	4.50	4.98	-1.38	0.90	0.25	1.19	0.65	0.27	-0.89	0.12	0.99	1.24
Iron (III) Hydroxide	$Fe(OH)_3$	-0.77	-0.29	-6.66	-4.36	-5.05	-4.09	-4.63	-5.00	-6.16	-5.18	-4.31	-4.05
Gibbsite	$Al(OH)_3$	0.07	-	-	0.20	-	-	-	-	-0.34	-	1.66	-
Kaolinite	$Al_2Si_2O_5(OH)_4$	0.80	-	-	3.49	-	-	-	-	2.66	-	6.61	-
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	1.47	-	-	4.82	-	-	-	-	3.08	-	7.17	-
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	2.29	-	-	4.62	-	-	-	-	2.52	-	6.65	-

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Name	Chemical Formula	West Groundwater Area											
		G6-D-072611	G6-D-101011	G6-S-072611	G6-S-101011	G7-D-072811	G7-D-100711	PZ-6-072711	PZ-6-100711	PZ-7-072711	PZ-7-100711	RL-1D-100611	RL-1S-100611
Cryolite	Na_3AlF_6	-	-	-3.37	-3.26	-13.14	-	-7.44	-7.81	-5.41	-5.31	-	-8.39
Chiolite	$Na_5Al_3F_{14}$	-	-	-0.73	-1.16	-20.08	-	-13.94	-15.49	-5.04	-4.72	-	-9.74
Villiaumite	NaF	-6.60	-6.12	-4.28	-4.09	-6.78	-6.94	-4.03	-3.93	-4.74	-4.75	-7.93	-5.80
Aluminum Fluoride	AlF_3	-	-	-4.42	-4.90	-6.73	-	-9.26	-9.93	-5.02	-4.98	-	-4.93
Corundum	Al_2O_3	-	-	-4.05	-2.74	-4.37	-	0.16	-1.13	-3.08	-3.05	-	-6.04
Sodium Aluminate	$Na_2Al_2O_4{:}2.5H_2O$	-	-	0.89	3.55	-2.79	-	10.46	9.11	1.06	1.68	-	-4.10
β-alumina	$NaAl_9O_{14}$	-	-	-17.05	-9.79	-19.58	-	5.29	-1.46	-15.08	-12.63	-	-26.37
β''-alumina	$Na_2Al_{12}O_{19}$	-	-	-30.30	-20.23	-34.83	-	1.22	-7.72	-27.76	-24.47	-	-43.81
Fluorite	CaF_2	-2.12	-1.35	1.75	1.51	-1.57	-1.67	0.58	0.50	0.59	0.60	-2.28	-0.17
Fluorapatite	$Ca_5(PO_4)_3F$	-	8.80	12.82	14.46	4.75	7.36	15.56	15.77	12.37	12.34	9.71	4.31
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	-	-3.04	0.01	1.99	-7.38	-4.15	5.02	5.30	0.06	-0.11	-1.52	-8.74
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	-5.31	-2.50	8.76	10.65	-9.86	-10.03	1.30	2.45	7.76	7.69	-9.18	-5.33
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	4.23	5.40	12.53	15.74	-2.60	2.60	18.62	18.86	11.16	11.41	6.54	-4.18
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	-4.98	-3.52	4.89	7.94	-11.31	-6.27	10.48	10.69	3.11	3.34	-2.59	-12.04
Brushite	$CaHPO_4{:}2H_2O$	-	-14.96	-14.67	-14.34	-15.86	-15.56	-15.29	-15.18	-14.42	-14.42	-14.66	-16.06
Calcium Monofluorophosphate	$CaPO_3F{:}2H_2O$	-6.89	-6.53	-5.18	-5.26	-7.11	-7.45	-8.15	-8.02	-5.24	-5.29	-6.85	-6.43
Calcite	$CaCO_3$	0.13	0.08	0.08	0.35	-0.73	-0.16	1.17	1.19	0.01	-0.02	-0.10	-1.53
Quartz	SiO_2	1.33	1.32	1.09	1.09	1.26	1.24	0.95	0.85	1.28	1.32	1.36	1.18
Chalcedony	SiO_2	1.05	1.04	0.81	0.80	0.98	0.95	0.67	0.57	1.00	1.04	1.08	0.90
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-	-	-7.65	-5.88	-9.55	-	-0.31	-1.81	-6.62	-6.63	-	-11.77
Albite (Na-Feldspar)	$NaAlSi_3O_8$	-	-	1.08	2.28	-0.34	-	5.34	4.49	2.01	2.16	-	-1.32
K-Feldspar	$KAlSi_3O_8$	-	-	2.12	3.28	1.10	-	5.51	4.60	2.57	2.80	-	-0.41
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	-	-	2.79	5.28	1.47	-	10.40	8.18	4.14	4.46	-	-1.69
Goethite	$FeO(OH)$	-1.06	-0.15	0.14	4.58	-1.57	-0.32	1.34	6.04	-1.99	2.49	0.74	0.92
Iron (III) Hydroxide	$Fe(OH)_3$	-6.31	-5.43	-5.12	-0.70	-6.85	-5.60	-3.94	0.78	-7.21	-2.78	-4.55	-4.37
Gibbsite	$Al(OH)_3$	-	-	-0.45	0.22	-0.59	-	1.67	1.01	-0.01	0.05	-	-1.41
Kaolinite	$Al_2Si_2O_5(OH)_4$	-	-	1.91	3.23	1.95	-	5.86	4.34	3.18	3.37	-	0.14
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	-	-	3.14	4.49	2.69	-	7.65	6.22	4.50	4.71	-	0.79
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	-	-	3.20	4.65	2.47	-	7.99	6.60	4.57	4.80	-	0.66

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Name	Chemical Formula	West Groundwater Area										
		RL-2D-100611	RL-2S-100611	RL-3D-100611	RL-3S-100611	RL-4D-100611	RL-4S-100611	RL-5-100711	RLSW-1-101011	RLSW-2-101111	RLSW-3-101111	RLSW-4-101011
Cryolite	Na_3AlF_6	-6.74	-	-	-	-	-	-10.14	-	-3.34	-7.62	-2.83
Chiolite	$Na_5Al_3F_{14}$	-7.90	-	-	-	-	-	-12.87	-	-0.57	-8.59	-0.42
Villiaumite	NaF	-5.02	-4.45	-7.94	-5.95	-7.84	-7.28	-6.33	-4.41	-4.30	-5.51	-3.96
Aluminum Fluoride	AlF_3	-5.62	-	-	-	-	-	-5.12	-	-4.34	-5.05	-4.87
Corundum	Al_2O_3	-4.75	-	-	-	-	-	-1.48	-	-5.95	-6.58	-5.54
Sodium Aluminate	$Na_2Al_2O_4{:}2.5H_2O$	-0.27	-	-	-	-	-	1.27	-	-1.60	-4.04	-0.02
β-alumina	$NaAl_9O_{14}$	-19.03	-	-	-	-	-	-4.75	-	-25.49	-28.15	-23.08
β''-alumina	$Na_2Al_{12}O_{19}$	-33.21	-	-	-	-	-	-14.77	-	-41.77	-46.02	-38.18
Fluorite	CaF_2	0.46	-0.80	-2.48	-0.26	-2.52	-1.85	-1.75	1.11	1.43	0.01	1.78
Fluorapatite	$Ca_5(PO_4)_3F$	11.16	13.28	9.94	11.02	10.34	8.31	1.23	12.24	8.91	6.13	13.99
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	-1.45	3.20	-1.19	-1.02	-0.92	-3.24	-11.05	-0.55	-4.27	-6.99	1.06
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	5.27	-3.03	-8.73	0.26	-5.95	-7.07	-13.50	9.35	4.87	-0.82	13.02
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	9.71	14.51	6.87	9.00	6.28	2.45	-9.64	11.11	5.03	0.10	14.57
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	1.50	5.83	-2.33	0.64	-2.58	-6.08	-17.92	3.27	-2.53	-8.07	6.90
Brushite	$CaHPO_4{:}2H_2O$	-14.64	-15.58	-14.54	-14.71	-14.21	-14.93	-16.85	-14.46	-15.42	-15.52	-14.20
Calcium Monofluorophosphate	$CaPO_3F{:}2H_2O$	-5.49	-8.89	-6.83	-6.01	-6.31	-6.56	-8.01	-5.01	-5.60	-5.85	-4.63
Calcite	$CaCO_3$	0.04	1.12	-0.11	-0.07	-0.89	-1.05	-1.72	-0.15	-0.59	-0.75	0.09
Quartz	SiO_2	1.44	0.70	1.36	1.27	1.35	1.22	0.96	1.23	1.07	1.29	1.13
Chalcedony	SiO_2	1.15	0.41	1.08	0.99	1.07	0.94	0.67	0.95	0.79	1.00	0.85
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-8.46	-	-	-	-	-	-7.65	-	-10.62	-12.05	-9.24
Albite (Na-Feldspar)	$NaAlSi_3O_8$	1.32	-	-	-	-	-	0.59	-	-0.29	-1.03	0.69
K-Feldspar	$KAlSi_3O_8$	2.15	-	-	-	-	-	1.30	-	0.31	0.06	1.66
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	2.16	-	-	-	-	-	4.59	-	-0.91	-1.76	0.85
Goethite	FeO(OH)	-0.48	4.75	0.58	1.02	0.49	1.02	0.79	0.14	0.02	-1.06	0.69
Iron (III) Hydroxide	$Fe(OH)_3$	-5.78	-0.53	-4.70	-4.25	-4.78	-4.21	-4.52	-5.13	-5.25	-6.35	-4.58
Gibbsite	$Al(OH)_3$	-0.76	-	-	-	-	-	0.88	-	-1.39	-1.68	-1.18
Kaolinite	$Al_2Si_2O_5(OH)_4$	1.94	-	-	-	-	-	4.27	-	-0.02	-0.18	0.52
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	3.65	-	-	-	-	-	3.73	-	1.04	0.81	2.03
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	3.68	-	-	-	-	-	3.70	-	1.14	0.75	2.19

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Note:

East and West Groundwater Area results are labeled by Well ID and date of sample collection.

Table 8

Geochemical Speciation Results for Site Surface Water and Ditch Water

Mineral Name	Chemical Formula	W1-080111	W1-101211	W2-080111	W2-101211	W3-080111	W3-101211	W4-080111	W4-101211	W5-080111	W5-101211	W6-080111	W6-101211	W7-080111	W7-101211
Cryolite	Na_3AlF_6	-19.61	-	-	-	-14.91	-	-13.22	-	-	-	-19.80	-	-19.54	-
Chiolite	$Na_5Al_3F_{14}$	-32.77	-	-	-	-23.75	-	-21.01	-	-	-	-33.34	-	-32.40	-
Villiaumite	NaF	-8.45	-8.61	-8.35	-8.19	-7.18	-7.11	-6.60	-6.66	-	-8.76	-8.45	-8.46	-8.49	-8.63
Aluminum Fluoride	AlF_3	-8.05	-	-	-	-7.07	-	-7.13	-	-	-	-8.19	-	-7.89	-
Corundum	Al_2O_3	-0.06	-	-	-	-0.22	-	-0.68	-	0.32	-	0.75	-	0.20	-
Sodium Aluminate	$Na_2Al_2O_4{:}2.5H_2O$	-0.63	-	-	-	0.23	-	0.90	-	-0.19	-	0.09	-	-0.21	-
β-alumina	$NaAl_9O_{14}$	-4.83	-	-	-	-7.65	-	-8.90	-	-3.96	-	-2.71	-	-2.73	-
β''-alumina	$Na_2Al_{12}O_{19}$	-15.59	-	-	-	-18.79	-	-20.10	-	-14.34	-	-12.67	-	-12.81	-
Fluorite	CaF_2	-3.57	-3.65	-3.42	-2.92	-1.77	-1.67	-1.09	-1.14	-	-3.74	-3.49	-3.36	-3.66	-3.68
Fluorapatite	$Ca_5(PO_4)_3F$	3.72	2.96	3.94	1.78	7.01	6.58	9.45	7.14	-	5.17	3.55	2.09	3.73	5.18
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	-7.01	-8.25	-6.43	-9.69	-3.89	-4.65	-1.53	-4.41	-6.71	-4.41	-6.89	-9.03	-7.07	-5.85
MFP Apatite	$Ca_6Na_4(PO_3F)_6O_2$	-19.84	-19.21	-21.50	-21.12	-12.52	-13.90	-7.59	-10.61	-	-27.47	-21.94	-22.44	-19.59	-16.03
Carbonate-Fluorapatite (Jahnke)	$Ca_{10}(PO_4)_5(CO_3)_{1.5}F_2$	-6.63	-8.29	-5.91	-9.53	-0.08	0.03	4.77	1.37	-	-2.66	-6.69	-8.91	-6.48	-4.42
Carbonate-Fluorapatite (Perrone)	$Ca_{10}(PO_4)_5(CO_3)(OH)_{0.28}F_{2.72}$	-15.49	-17.06	-14.79	-18.17	-8.48	-8.39	-3.53	-6.97	-	-11.73	-15.58	-17.74	-15.40	-13.22
Brushite	$CaHPO_4{:}2H_2O$	-16.05	-15.92	-16.33	-16.58	-15.82	-16.03	-15.40	-15.88	-16.57	-16.69	-16.35	-16.52	-15.98	-15.32
Calcium Monofluorophosphate	$CaPO_3F{:}2H_2O$	-8.36	-7.98	-8.83	-8.45	-7.69	-8.11	-7.23	-7.66	-	-10.28	-8.80	-8.71	-8.30	-7.55
Calcite	$CaCO_3$	-1.66	-2.17	-1.27	-1.84	-0.87	-0.91	-0.45	-0.72	-1.53	-0.75	-1.37	-1.70	-1.65	-2.05
Quartz	SiO_2	1.07	0.96	0.97	1.06	0.87	1.02	0.85	1.01	0.30	0.42	0.88	1.04	1.11	0.95
Chalcedony	SiO_2	0.80	0.68	0.69	0.78	0.60	0.74	0.57	0.73	0.03	0.14	0.61	0.75	0.83	0.67
Anorthite (Ca-Feldspar)	$CaAl_2Si_2O_8$	-5.08	-	-	-	-4.40	-	-4.35	-	-5.31	-	-4.12	-	-4.91	-
Albite (Na-Feldspar)	$NaAlSi_3O_8$	0.71	-	-	-	0.90	-	1.13	-	-1.27	-	0.70	-	0.89	-
K-Feldspar	$KAlSi_3O_8$	2.86	-	-	-	2.57	-	2.53	-	0.84	-	2.59	-	3.05	-
Muscovite	$KAl_3Si_3O_{10}(OH)_2$	7.41	-	-	-	6.86	-	6.38	-	5.74	-	7.90	-	7.89	-
Goethite	FeO(OH)	1.12	0.89	1.96	1.30	3.55	3.69	2.91	3.09	4.29	4.44	2.41	1.42	1.07	1.33
Iron (III) Hydroxide	$Fe(OH)_3$	-4.07	-4.36	-3.20	-3.97	-1.59	-1.57	-2.24	-2.17	-0.89	-0.78	-2.76	-3.84	-4.15	-3.92
Gibbsite	$Al(OH)_3$	1.48	-	-	-	1.33	-	1.11	-	1.64	-	1.84	-	1.63	-
Kaolinite	$Al_2Si_2O_5(OH)_4$	5.76	-	-	-	5.08	-	4.59	-	4.56	-	6.12	-	6.12	-
Ca-Montmorillonite	$Ca_{0.165}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	5.69	-	-	-	5.23	-	5.04	-	3.25	-	5.76	-	5.99	-
Na-Montmorillonite	$Na_{0.33}Mg_{0.33}Al_{1.67}Si_4O_{10}(OH)_2$	5.22	-	-	-	4.85	-	4.75	-	2.68	-	5.26	-	5.52	-

Note:
Results are labeled by location and date of sample collection.

2 GROUNDWATER FLOW AND REACTIVE TRANSPORT MODELING

Groundwater flow and transport modeling was performed to evaluate fluoride fate and transport to document the CSM and support development and evaluation of remedial alternatives in the FS. First, groundwater flow at the site was simulated using the U.S. Geological Survey (USGS) three-dimensional (3-D) finite-difference groundwater modeling software MODFLOW-2005 (Harbaugh 2005). Then, fluoride transport was modeled using the USGS modeling software PHAST (Parkhurst et al. 2010), which simulates multi-component, reactive solute transport in 3-D groundwater flow systems. The main modeling objectives were to quantitatively evaluate: 1) fluoride natural attenuation processes; 2) groundwater fluoride transport to internal site and Consolidated Diking Improvement District (CDID) ditches; and 3) the effectiveness of the different capping alternatives. The groundwater flow model was also used to support technology screening.

Section 2 is divided into the following subsections:

- 2.1 – Groundwater Flow Modeling
  - 2.1.1 – Groundwater Flow Model Setup and Calibration
  - 2.1.2 – Seasonal Variation Model Scenarios
  - 2.1.3 – Fill Deposit Dewatering Model Scenario
- 2.2 – Geochemical Reactive Transport Modeling
  - 2.2.1 – Geochemical Reactive Transport Model Setup and Calibration
  - 2.2.2 – East Groundwater Area Reactive Transport Simulations
  - 2.2.3 – West Groundwater Area Reactive Transport Simulations
  - 2.2.4 – FS Remedial Alternative 4 Reactive Transport Simulations

2.1 Groundwater Flow Modeling

As mentioned above, groundwater flow was simulated using the 3-D groundwater modeling software MODFLOW-2005. The East and West Groundwater Areas were modeled as one contiguous area to accurately simulate groundwater flow across the site. Pre-processing and post-processing of hydrogeologic data associated with the groundwater flow modeling was performed using the USGS software package ModelMuse (Winston 2009), which provides a graphical user interface (GUI) for creating the input files needed to run MODFLOW-2005, as well as a means for viewing the output files.

2.1.1 Groundwater Flow Model Setup and Calibration

The groundwater flow model was set up using the ModelMuse GUI. Table 9 lists the model input parameters. Figure 1 illustrates the model domain, as well as model input parameter boundaries. The groundwater flow model was set up to simulate steady state flow in an unconfined aquifer. In order to model the East and West Groundwater Areas as one contiguous area, the horizontal grid spacing was set to 5 by 5 meters, while the vertical grid spacing was set at 1 meter. The hydraulic conductivity values input into the model were based on slug testing conducted at the site in October 2006. The Columbia River, CDID, and internal ditches were represented as constant head boundaries. Surface water level measurements, collected from staff gauges (installed during the 2012 tidal study) located across the site, were used to define constant head values. As described in Section 4 of the RI/FS report, groundwater generally flows from upgradient locations through historical source areas, with groundwater ultimately discharging into segments of the CDID ditch system. Recharge areas at the site were defined based on the 2011 National Pollutant Discharge Elimination System (NPDES) Application Engineering Report (Anchor QEA 2011). Three different groundwater flow scenarios were modeled; representing site conditions during the dry and wet seasons, as well as long-term average site conditions.

Table 9
Groundwater Flow Model Input Parameters

Hydrogeologic Parameters		Units	Dry Season[1]	Wet Season[2]	Long-term Average
Model Domain (X × Y × Z)		m	2900 × 2700 × 15		
Horizontal Grid Spacing (X × Y)		m	5 × 5		
Vertical Grid Spacing		m	1		
Porosity		-	0.35		
Recharge		m/yr	0.061	0.366	0.305
Hydraulic Conductivity	Horizontal (K_x=K_y)	m/yr	556		
	Vertical (K_z)	m/yr	55.6		

Hydrogeologic Parameters		Units	Dry Season[1]	Wet Season[2]	Long-term Average
Constant Head Boundaries (Surface Water)	CDID Ditch No.5	m	0.28	1.20	1.25
	CDID Ditch No.10	m	0.28	1.20	1.25
	CDID Ditch No.14	m	0.26	1.16	1.25
	Columbia River	m	1.86	3.00	2.60
	U-Ditch	m	1.68	2.00	1.81
	Dredge Material Storage Area Pond	m	2.26	3.40	3.00
	Cryolite Area Ditches	m	2.75	3.50	3.18
	004PS Ditch A[3]	m	0.70	1.58	1.29
	004PS Ditch B[4]	m	2.00	2.11	2.10

Notes:
1. Based on site measurements collected in October 2012
2. Based on site measurements collected in December 2012
3. Internal ditch, adjacent to Fill Deposit A, draining to 004 Pump Station
4. Internal ditch, adjacent to Fill Deposits B-1 and B-2, draining to 004 Pump Station

m = meter
yr = year

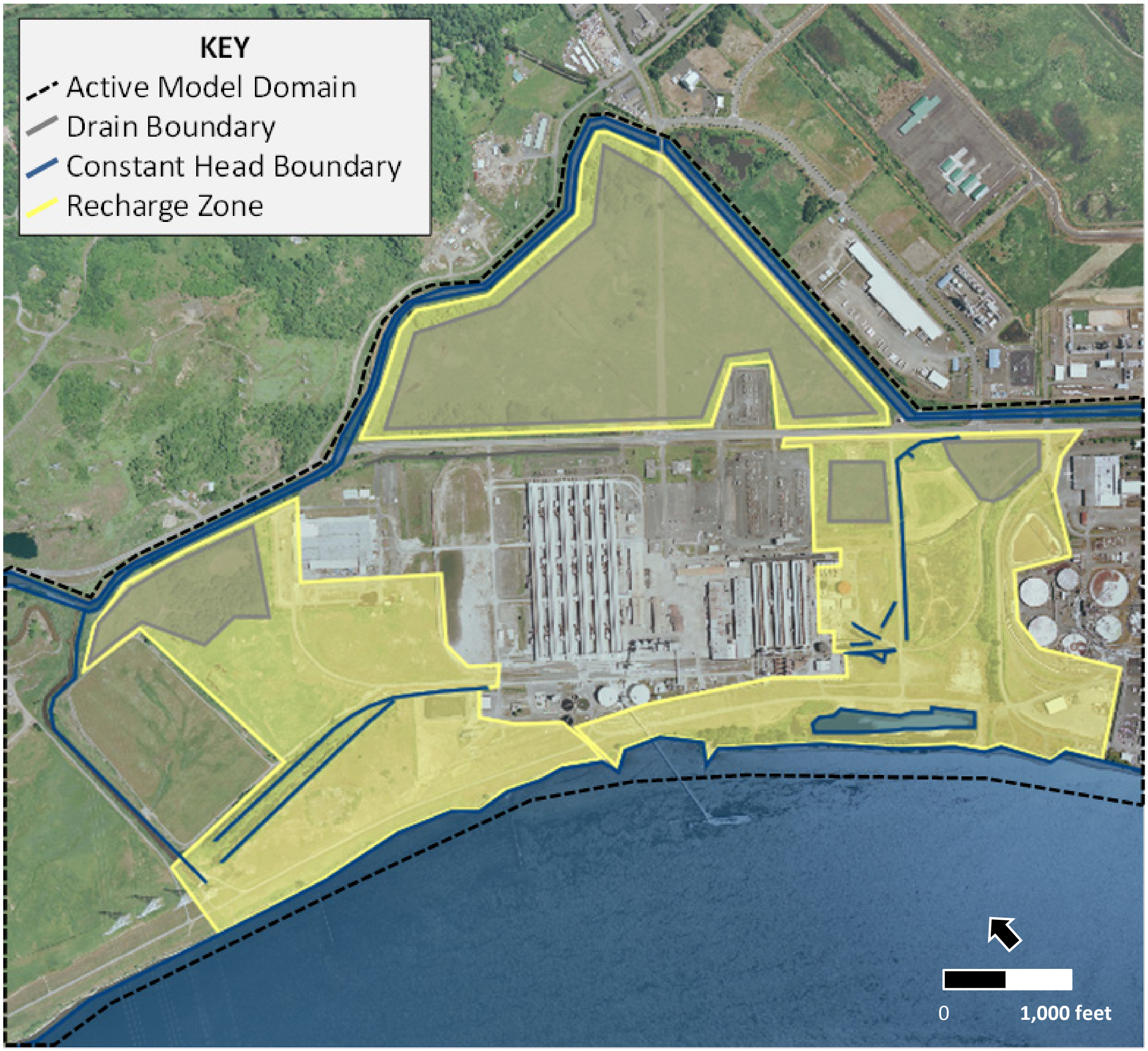

Figure 1
Groundwater Flow Model Domain and Input Parameter Boundaries

The groundwater flow model was calibrated by adjusting the hydraulic conductivity and recharge and running iterative model simulations to best match the calculated groundwater head to measured values (collected in October and December 2012). Separate model calibrations were performed for the wet and dry seasons. A hydraulic conductivity of 5.0 feet/day (556 meters per year) was determined to produce the best overall match to observed heads for both the wet and dry seasons (this value is within the range of hydraulic conductivities estimated from slug tests and is consistent with the types of soils observed in the shallow water bearing zone [WBZ]). The average annual precipitation for Longview, Washington, is 48 inches (i.e., 1.22 meters per year). For the wet season, a recharge amount equal to 30% of annual precipitation was determined to best represent site conditions; during the dry season, recharge was set to 5% of annual precipitation. Groundwater elevations measured in site monitoring wells on October 1 and December 18, 2012 (representing the dry and wet seasons, respectively) were compared to the groundwater elevations calculated in the dry and wet season flow models as a calibration check. The average difference between calculated and measured groundwater elevations shown in Figure 2 is 1.3 feet and indicates very good model calibration to both dry and wet conditions.

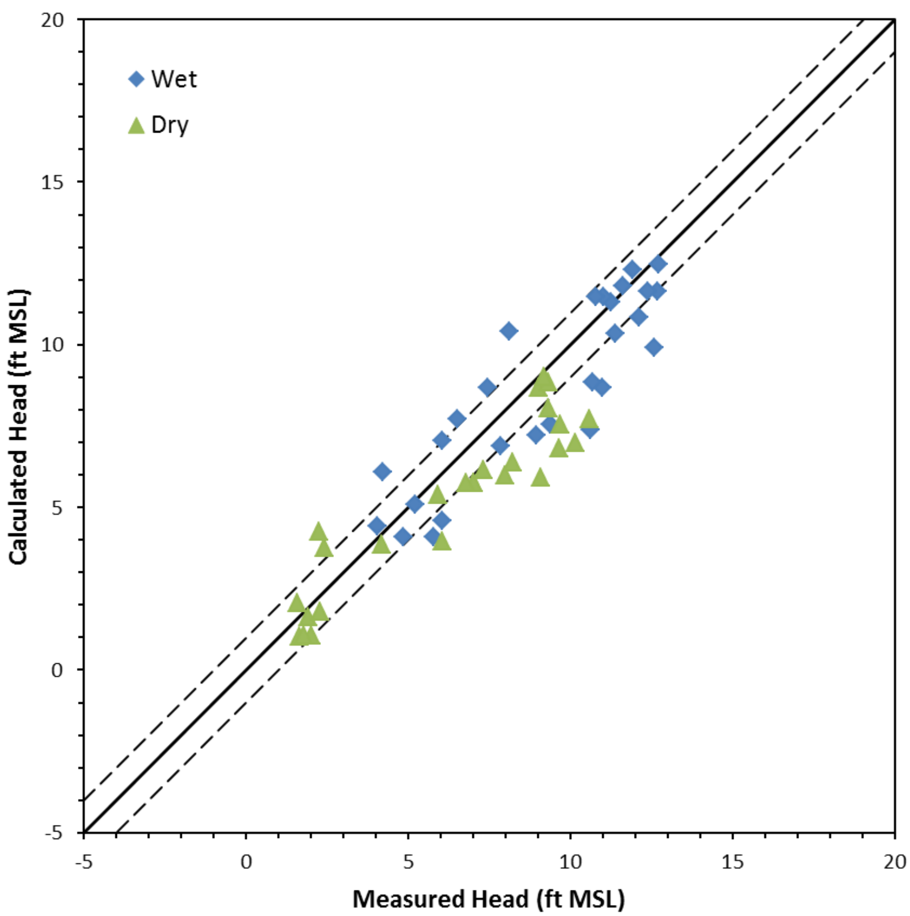

Figure 2
Calculated versus Measured Groundwater Elevations for the Wet and Dry Seasons

2.1.2 Seasonal Variation Model Scenarios

As previously mentioned, three groundwater flow scenarios were modeled to represent site conditions during the dry and wet seasons, as well as long-term average site conditions (important for the long-term fluoride fate and transport evaluation). Constant head boundaries were set to different values for the three model scenarios. The dry season constant head boundary head values were based on staff gauge data collected during the October 2012 tidal study. Since the Columbia River is tidally influenced, an average river stage elevation was used in the model to represent this constant head boundary. The wet season constant head boundaries were based on staff gauge data collected in December 2012. For the long-term average model, the constant head boundaries for the CDID ditches were based on data from Section 4.4 of the draft RI/FS; the long-term average Columbia River elevation was based on river stage data collected (from 1990 to 2011) at the National Oceanic and Atmospheric Administration gauging station near the site. The remaining constant head boundaries were weighted averages calculated from the October and December 2012 data (1/3 dry season conditions; 2/3 wet season conditions). Recharge during the wet and dry seasons was modeled as 30% and 5% of average annual precipitation, respectively. The long-term average modeled recharge was set at 25% of average annual precipitation. Figures 3, 4, and 5 illustrate the dry season, wet season, and long-term average groundwater flow patterns, respectively. Table 10 summarizes the calculated groundwater flow to the internal site and CDID ditches for the three model scenarios. Groundwater flow represents all groundwater whether or not it contains fluoride. As discussed in Section 5 of the RI/FS, CDID ditches are not impacted. Internal ditches are managed under the facility's NPDES permit.

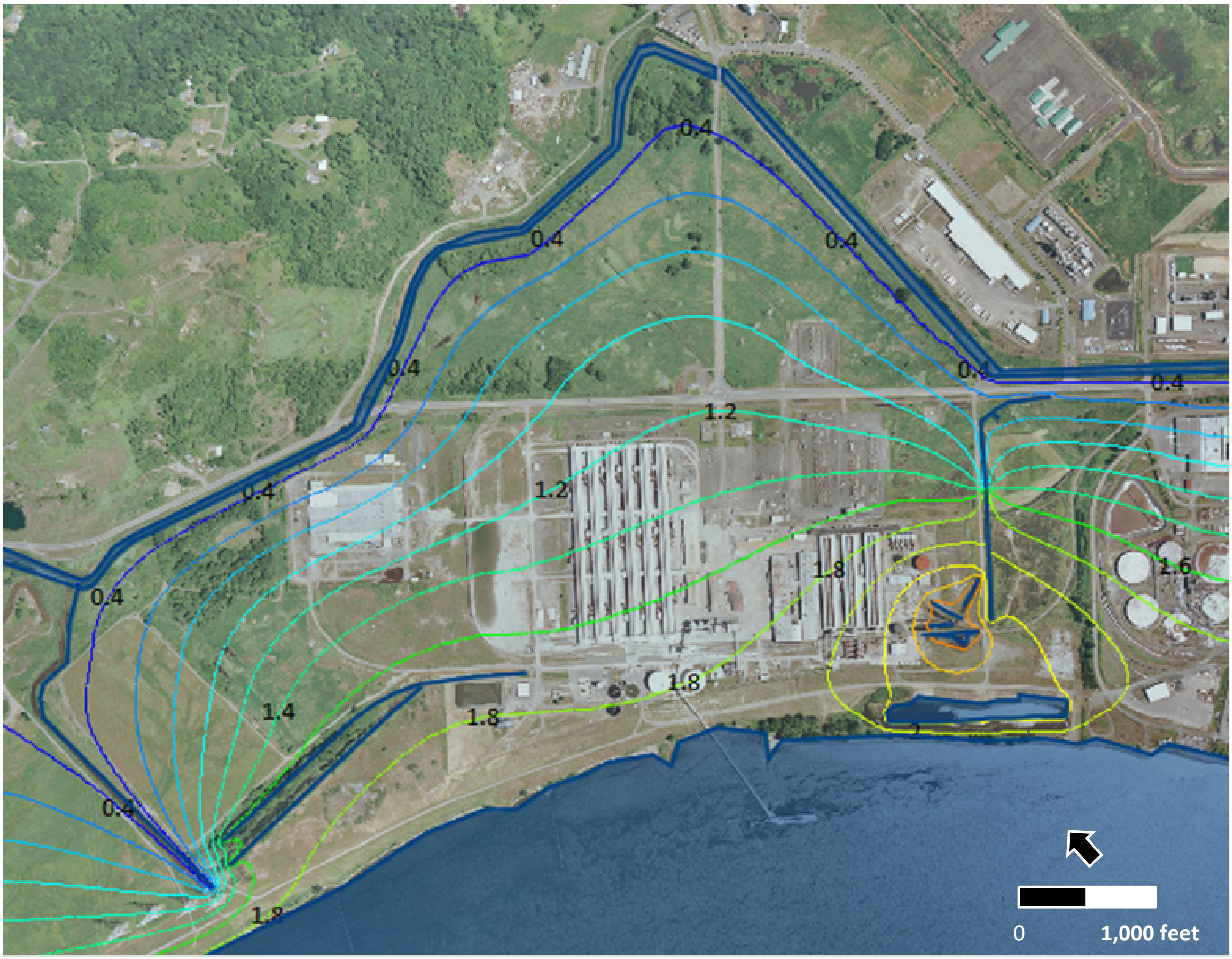

Figure 3
Groundwater Flow Pattern for the Dry Season Model

Note: Groundwater elevations are shown in meters above Mean Sea Level.

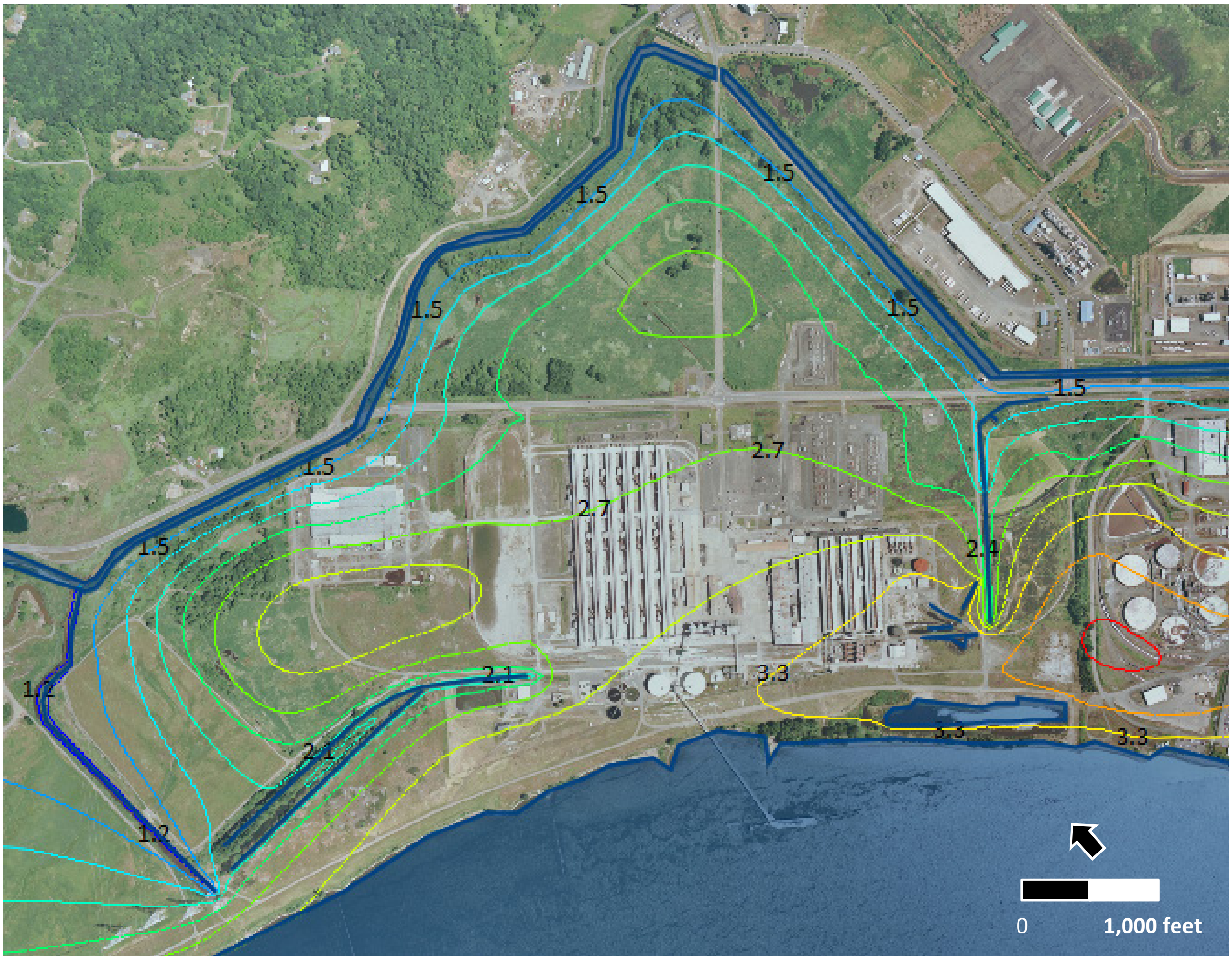

Figure 4
Groundwater Flow Pattern for the Wet Season Model

Note: Groundwater elevations are shown in meters above Mean Sea Level.

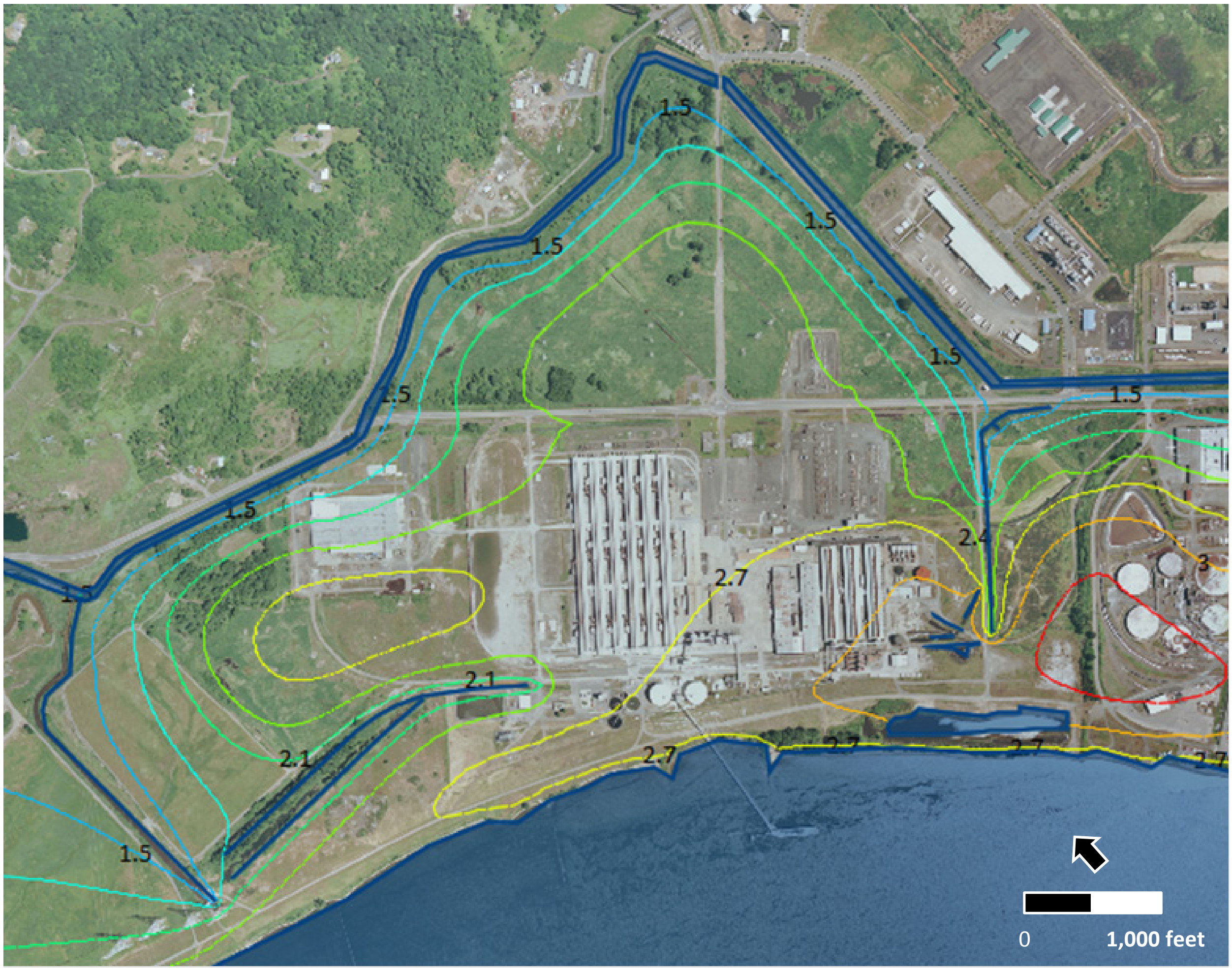

Figure 5
Groundwater Flow Pattern for the Long-term Average Model

Note: Groundwater elevations are shown in meters above Mean Sea Level.

Table 10
Calculated Groundwater Flow to Internal and CDID Ditches

Water Flow [1]	Wet Season Model		Dry Season Model		Long-term Average Model	
	MGY	GPM	MGY	GPM	MGY	GPM
To Columbia River	30.7	58.5	14.9	28.4	27.2	51.8
To CDID Ditches	77.9	148	35.5	67.5	64.0	122
To U-Ditch (West)	29.1	55.4	5.48	10.4	24.7	47.0
To 004 Pump Station (East)	20.8	39.6	10.1	19.2	19.8	37.7
To Cryolite Area Ditches	4.06	7.72	6.57	12.5	3.1	5.9

Notes:
1. Flow rates represent all groundwater regardless of whether it contains fluoride. As described in Section 5, CDID ditches are not impacted. Internal ditches are managed under the facility's NPDES permit.
GPM = gallons per minute
MGY = million gallons per year

2.1.3 Fill Deposit Dewatering Model Scenario

The groundwater flow model was used to evaluate groundwater extraction rates in support of technology screening of a pump and treat alternative. For this evaluation, dewatering trenches were placed around the fill deposits in the East and West Groundwater Areas where shallow groundwater is impacted by remaining residual carbon. This included Fill Deposit B-3 and Landfill #2 in the southwestern corner of the site in the West Groundwater Area, and Fill Deposits A, B-1, and B-2; the Former Stockpile Area; and Landfill #1 in the East Groundwater Area. Fill deposit thicknesses were determined from site-wide test pit data collected in November 2012. None of the fill deposits or landfills extend below mean sea level (MSL). To ensure the fill deposits and landfills would remain completely unsaturated and that all potentially impacted shallow groundwater would be pumped to the treatment plant, the base elevation of the trenches was set to 1 meter below MSL. Table 11 summarizes the groundwater pumping rates needed to maintain the East and West Groundwater Area fill deposits and landfills completely dewatered, and provides an estimate of the treatment capacity needed. Note that in this model scenario, water from the Columbia River is being drawn into the site due to the steep hydraulic gradient created by the dewatering trenches.

Table 11
Pumping Requirements for East and West Groundwater Area Fill Deposit Dewatering

Water Flow [1]	Dewatering Model Scenario	
	MGY	GPM
East Groundwater Area	77.5	147
West Groundwater Area	112	212
From Columbia River	106	202
To CDID Ditches	50.2	95.4

Notes:
1. Flow rates represent all groundwater regardless of whether it contains fluoride. As described in Section 5, CDID ditches are not impacted. Internal ditches are managed under the facility's NPDES permit.
GPM = gallons per minute
MGY = million gallons per year

2.2 Geochemical Reactive Transport Modeling

An integral component to the fluoride fate and transport evaluation is the reactive transport modeling that was conducted for the East and West Groundwater Areas. This modeling effort was accomplished using the USGS computer program PHAST, which simulates multi-component, reactive solute transport in 3-D groundwater flow systems. Flow and transport calculations are based on a modified version of HST3D (Kipp 1987, 1997). Geochemical reactions are simulated using PHREEQC, which is embedded in PHAST. Implementing a sequential solution approach, the combined flow and reactive transport model first includes the steady-state simulation of groundwater flow, followed by a transient reactive transport simulation. PHAST solves a set of partial differential equations for flow and transport and a set of nonlinear algebraic (equilibrium) and ordinary differential (kinetic) equations for chemistry. The groundwater flow and solute-transport equations are coupled through the dependence of advective transport on the interstitial fluid-velocity field. The solute-transport equations and the chemical equations (which are solved simultaneously) are coupled through the chemical concentration terms.

Pre-processing of hydrogeologic and geochemical data associated with the groundwater flow reactive transport modeling was performed using the USGS software package Phast4Windows (Charlton and Parkhurst 2012), which provides a GUI for creating the input files needed to run PHAST. Post-processing was performed using Model Viewer (Hsieh and Winston 2002) for 3-D visualization of simulation results.

2.2.1 Geochemical Reactive Transport Model Setup and Calibration

The geochemical reactive transport model was set up using the Phast4Windows GUI. Table 12 lists the hydrogeologic model input parameters. Pertinent to the fluoride fate and transport evaluation, long-term average surface water and ditch water elevations and recharge were used in the reactive transport model. As discussed in Section 4 of the RI/FS, the Upper Alluvium consists of surficial fill soils and interbedded fine- to medium-grained sand, silt, and clay layers, which extend approximately 200 feet beneath the RI/FS study area. The hydraulic conductivity value input into the reactive transport model for the surficial fill soils and fine- to medium-grained sand was based on slug testing conducted at the site in October 2006 (see also Section 2.1.1). The hydraulic conductivity value used for the silt/clay was based on the City of Longview's preliminary design studies for water production wells at the Mint Farm (Kennedy Jenks 2010), also discussed in Section 4.3.3 of the RI/FS. In March 2013, laboratory permeability tests were conducted on samples collected from Fill Deposits A, B-1, B-2, and B-3. The calculated permeability values were used to adjust the modeled hydraulic conductivity of the saturated fill deposits. Fill deposit thicknesses were determined from site-wide test pit data collected in November 2012. None of the fill deposits extend below MSL. For the initial PHAST groundwater flow simulation, the East and West Groundwater Areas were modeled as one contiguous area. This was done as a calibration check to confirm that the PHAST groundwater flow model produced comparable results to the MODFLOW-2005 groundwater flow model. After this calibration check, the PHAST groundwater flow model was divided into two sub-models to reduce computing time and increase the spatial resolution for the reactive transport calculations in the East and West Groundwater Areas. Figure 6 illustrates the extent of the PHAST groundwater flow model, as well as the East and West Groundwater Area sub-models. Figures 7 and 8 show the groundwater flow patterns for the calibrated East and West Groundwater Area sub-models, respectively.

Table 12
Reactive Transport Model Hydrogeologic Input Parameters

Hydrogeologic (physical) Parameters			Units	Long-term Average Simulation
Model Domain (X × Y × Z)			m	2600 × 1900 × 33
Finest Horizontal Grid Spacing[1] (X × Y)			m	10 × 5 [6 × 11]
Finest Vertical Grid Spacing			m	1
Porosity[2]			-	0.35 [0.45]
Recharge		Long-Term Average	m/yr	0.305
Recharge		0% Recharge Reduction[3]	m/yr	0.305
Recharge		50% Recharge Reduction[3]	m/yr	0.153
Recharge		100% Recharge Reduction[3]	m/yr	0
Hydraulic Conductivity	Surficial Fill Soils and Upper Alluvium Sand[4]	Horizontal (K_x=K_y)	m/yr	556
Hydraulic Conductivity	Surficial Fill Soils and Upper Alluvium Sand[4]	Vertical (K_z)	m/yr	55.6
Hydraulic Conductivity	Upper Alluvium Silt/Clay[5]	Horizontal (K_x=K_y)	m/yr	3.3×10^{-3}
Hydraulic Conductivity	Upper Alluvium Silt/Clay[5]	Vertical (K_z)	m/yr	3.3×10^{-5}
Hydraulic Conductivity	Saturated Fill Deposits	Horizontal (K_x=K_y)	m/yr	20
Hydraulic Conductivity	Saturated Fill Deposits	Vertical (K_z)	m/yr	20
Dispersivity		Longitudinal	m	1
Dispersivity		Horizontal Transverse	m	0.1
Dispersivity		Vertical Transverse	m	0.01
Constant Head Boundaries (Surface and Ditch Water)		CDID Ditch No.5	m	1.25
Constant Head Boundaries (Surface and Ditch Water)		CDID Ditch No.10	m	1.25
Constant Head Boundaries (Surface and Ditch Water)		CDID Ditch No.14	m	1.25
Constant Head Boundaries (Surface and Ditch Water)		Columbia River	m	2.60
Constant Head Boundaries (Surface and Ditch Water)		U-Ditch	m	1.81
Constant Head Boundaries (Surface and Ditch Water)		Leachate Ditch (W)	m	1.87
Constant Head Boundaries (Surface and Ditch Water)		Dredge Material Storage Area Pond	m	3.00
Constant Head Boundaries (Surface and Ditch Water)		Cryolite Area Ditches	m	3.18
Constant Head Boundaries (Surface and Ditch Water)		004PS Ditch A[6]	m	1.29
Constant Head Boundaries (Surface and Ditch Water)		004PS Ditch B[7]	m	2.10

Notes:
1. East Groundwater Area Sub-model grid spacing, [West Groundwater Area Sub-model grid spacing]
2. Surficial fill soils and fine- to medium-grained sand porosity, [silt/clay porosity]
3. Percent reduction from long-term average recharge (in areas subject to capping)
4. Surficial fill soils, fine- to medium-grained sand, and silty sand (3 to -15 meters MSL)
5. Clayey silt and silty clay (-15 to -30 meters MSL)
6. Internal ditch, adjacent to Fill Deposit A, draining to 004 Pump Station
7. Internal ditch, adjacent to Fill Deposits B-1 and B-2, draining to 004 Pump Station

m = meter
yr = year

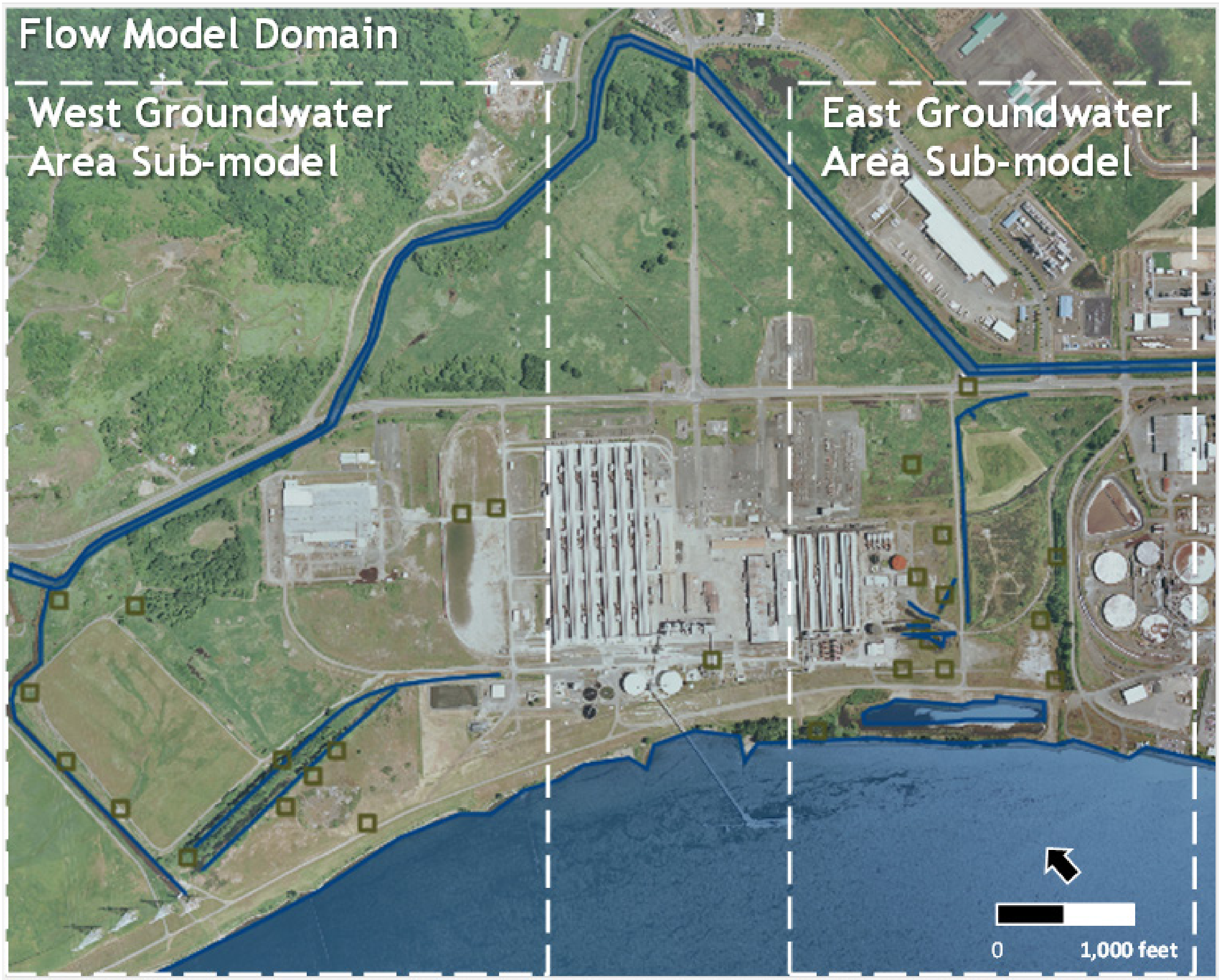

Figure 6

Extent of the PHAST Groundwater Flow Model Domain and the East and West Groundwater Area Reactive Transport Sub-models

Note: Olive squares denote monitoring well locations.

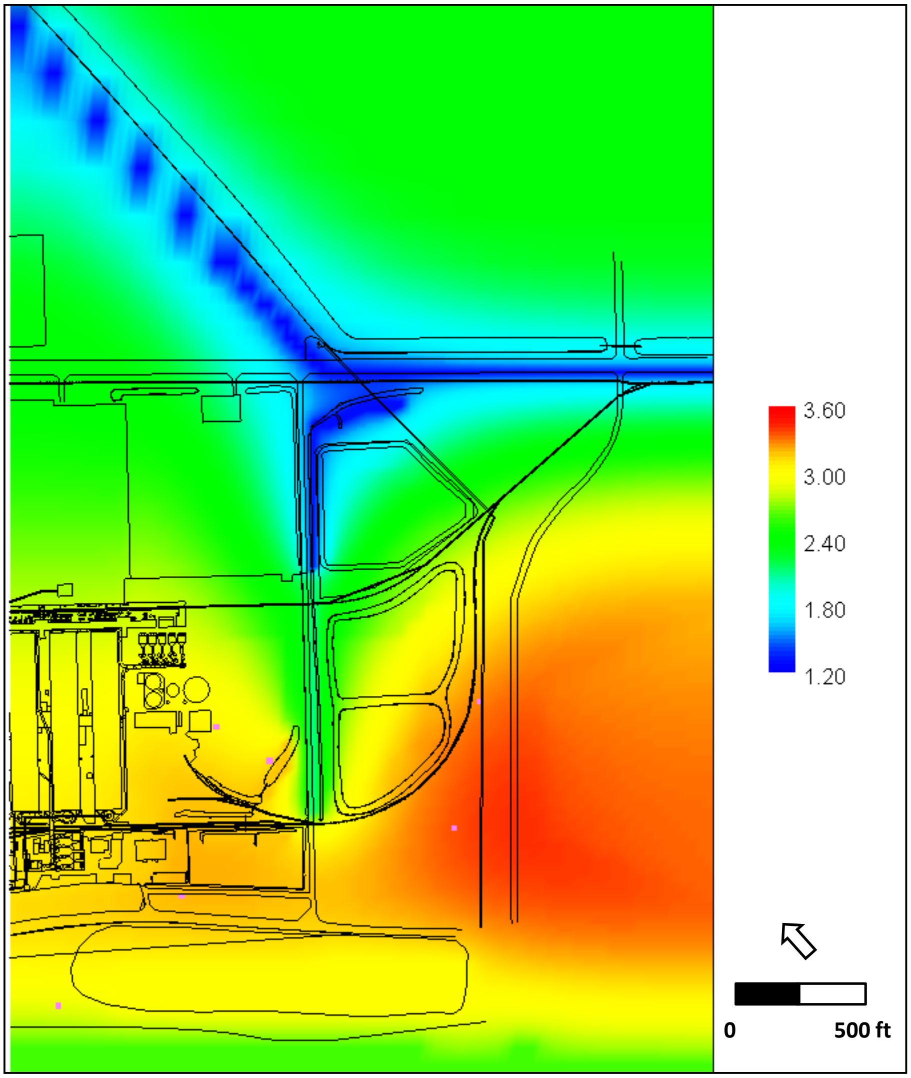

Figure 7
Groundwater Flow Pattern for the East Groundwater Area Sub-model

Note: Groundwater elevation in meters above Mean Sea Level; pink squares denote monitoring well locations.

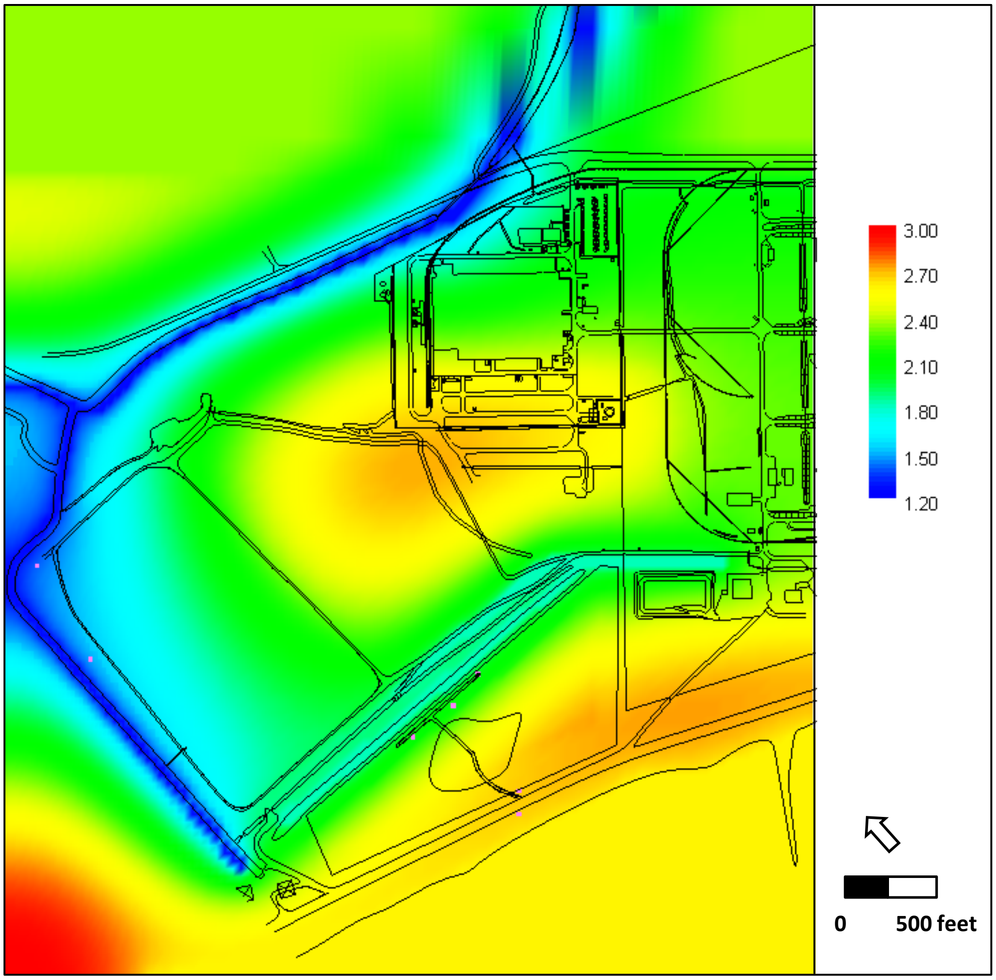

Figure 8
Groundwater Flow Pattern for the West Groundwater Area Sub-model

Note: Groundwater elevation in meters above Mean Sea Level; pink squares denote monitoring well locations.

Initial and boundary chemistry conditions were assigned to the various model components including background groundwater, recharge, surface and ditch water (constant head) boundaries, fluoride source zones, and source zone recharge, using the Phast4Windows GUI. Initial chemistry conditions included solution chemistry, equilibrium mineral phases, cation exchange, and adsorbing surfaces, and are defined in a PHREEQC input file. Exchange sites and adsorbing surfaces were equilibrated with the corresponding initial solution chemistry. Initial solution chemistries were based on site groundwater, unsaturated zone porewater, surface water, and ditch water data collected in 2011 and 2012 (presented in Section 5 of the RI/FS report). The recharge solution chemistry was modified from an average rainwater composition provided in PHREEQC to better represent site-specific conditions. The recharge chemistry for the fluoride source zones was based on the 2012 lysimeter data. Mineral phases and their initial concentrations were assigned based on the mineralogical data and geochemical speciation modeling discussed in Section 1 herein. The concentration of exchangeable calcium was based on the East Groundwater Area CEC data discussed in Section 1.4. The average concentration of soil aluminum oxides representing the adsorbing surface for surface complexation of fluoride was determined based on the East Groundwater Area extractable oxide data discussed in Section 1.5. Table 13 lists the geochemical initial and boundary conditions used for the East and West Groundwater Area reactive transport models.

The East and West Groundwater Area reactive transport models were initially run for a 40-year simulation period to "pre-condition" the models for present conditions. Spatially distributed dissolved, adsorbed, and solid-phase concentrations at the end of the pre-conditioning period (representing present day) were used as initial concentration distributions for predictive reactive transport simulations (projecting 2,000 years into the future). More specific detail regarding the East and West Groundwater Area sub-models is discussed in the following sections. Figure 9 compares the simulated present-day fluoride concentrations with the measured fluoride concentrations at wells in the East and West Groundwater Areas in 2012. The majority of the simulated concentrations match observed values within a factor of ten.

Long-term reactive transport simulations were carried out for the East and West Groundwater Areas to evaluate the effectiveness of natural geochemical processes in regulating future fluoride concentrations and transport in groundwater. Additional scenarios were simulated to evaluate the effects of reducing infiltration over specific source areas (i.e., capping of the Fill Deposit B-3 and Landfill #2 in the West Groundwater Area, and Fill Deposits A, B-1, B-2, and Landfill #1 in the East Groundwater Area). Reduced infiltration was modeled by adjusting the recharge flux in the areas subject to capping. The infiltration reduction simulations that were evaluated include 50% and 100% reduction in recharge. The long-term reactive transport simulations for the East and West Groundwater Area sub-models are discussed in greater detail in the following sections.

Table 13
Reactive Transport Model Initial and Boundary Conditions

	Parameter	Units	East and West Groundwater Areas			East Groundwater Area								West Groundwater Area		
			Background Aquifer[1]	Columbia River[2]	Precipitation[3]	Fill Deposit B-2 and Former Stockpile Area[5]	Fill Deposit A[6]	Fill Deposit B-1[7]	Impacted Shallow GW Area[8]	Landfill #1[9]	Fill Deposit B-2[10]	Area Surrounding PZ-4[11]	Former Stockpile Area[12]	Fill Deposit B-3[13]	Fill Deposit B-3[4]	Closed BMP Facility[14]
			Initial Condition	Constant Head	Recharge	Recharge	Recharge and Source Zone	Recharge and Source Zone	Source Zone	Recharge and Source Zone	Source Zone	Recharge and Source Zone	Recharge and Source Zone	Source Zone	Recharge	Source Zone
Solution Chemistry	Temperature	°C	15	15	15	15	15	15	15	15	15	15	15	15	15	15
	pH	-	6.50	7.09	5.60	8.06	10.46	7.54	6.95	6.95	9.36	9.70	10.25	7.03	7.70	9.90
	Dissolved Inorganic Carbon	mg/L	45	54	0.2	95	75	75	120	120	195	700	1100	96	75	525
	Aluminum	mg/L	0.019	6.73×10^{-3}	-	3.16	15.14	4.05	0.10	0.10	0.19	0.6	0.22	1.25	2.3	0.75
	Calcium	mg/L	40	14.57	0.34	6.01	0.85	11.5	54.7	54.7	4.17	4.1	1.0	14	7.47	15
	Sodium	mg/L	23	6.75	0.141	557	378	327	400	400	1000	4250	6750	449	400	3500
	Chloride	mg/L	6	4.38	0.36	8.58	7.95	3.41	49.5	49.5	25.6	110	63.5	6.14	2.73	10
	Fluoride	mg/L	0.15	0.13	0.13	123.4	94.35	54.7	21	21	222	1080	2280	80	80	500
	Phosphorus	mg/L	1.47	0.029	0.05	0.046	0.021	0.012	1.9	1.9	7.48	36.5	21.1	0.93	0.042	10
	Silica	mg/L	31.1	4.62	-	11.21	3.75	17.2	22	22	11.8	15.3	26.5	18.25	14.21	10
Equilibrium Mineral Phases	Calcite	moles/kg_w	0				0	0	0	0	0	1	1	0		0
	Cryolite	moles/kg_w	-				-	-	-	-	-	1000	1000	-		-
	Gibbsite	moles/kg_w	0				1	1	0	0	1	1	1	0		0
	Fluorite	moles/kg_w	0	NA		NA	1	1	0	1	1	1	1	1	NA	1
	Amorphous Silica	moles/kg_w	1				0	1	1	1	0	0	0	1		1
Cation Exchanger[15] (CaX_2)		moles/kg_w	0.1				0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		0.1
Aluminum Oxide (≡AlOH Adsorbing Surface)[16]		grams/kg_w	2				2	2	2	2	2	2	2	2		2

Notes:
1. Average site-wide background chemistry (based on monitoring wells G4-S, G4-D, G5-S, G5-D, R-2, RL-4S, and RL-4D 2011/2012 data)
2. Average Columbia River water chemistry (based on surface water sampling location W5 2006/2011 data)
3. Site-wide non-source zone recharge chemistry (modified rainwater chemistry provided in PHREEQC manual [example 4])
4. Average recharge chemistry for the West Groundwater Area Fill Deposit B-3 and Landfill #2 (based on lysimeters GC-LY-07 and GC-LY-08 2012 data)
5. Average recharge chemistry for the Fill Deposit B-2 and the Former Stockpile Area (based on lysimeters GC-LY-05 and GC-LY-06 2012 data)
6. Average recharge and initial source zone chemistry for the East Groundwater Area Fill Deposit A (based on lysimeters GC-LY-01 and GC-LY-02 2012 data); Recharge: solution chemistry only
7. Average recharge and initial source zone chemistry for the East Groundwater Area Fill Deposit B-1 (based on lysimeters GC-LY-03 and GC-LY-04 2012 data); Recharge: solution chemistry only
8. Average initial source zone chemistry for the East Groundwater Area encompassing Fill Deposits A, B-1, and B-2, the Former Stockpile Area, and Landfill #1 (based on monitoring wells G1-S, G2-S, G3-S, R-1S, and R-4S 2011/2012 data)
9. Contains the same geochemical parameters as the impacted shallow groundwater area, with the exception of Landfill #1 being supersaturated with Fluorite; Recharge: solution chemistry only
10. Average initial source zone chemistry for Fill Deposit B-2 and Cryolite Area Ditches (based on monitoring wells PZ-1S, PZ-2D, PZ-3, and soil borings GC-SB-01, GC-SB-02, and GC-SB-03 2011/2012 data)
11. Average initial recharge and source zone chemistry for the area surrounding monitoring well PZ-4 and soil borings GC-SB-02 and GC-SB-03 (based on monitoring well PZ-4 and soil borings GC-SB-01, GC-SB-02, and GC-SB-03 2011/2012 data)
12. Average initial recharge and source zone chemistry for the area surrounding monitoring wells R-3 and PZ-5 [i.e., Former Stockpile Area] (based on monitoring wells R-3, PZ-5, and soil borings GC-SB-01, GC-SB-02, and GC-SB-03 2011/2012 data)
13. Average initial source zone chemistry for the West Groundwater Area Fill Deposit B-3 and Landfill #2 (based on RLSW-2 2011/2012 data)
14. Average initial source zone chemistry for the West Groundwater Area Closed BMP Facility [including pre-closure recharge] (based on monitoring well RL-2S historical data, as well as site source zones containing residual carbon)
15. Calculated from the CEC and exchangeable calcium data discussed in Section 1.4
16. Amount of aluminum oxides determined based on the extractable oxide data discussed in Section 1.5

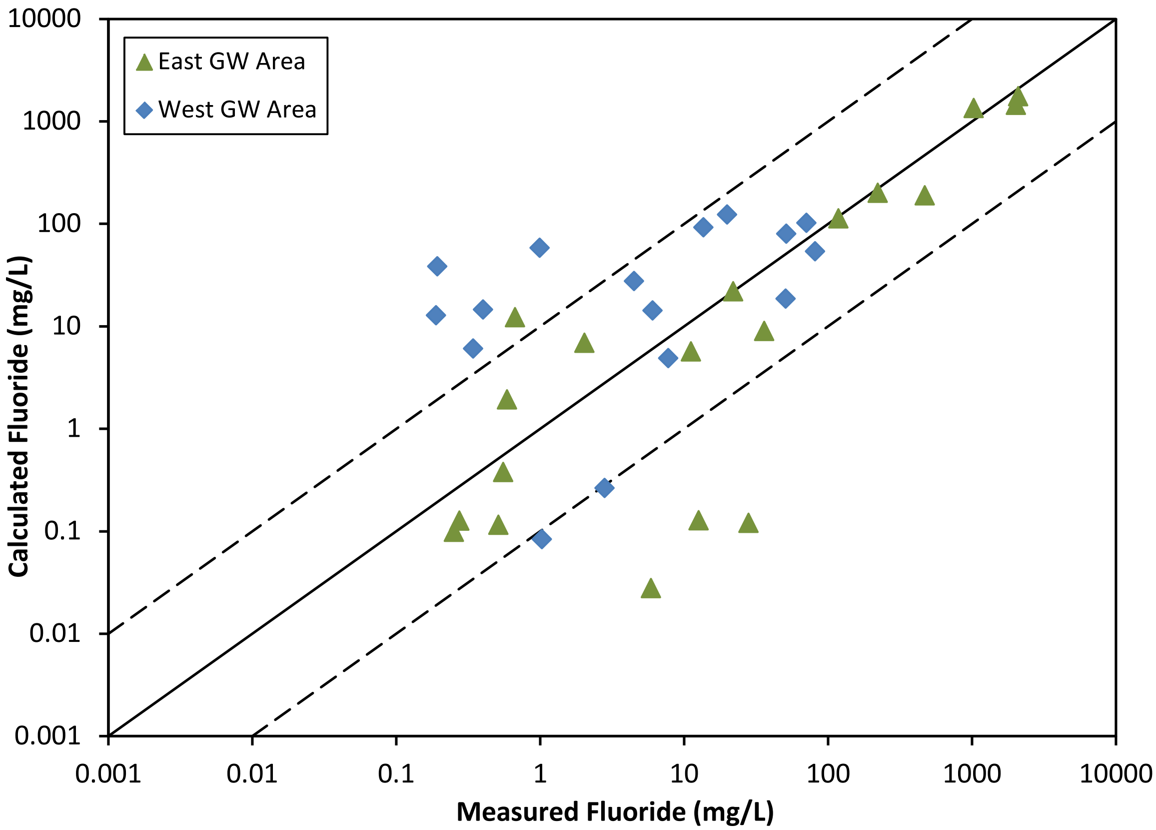

Figure 9
Present-day Simulated versus 2012 Measured Fluoride Concentrations in Site Monitoring Wells

2.2.2 East Groundwater Area Reactive Transport Simulations

As previously mentioned, an initial conditioning simulation for a 40-year time period was performed to obtain geochemical conditions present at the site today. The 40-year timeframe was chosen for the short-term simulation because it represents the duration the Cryolite Recovery Plant was in operation. During this period, cryolite-bearing materials were handled in the East Plant Area, and it was assumed for purposes of the model that the fluoride concentrations leaching to the shallow groundwater were in solubility equilibrium with cryolite. Following this 40-year period, it was assumed that spent potliner (SPL) is no longer stockpiled above ground (consistent with aluminum production operations described in Section 2 of the RI/FS) and, therefore, cryolite is not included as a geochemical constraint on fluoride concentrations in the source zones. However, the resulting groundwater and soil impacts from 40 years of operation are set as initial conditions for the long-term predictive simulations. For the long-term simulations, the constant head boundaries representing the

Cryolite Area Ditches were also removed, as these are assumed to be backfilled during future site development. Figure 10 illustrates the simulated East Groundwater Area fluoride plume (plan view and vertical x-sections) for current site conditions, which is also the initial state for the long-term simulations.

A series of three long-term simulations were carried out as follows: 1) with no reduction of infiltration; 2) with 50% reduction in infiltration in areas with soils impacted by fluoride-bearing wastes; and 3) with 100% reduction in infiltration in areas with soils impacted by fluoride-bearing wastes. The recharge flux was adjusted for the three long-term simulations to evaluate the effect of infiltration reduction on fluoride fate and transport. The solution chemistry of the recharge in the capping areas is the same as was used for the 40-year simulation. Figures 11, 12, and 13 illustrate the extent of the simulated East Groundwater Area fluoride plume (plan view and vertical x-sections) after 200 years for the three different infiltration scenarios; Figures 14, 15, and 16 illustrate the extent of the simulated fluoride plume after 1,000 years for the three different infiltration scenarios; and Figures 17, 18, and 19 illustrate the extent of the simulated fluoride plume after 2,000 years for the three different infiltration scenarios. Figures 20 and 21 show the calculated fluoride concentration after 2,000 years and fluoride breakthrough curves at monitoring well G4-S (proximal to CDID Ditch No. 5), respectively, for the three scenarios.

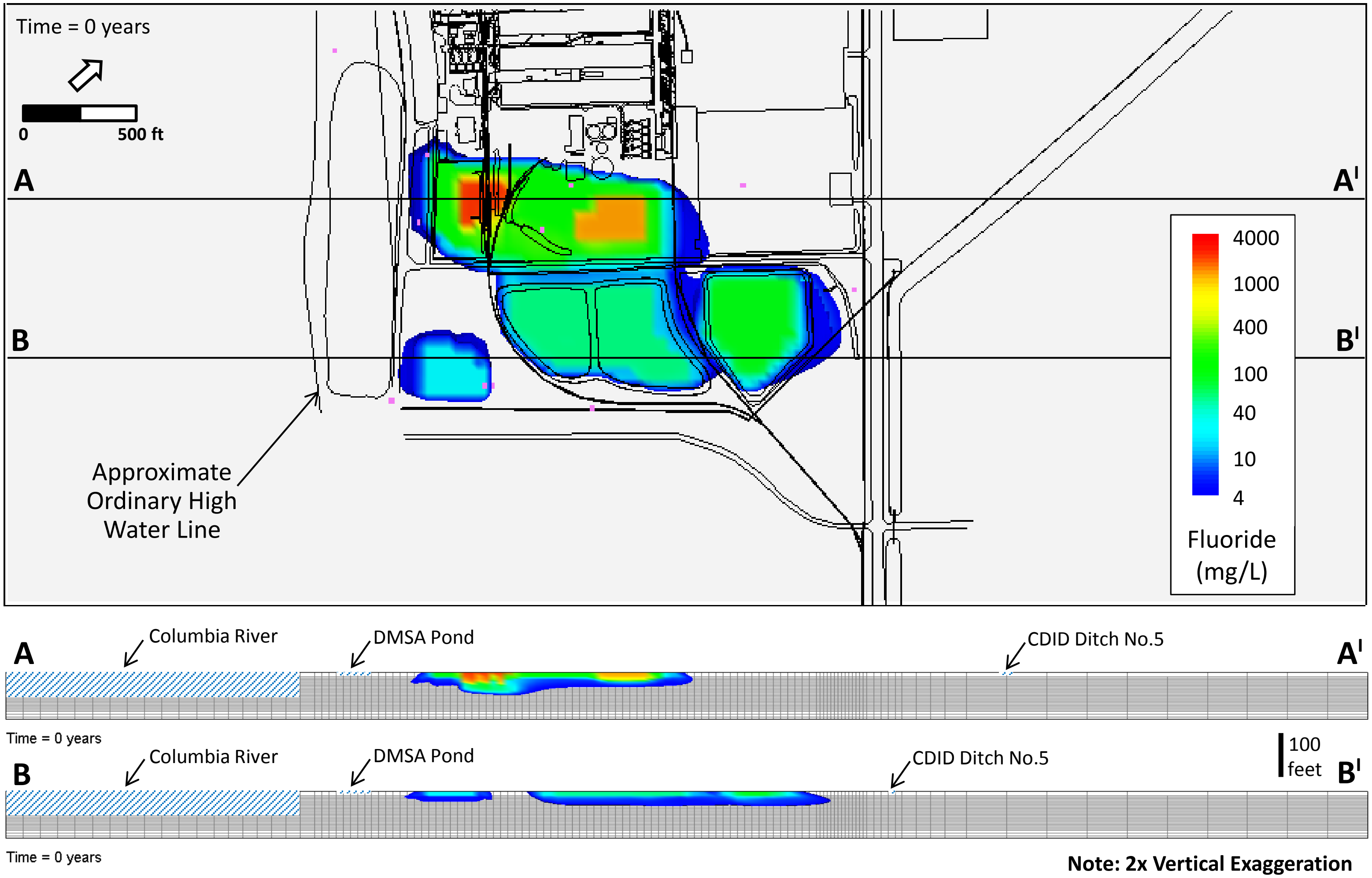

Figure 10

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume for Current Site Conditions

Note: Pink squares denote monitoring well locations.

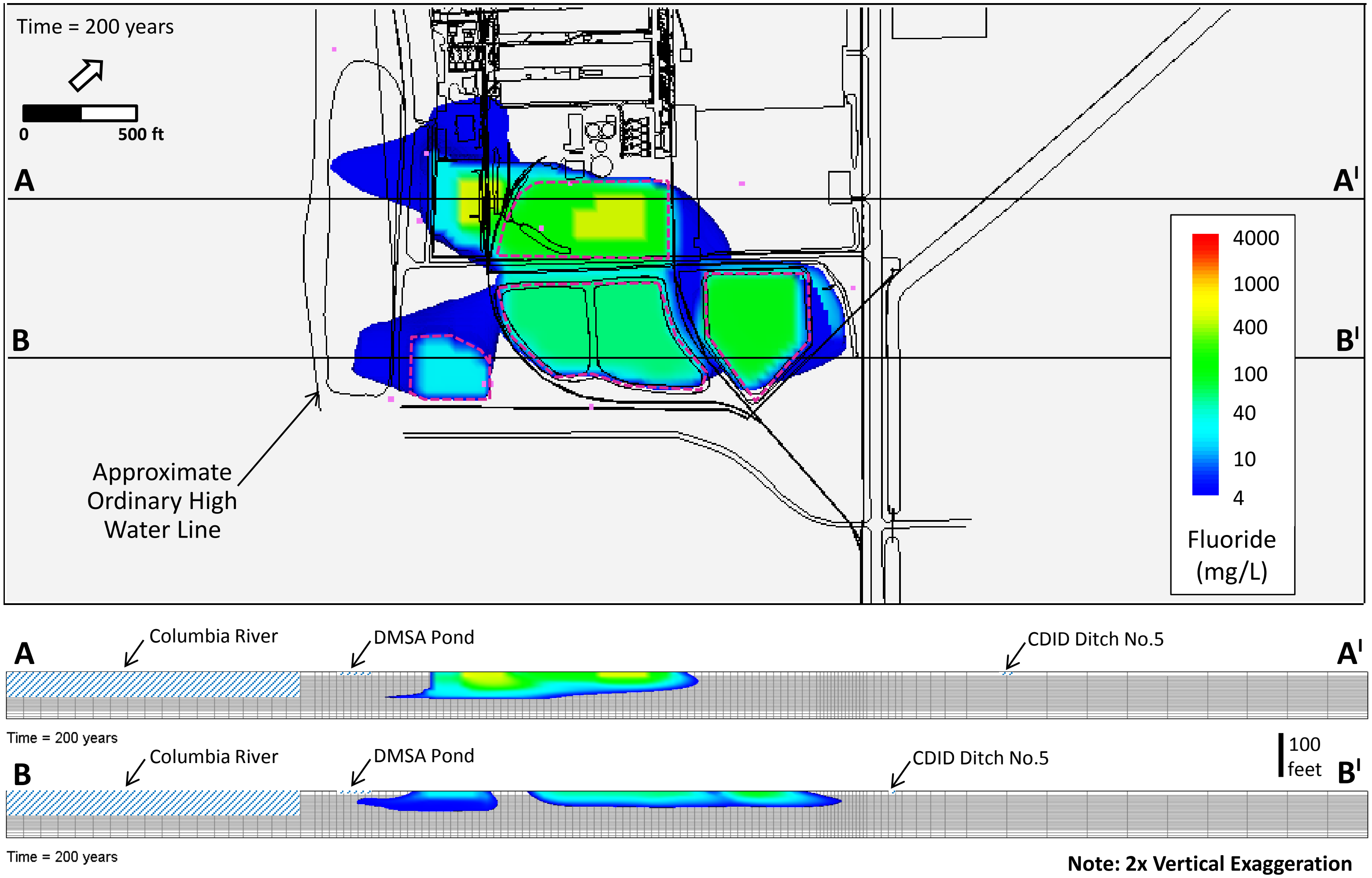

Figure 11

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 200 Years with No Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

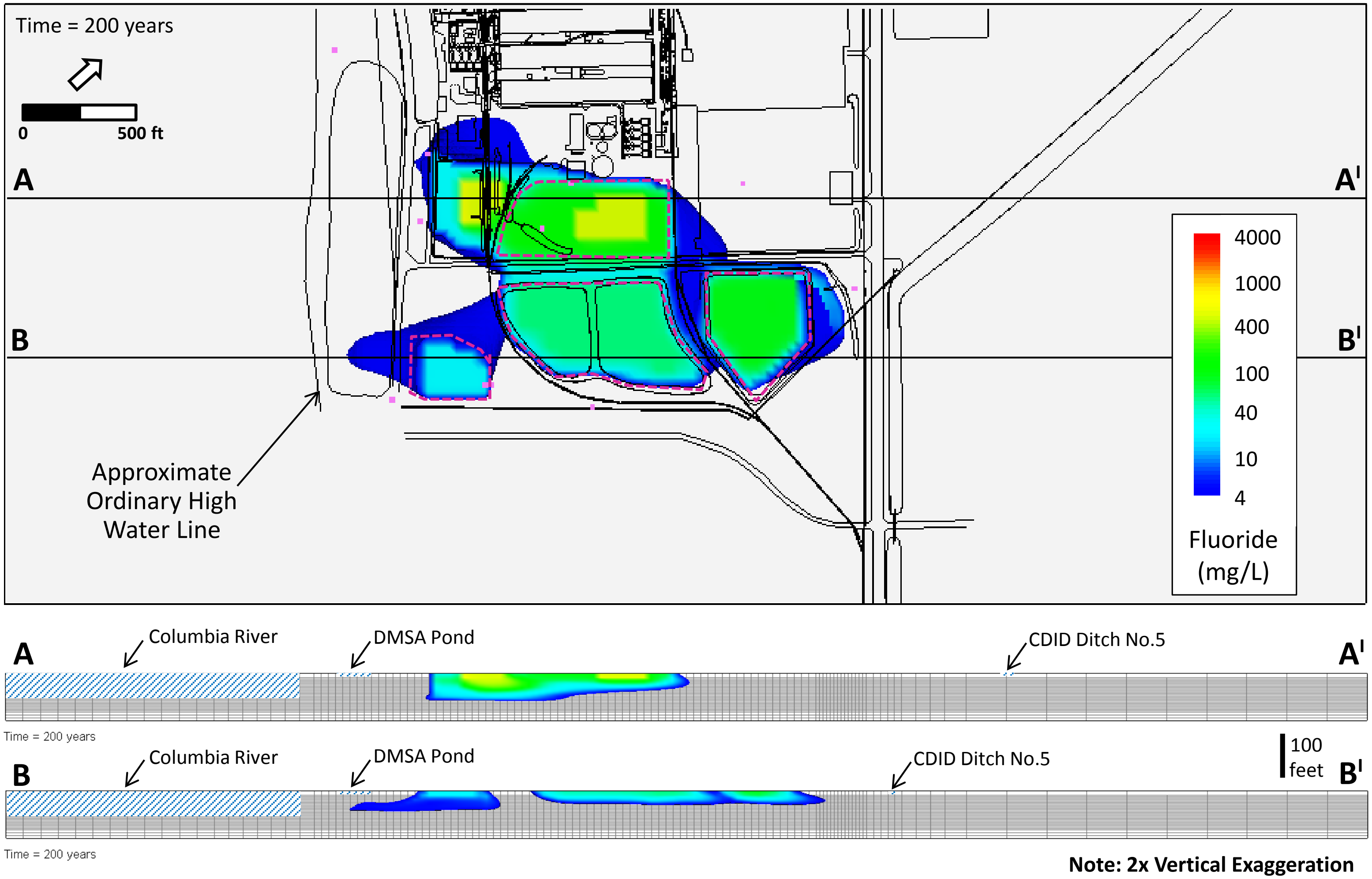

Figure 12

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 200 Years with 50% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

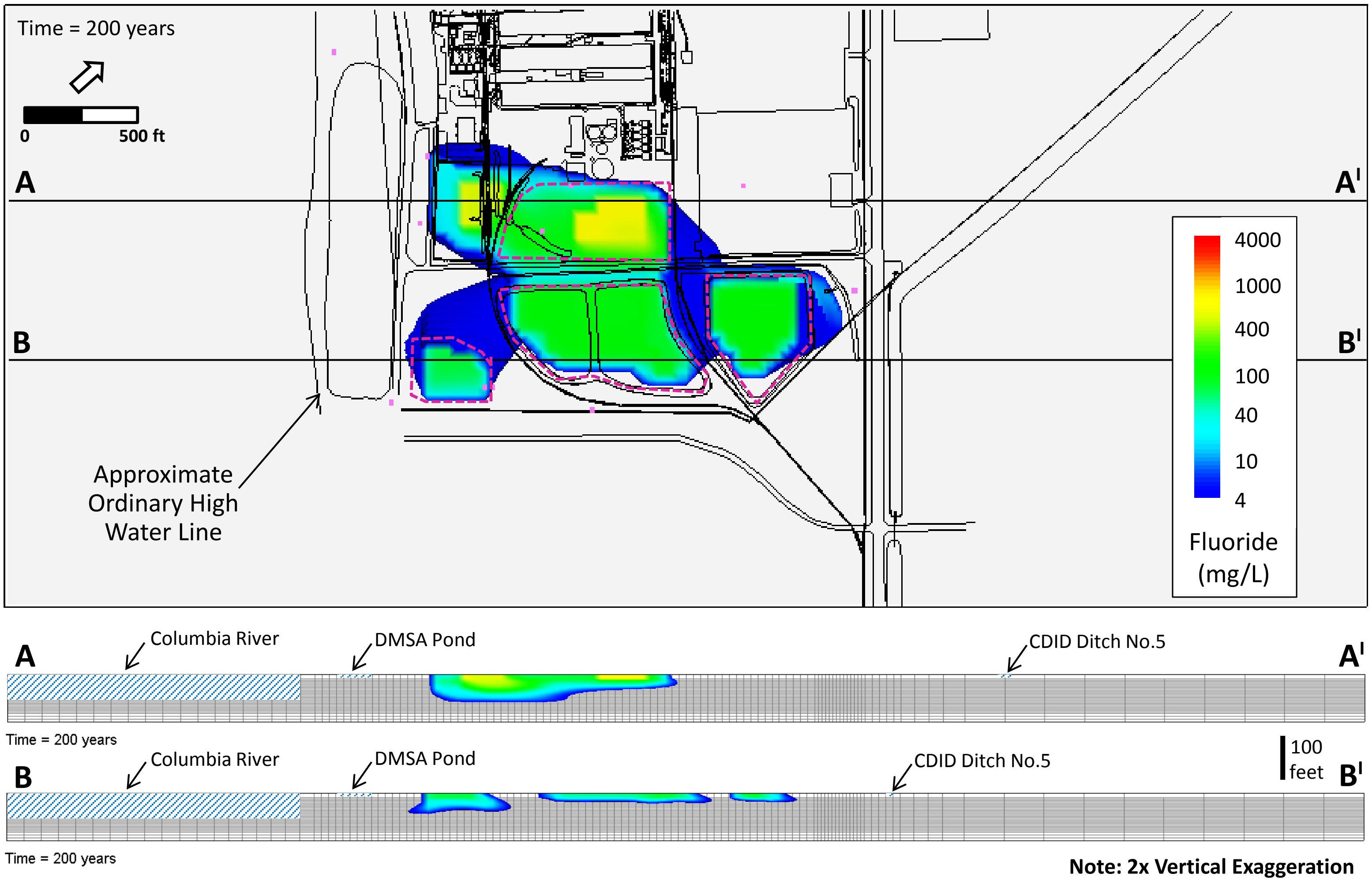

Figure 13

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 200 Years with 100% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

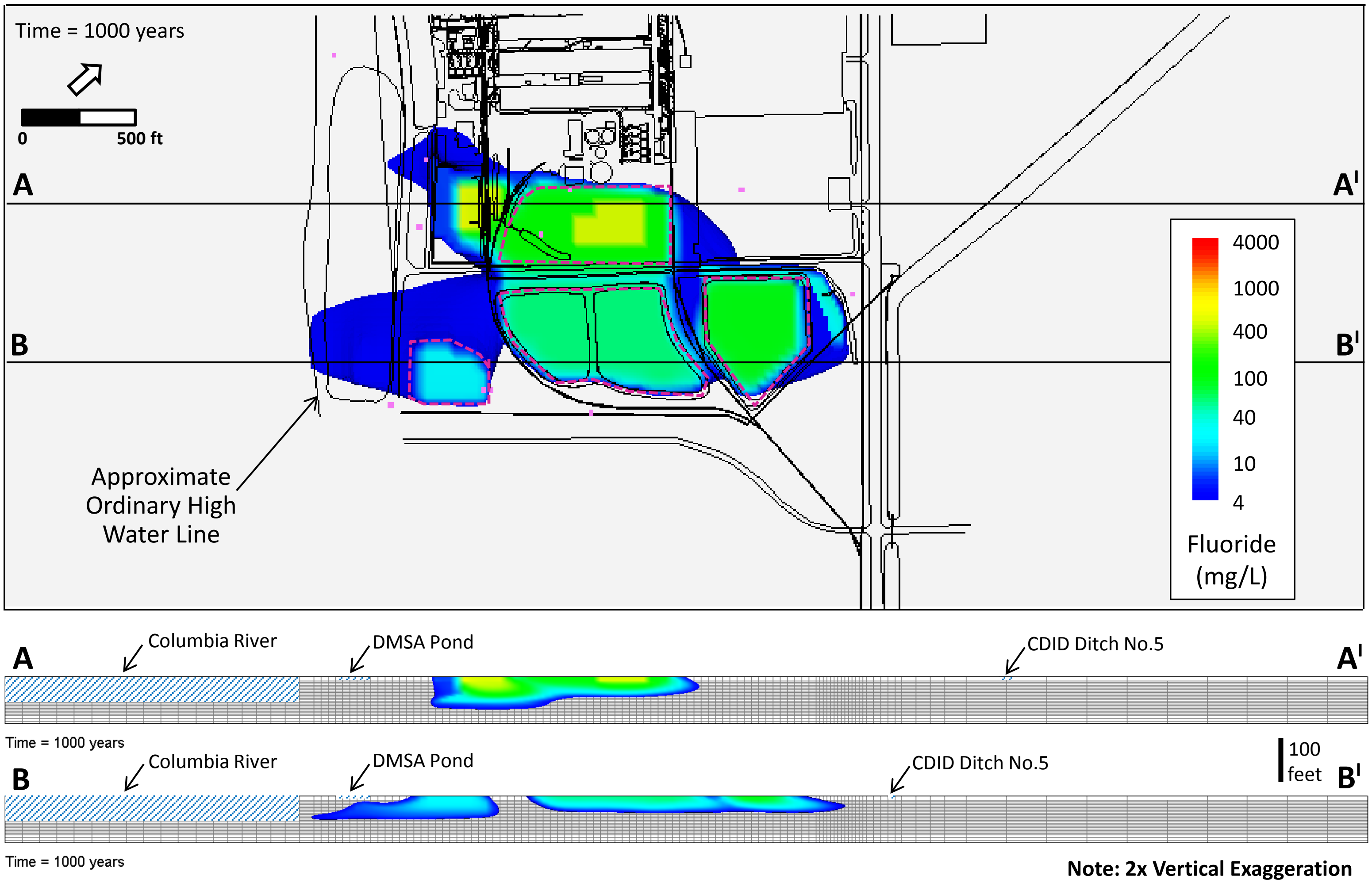

Figure 14

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 1,000 Years with No Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

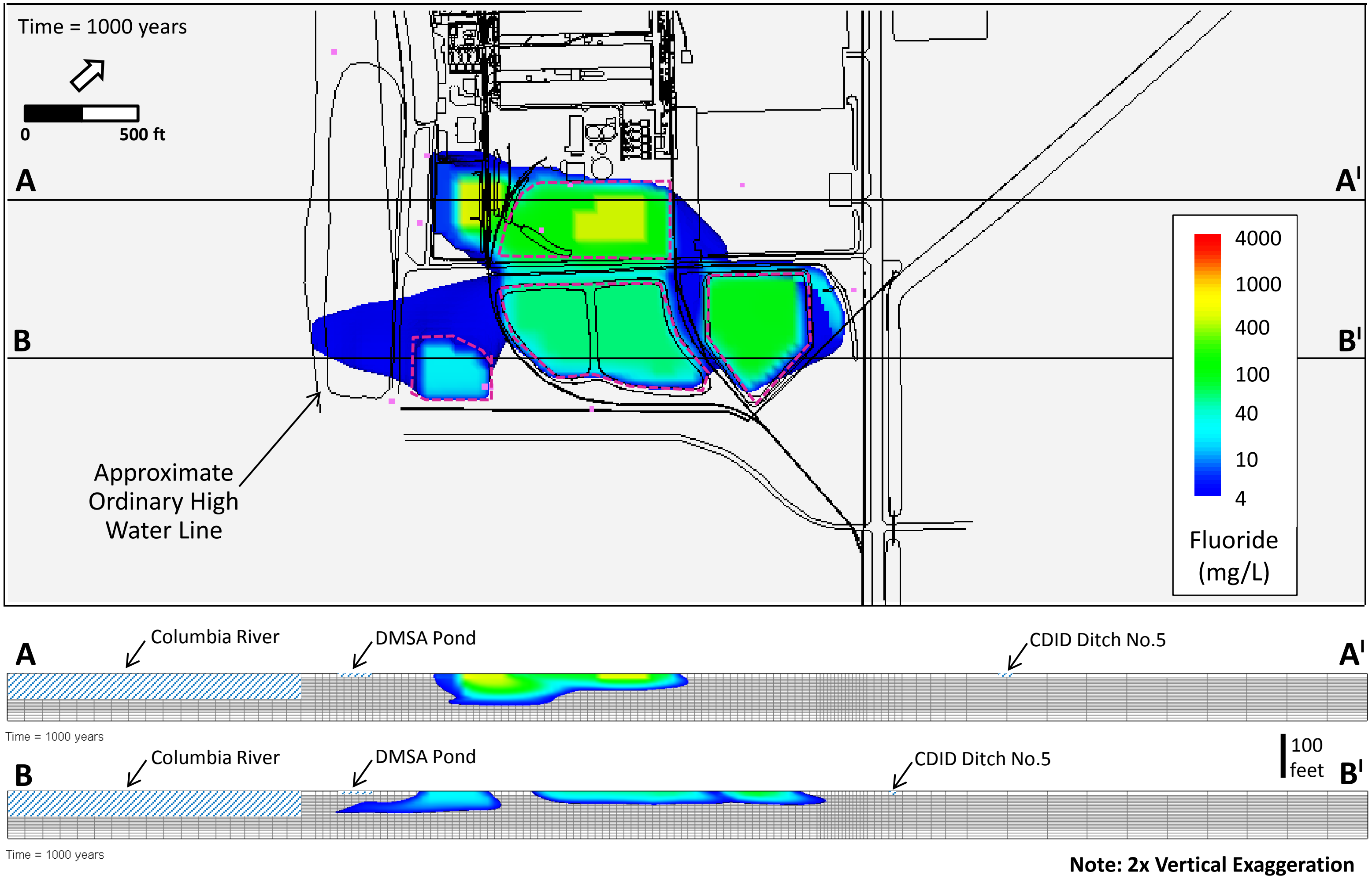

Figure 15

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 1,000 Years with 50% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

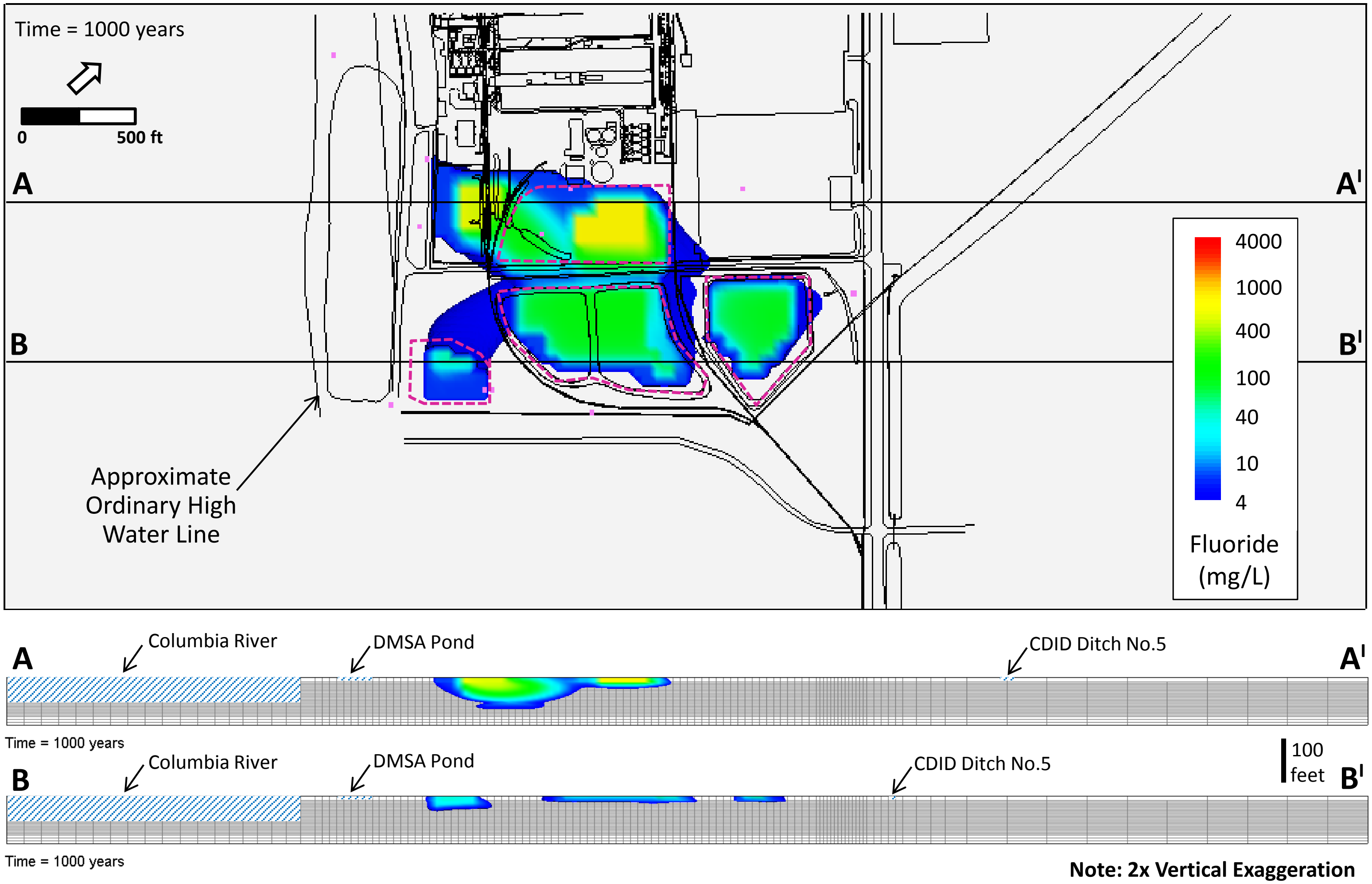

Figure 16

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 1,000 Years with 100% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

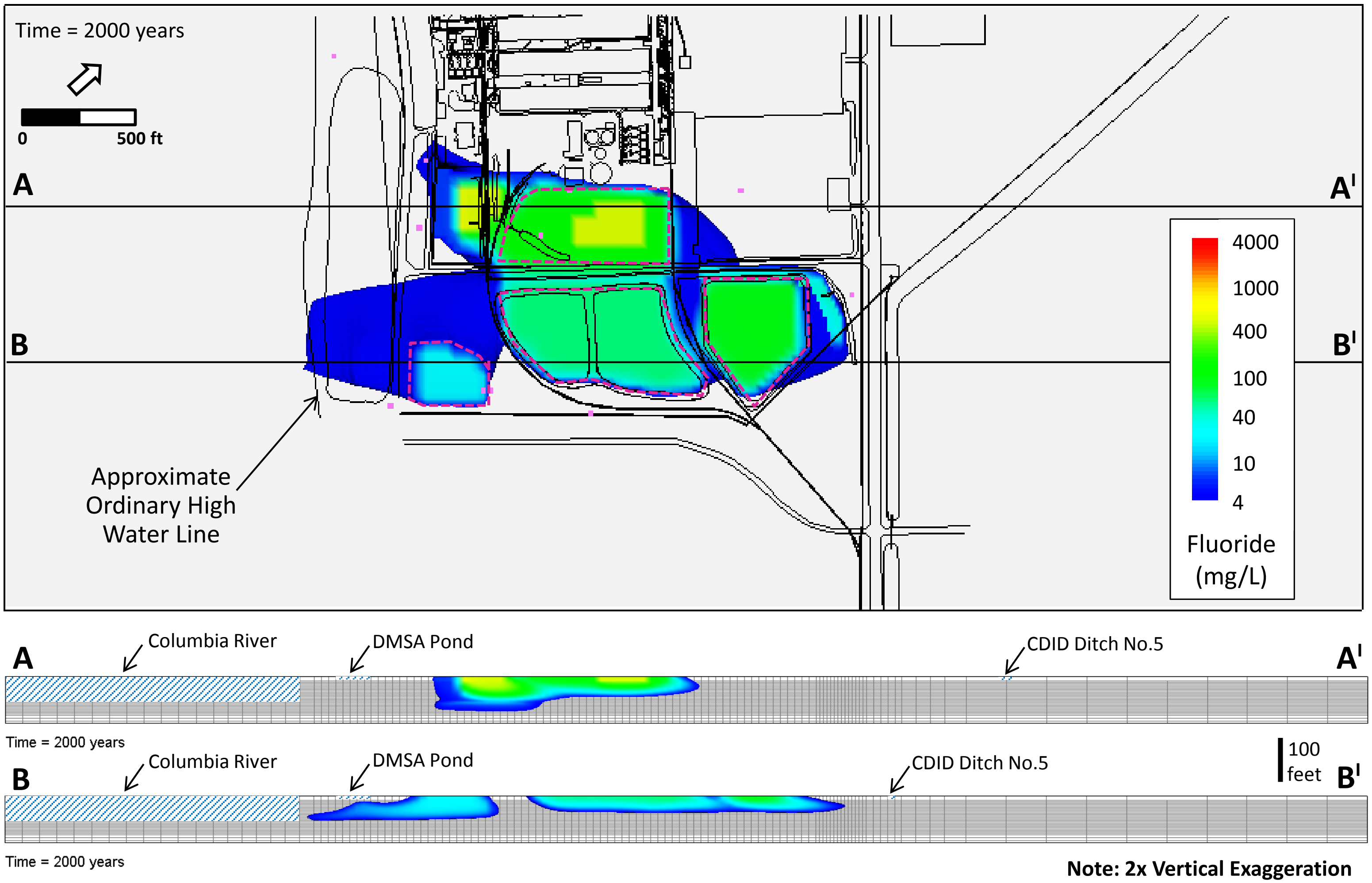

Figure 17

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 2,000 Years with No Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

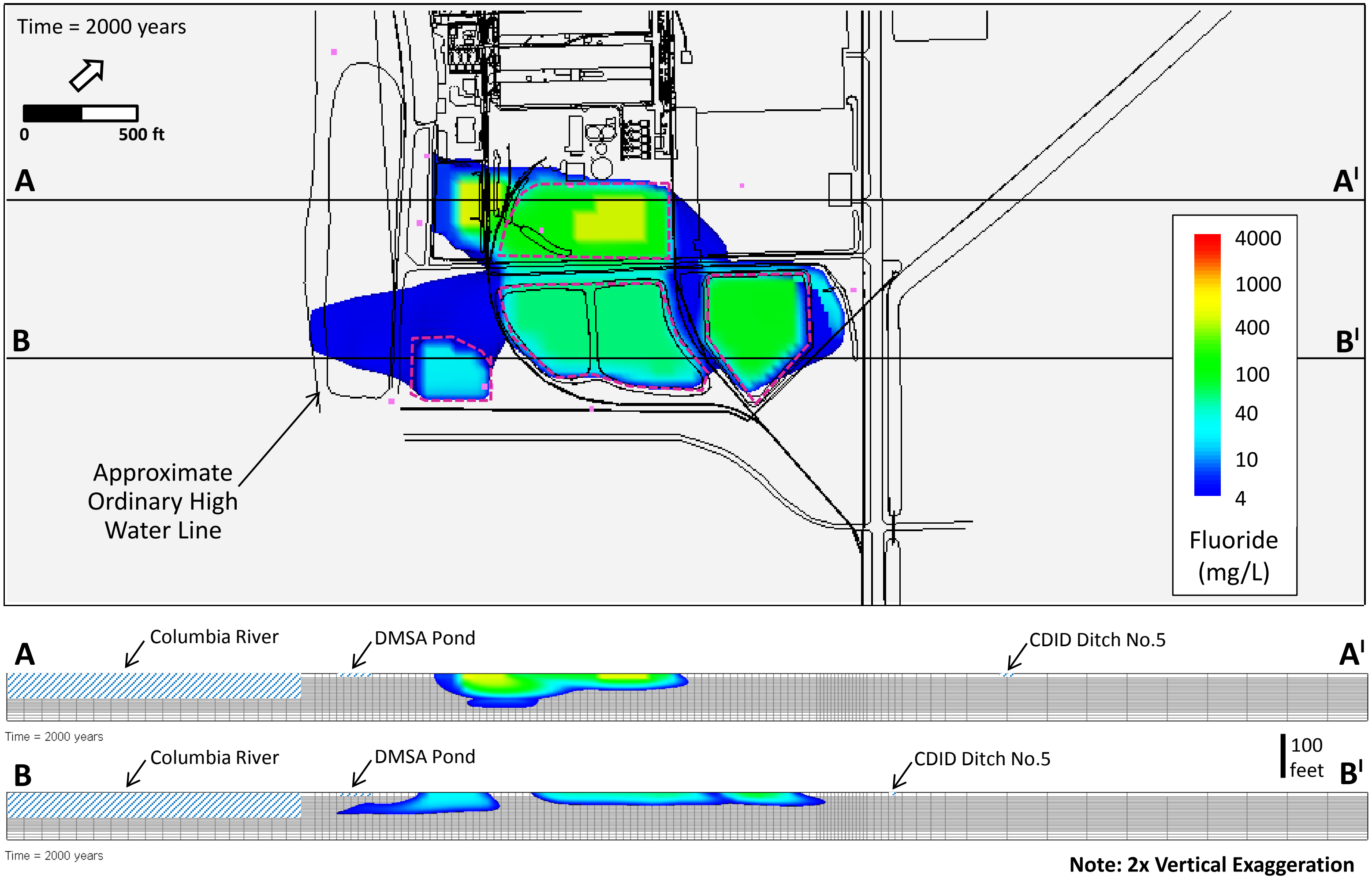

Figure 18

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 2,000 Years with 50% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

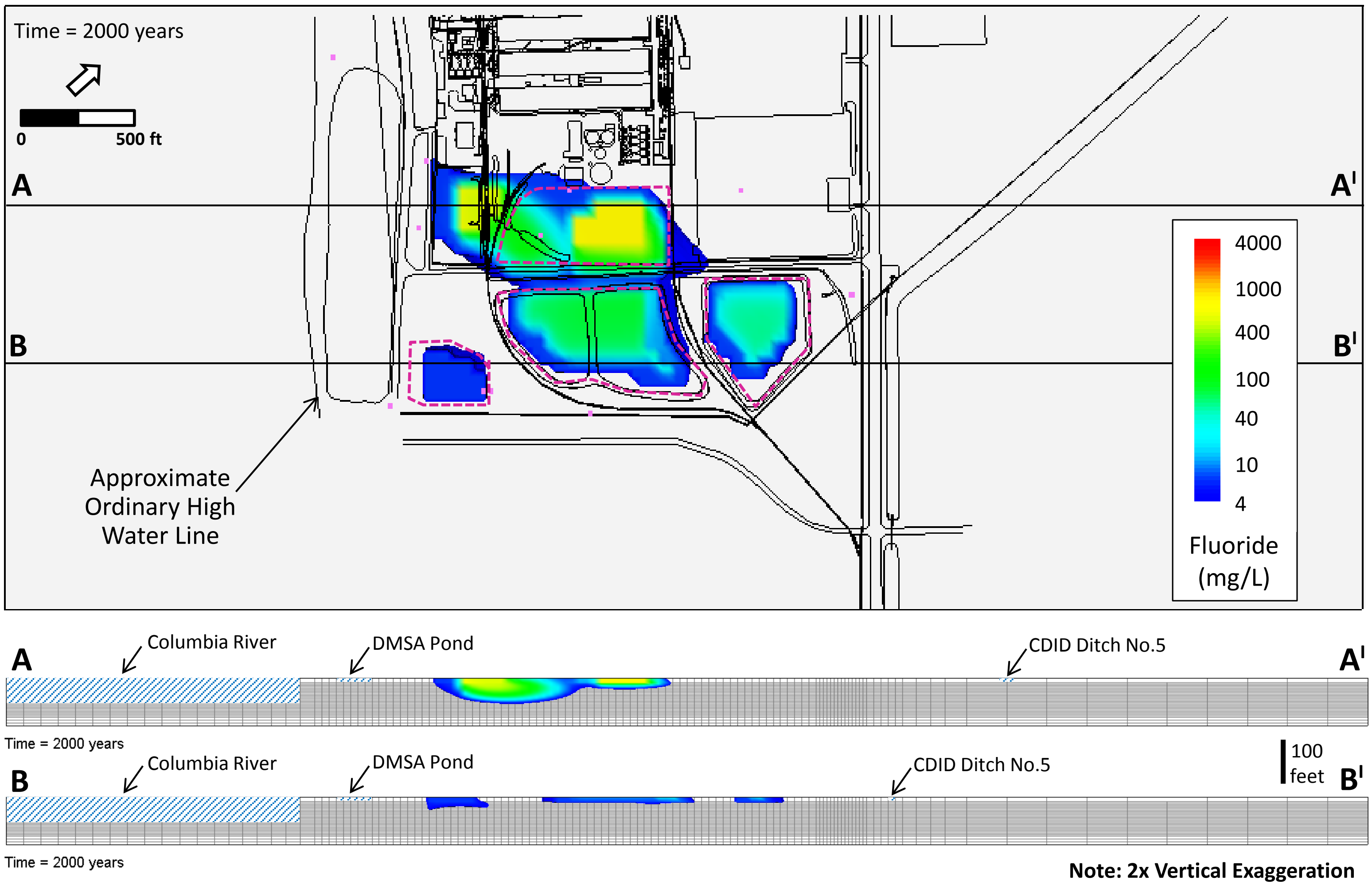

Figure 19

Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume after 2,000 Years with 100% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed lines denote Fill Deposit and Landfill boundaries.

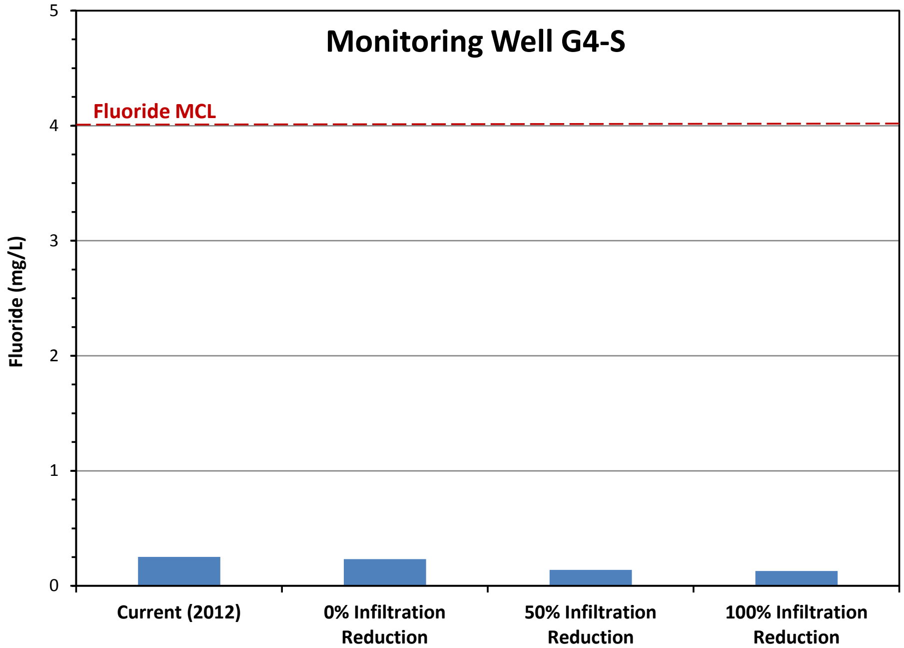

Figure 20

Current Measured Fluoride and Simulated Fluoride Concentrations at Well G4-S after 2,000 Years for the Three Different Infiltration Reduction Scenarios

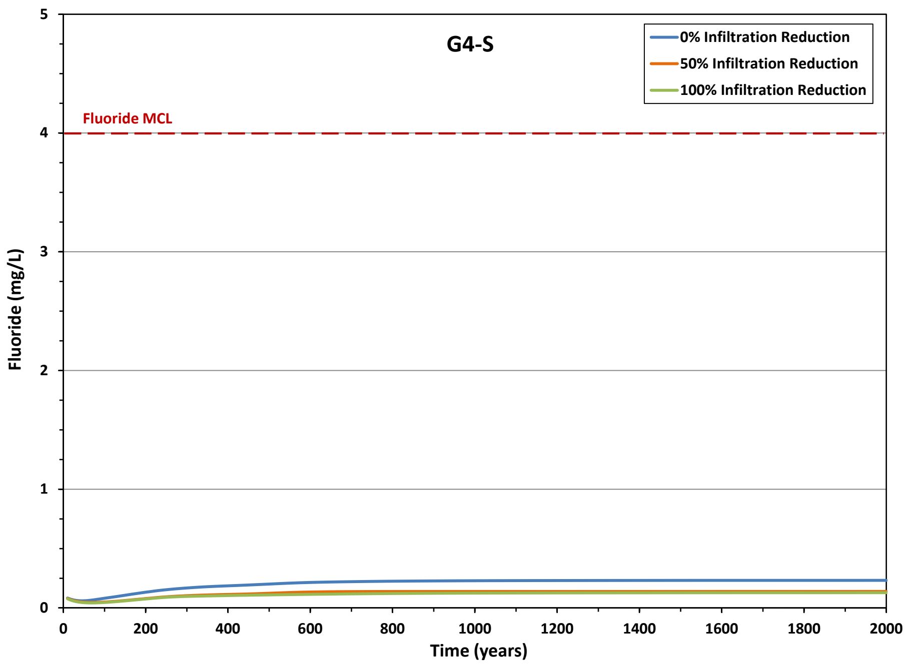

Figure 21

Fluoride Breakthrough Curves at Monitoring Well G4-S for the Different Infiltration Reduction Scenarios

2.2.3 West Groundwater Area Reactive Transport Simulations

For the West Groundwater Area sub-model, a two-step process was used to obtain current concentration distributions. The first 20 years of the simulation represents operation of the BMP Facility prior to its closure (from approximately 1970 to 1990), during which time it is assumed that the BMP Facility would have leached fluoride to shallow groundwater underneath. The initial geochemical conditions used for this area were based on historical data collected at monitoring well RL-2S, as well as data collected from other areas at the site containing residual carbon. The following 20 years of the simulation represents conditions in the West Groundwater Area from approximately 1990, when the BMP Facility was capped as part of closure, to present. During this time period, no infiltration occurs through the BMP Facility. Figure 22 shows the simulated extent of the West Groundwater Area fluoride plume (plan view and vertical x-sections) under current site conditions, which is also the initial condition for the predictive simulations.

The recharge flux to Fill Deposit B-3 and Landfill #2 was adjusted for the three long-term simulations to evaluate the effect of infiltration reduction on fluoride fate and transport. The solution chemistry of the recharge in this capping area is the same recharge chemistry that was used for the short-term simulations. Figures 23, 24, and 25 illustrate the extent of the simulated West Groundwater Area fluoride plume (plan view and vertical x-sections) after 200 years under the different infiltration reduction scenarios; Figures 26, 27, and 28 illustrate the extent of the simulated fluoride plume after 1,000 years under the different infiltration reduction scenarios; and Figures 29, 30, and 31 illustrate the extent of the simulated fluoride plume after 2,000 years under the different infiltration reduction scenarios. Figure 32 shows the simulated fluoride concentration after 2,000 years at monitoring well RL-1S (in the southwestern corner of the site) for the different infiltration reduction scenarios, as compared to the current (2012) measured fluoride concentrations at RL-1S and in the nearby CDID ditch (at surface water Station W4). Figure 33 shows the fluoride breakthrough curves at monitoring well RL-1S for the different infiltration reduction scenarios. Figure 34 shows the simulated fluoride concentration after 2,000 years at monitoring well RL-2S (proximal to the NW corner of the Closed BMP Facility and CDID Ditch No. 14), as compared to the current (2012) measured fluoride concentrations at RL-2S and in the nearby CDID ditch (at surface water Station W3); while Figure 35 shows the fluoride breakthrough curve at RL-2S.

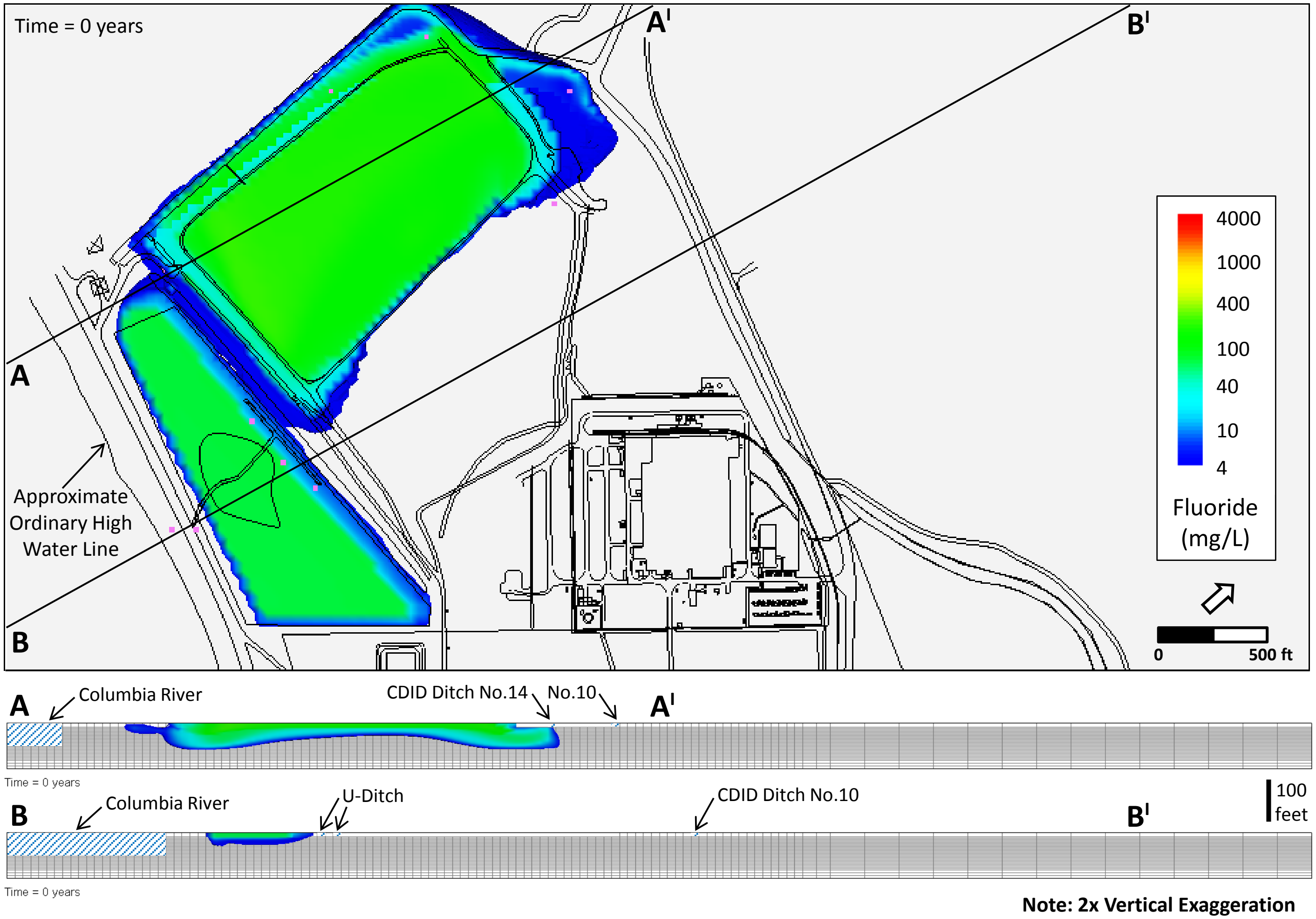

Figure 22

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume under Current Site Conditions

Note: Pink squares denote monitoring well locations.

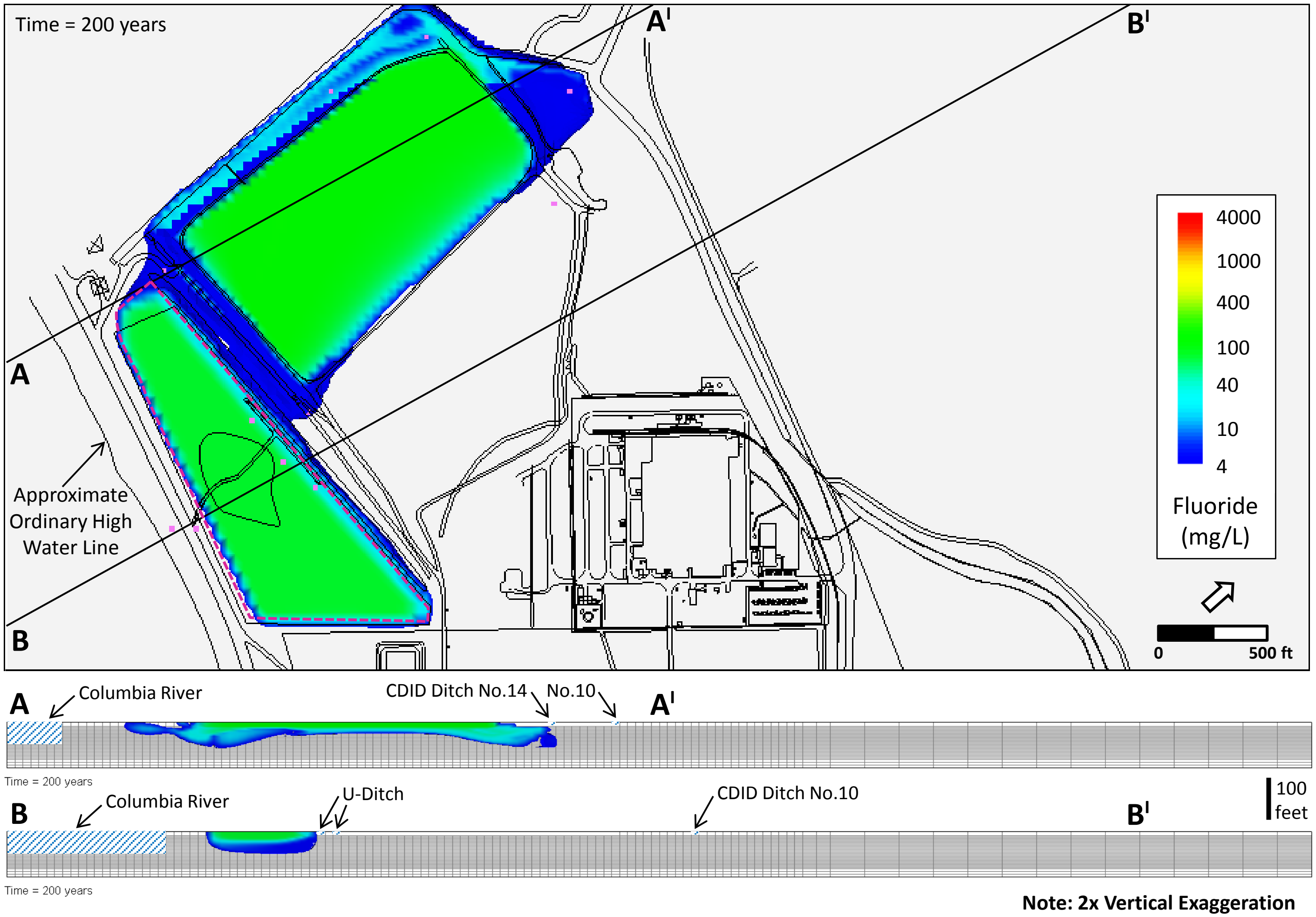

Figure 23

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 200 Years with No Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

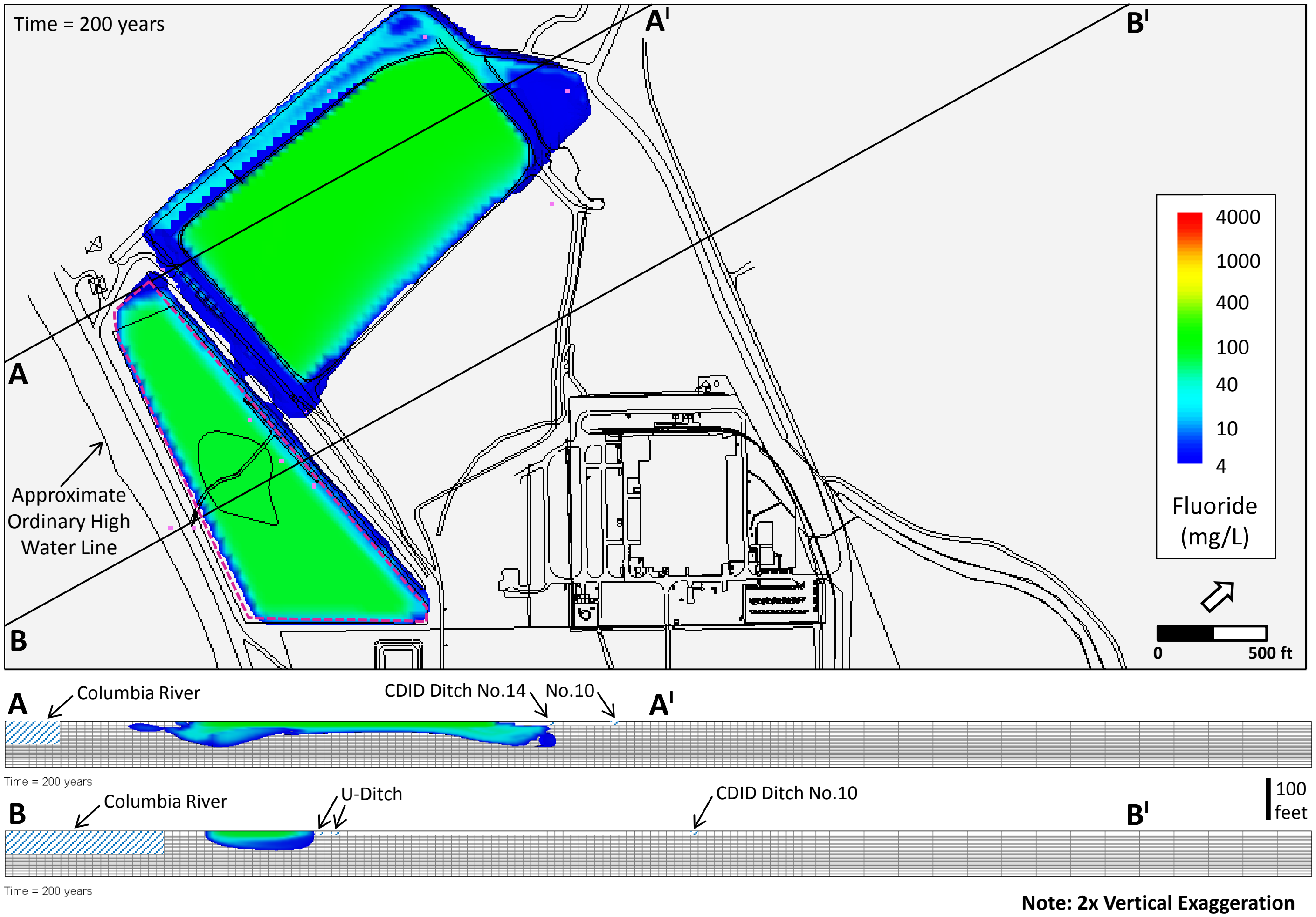

Figure 24

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 200 Years with 50% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

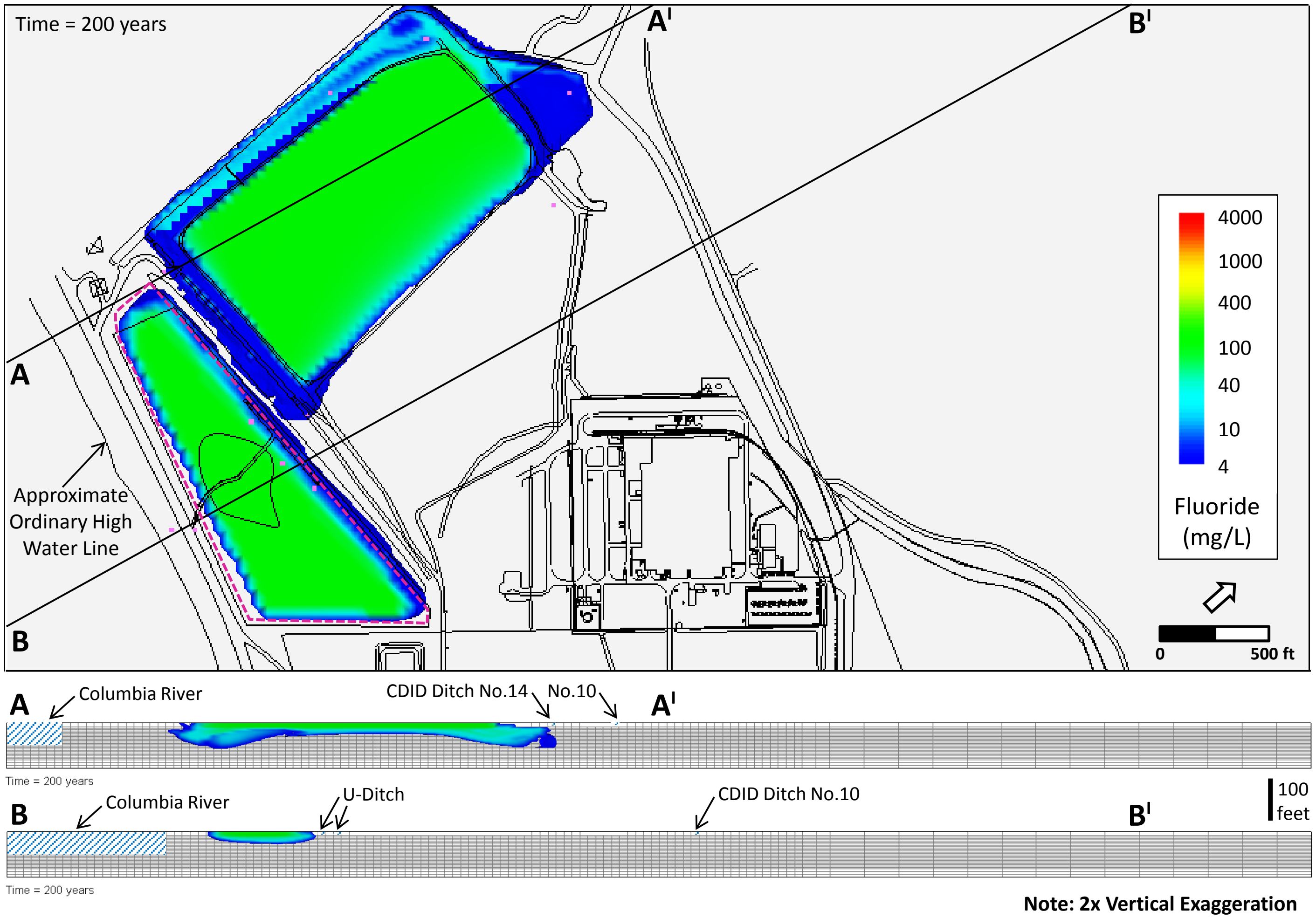

Figure 25

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 200 Years with 100% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

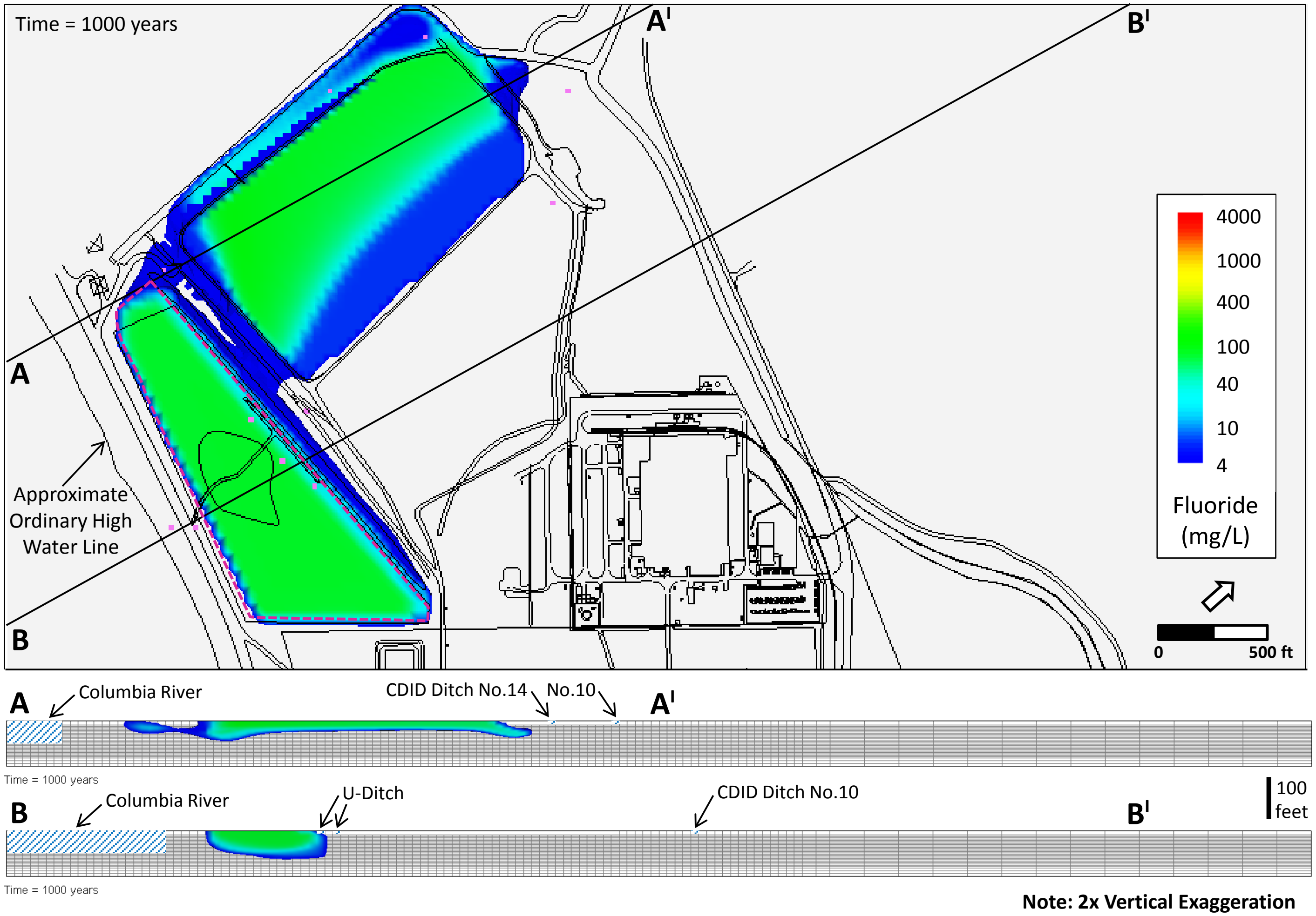

Figure 26

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 1,000 Years with No Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

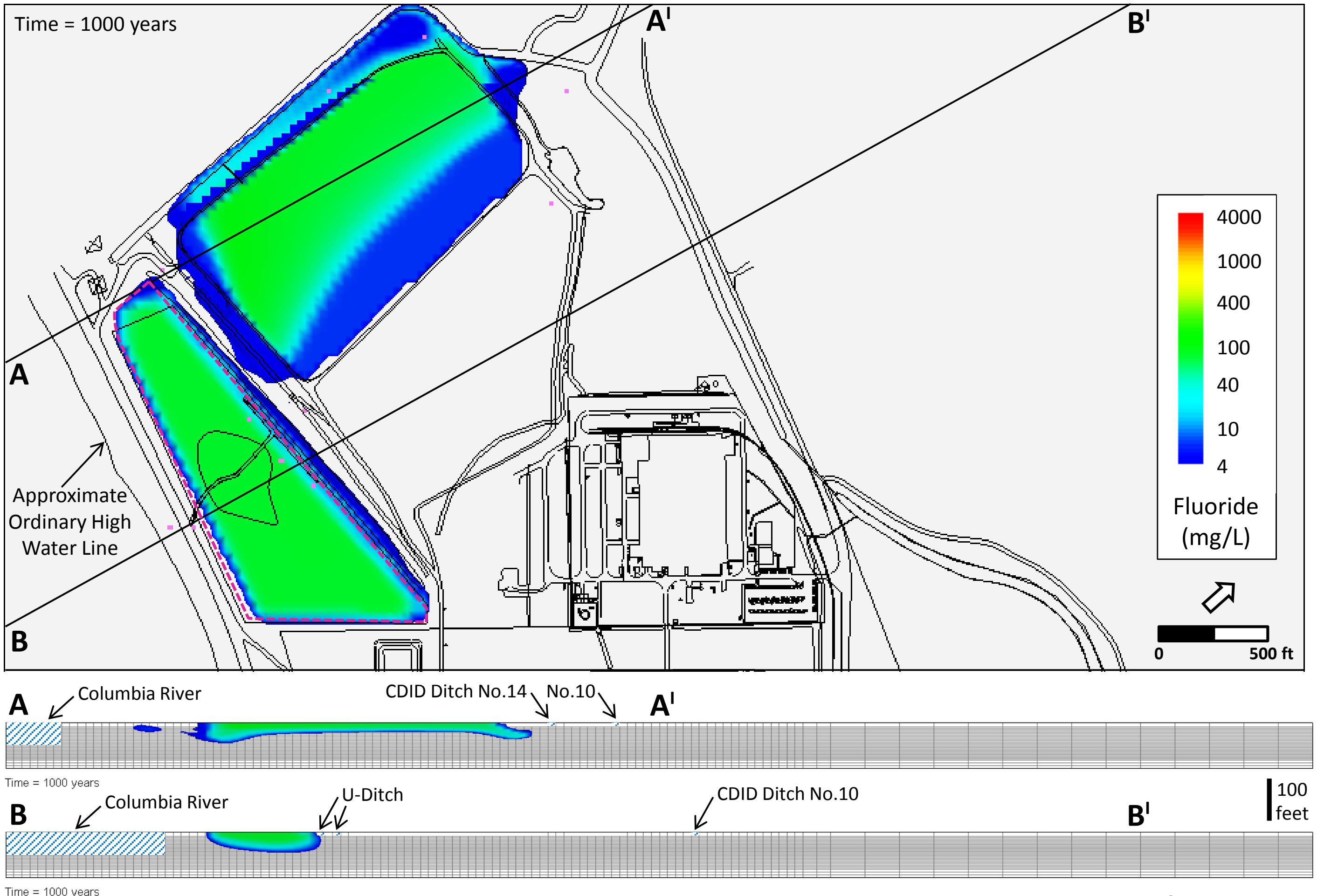

Figure 27

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 1,000 Years with 50% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

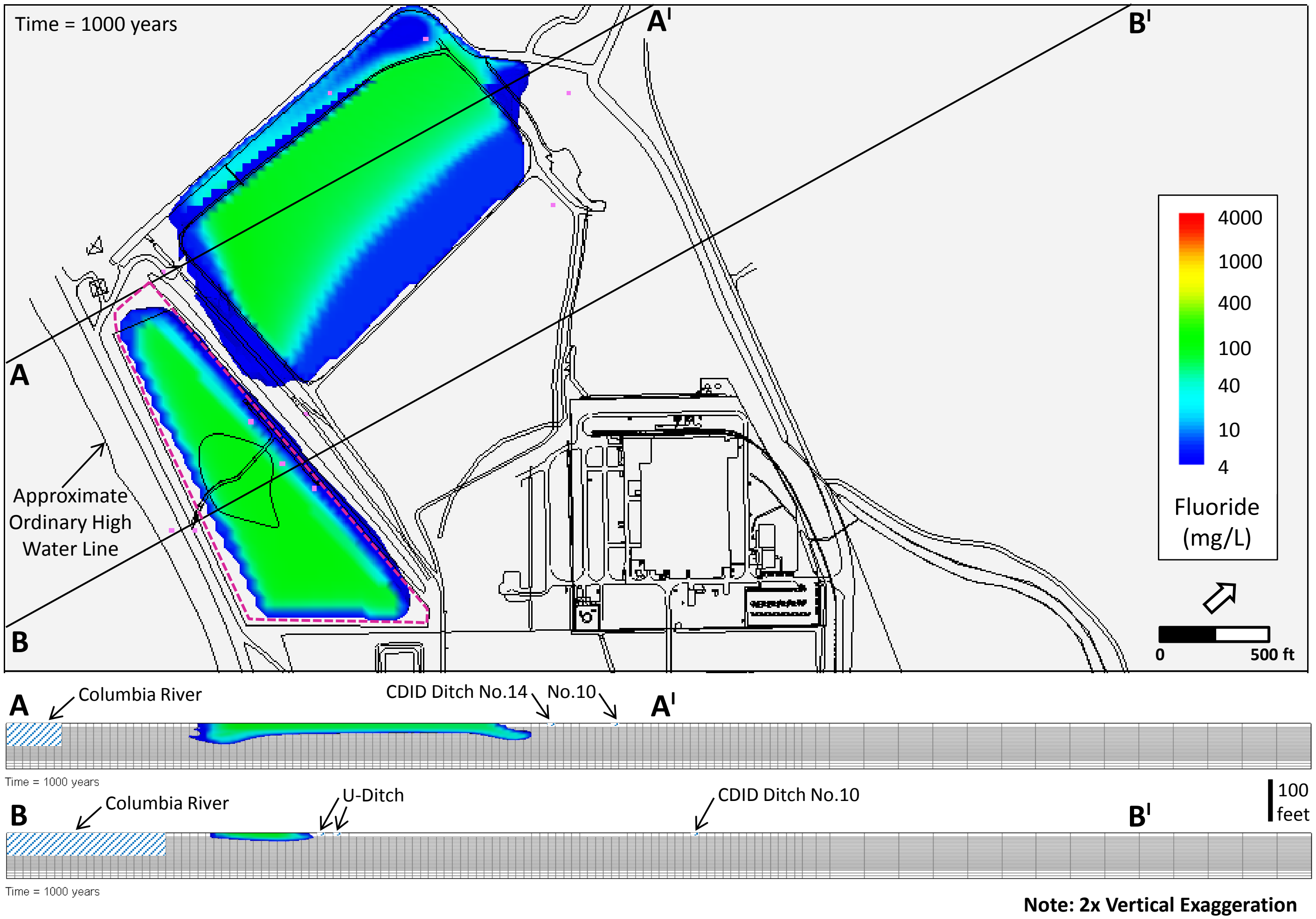

Figure 28

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 1,000 Years with 100% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

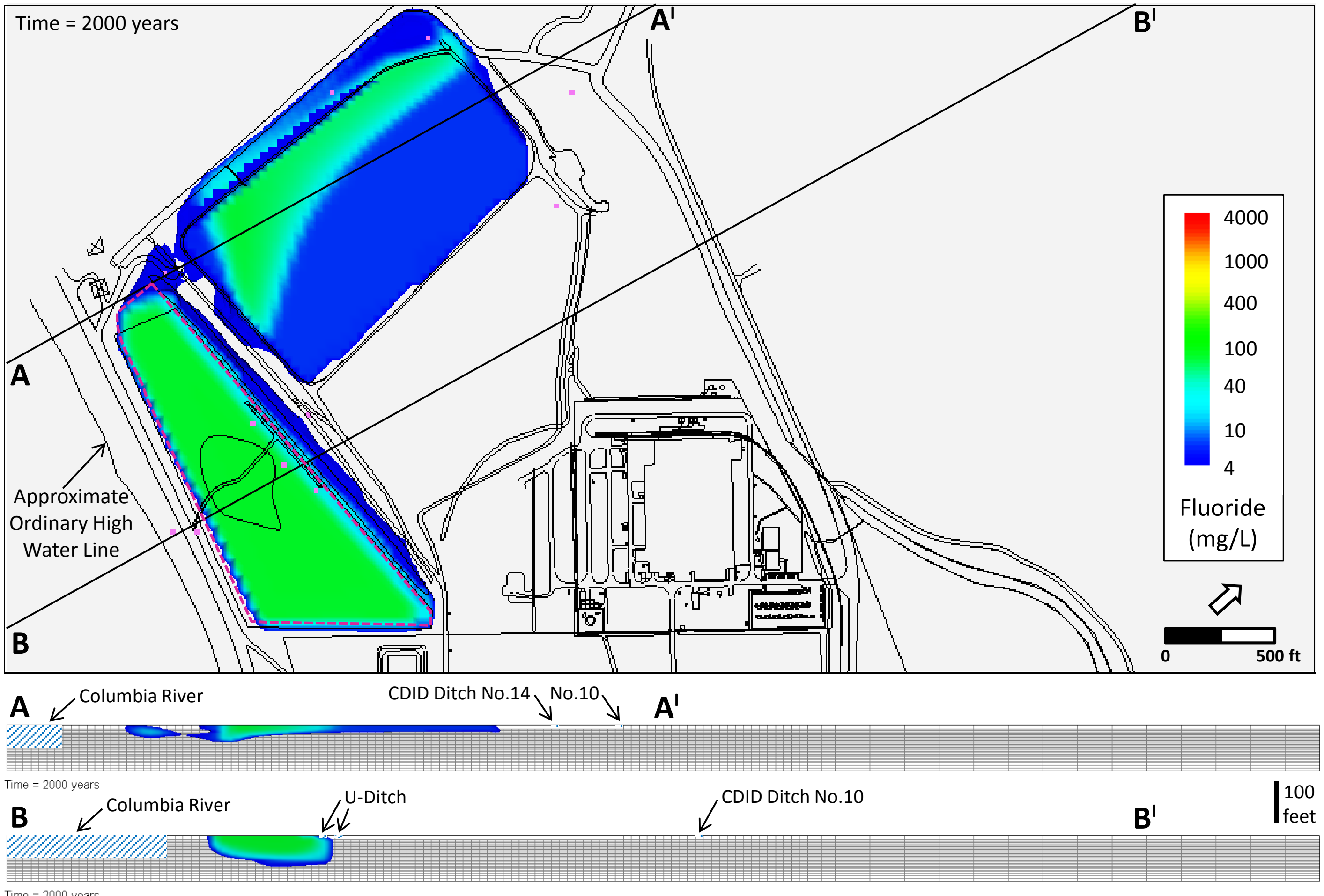

Figure 29

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 2,000 Years with No Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

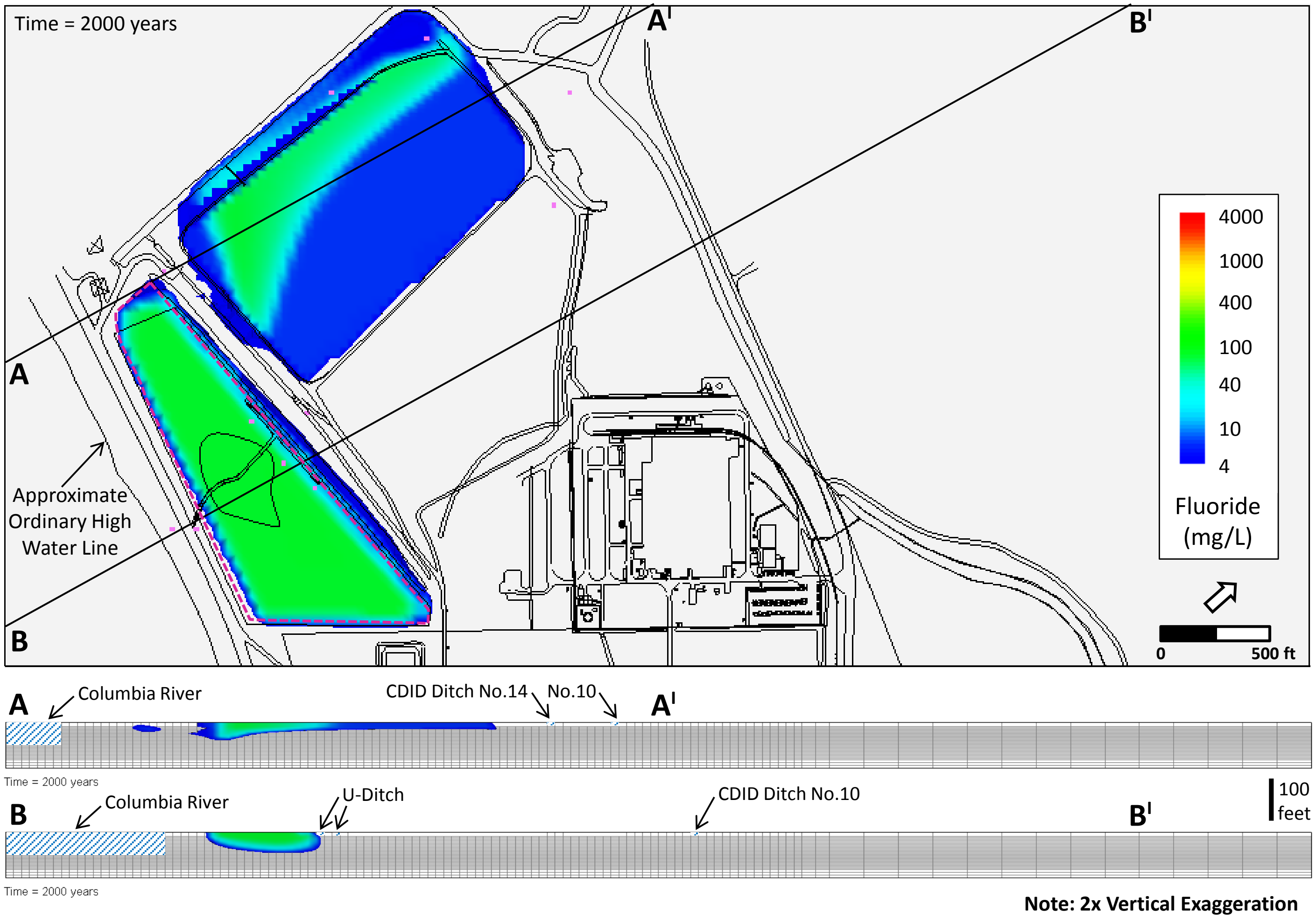

Figure 30

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 2,000 Years with 50% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

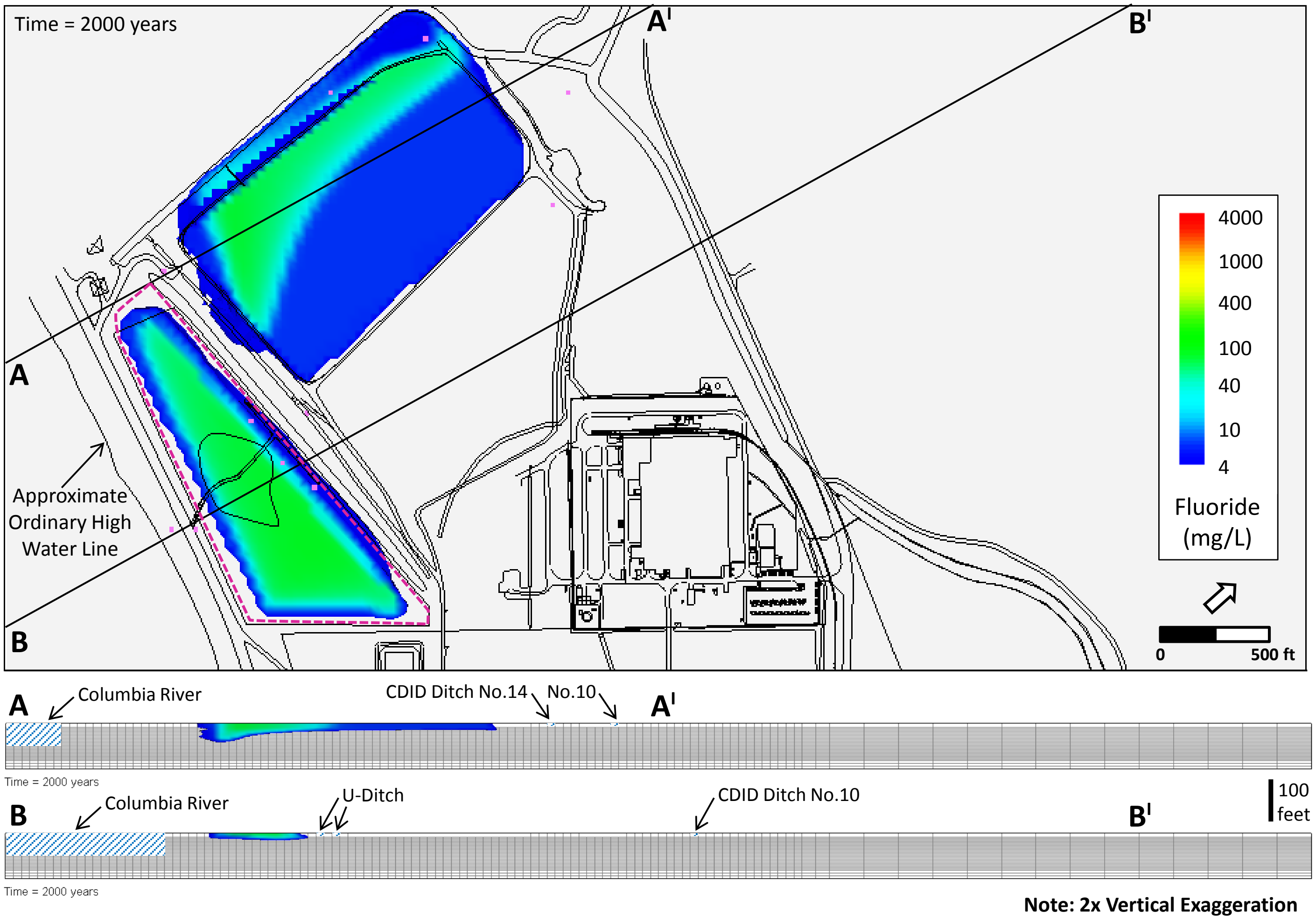

Figure 31

Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume after 2,000 Years with 100% Reduction in Infiltration

Note: Pink squares denote monitoring well locations; pink dashed line denotes the Fill Deposit boundary.

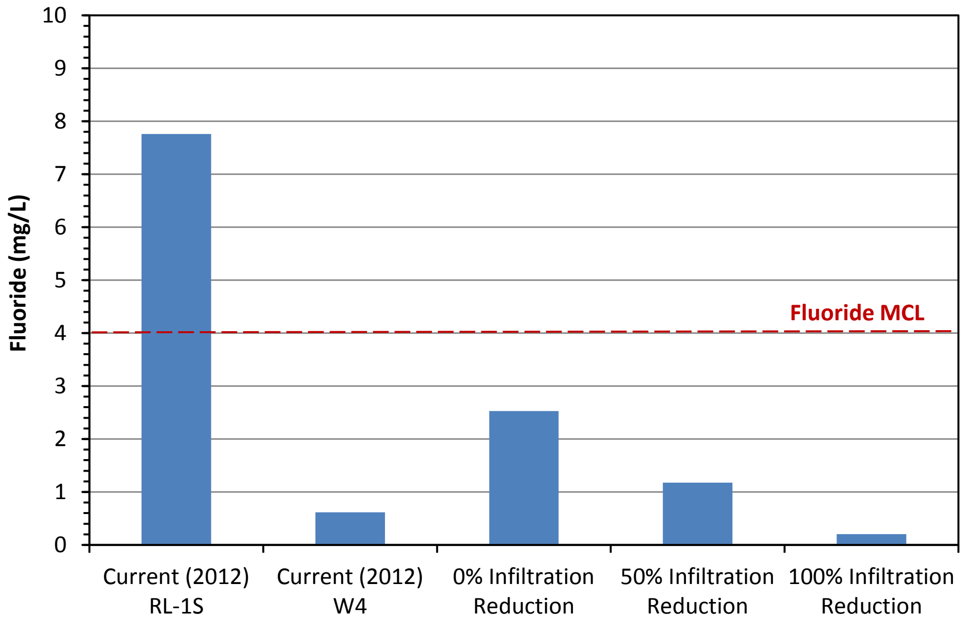

Figure 32

Current Measured Fluoride Concentrations at Well RL-1S and Surface Water Station W4 and Simulated Fluoride Concentration at RL-1S after 2,000 Years

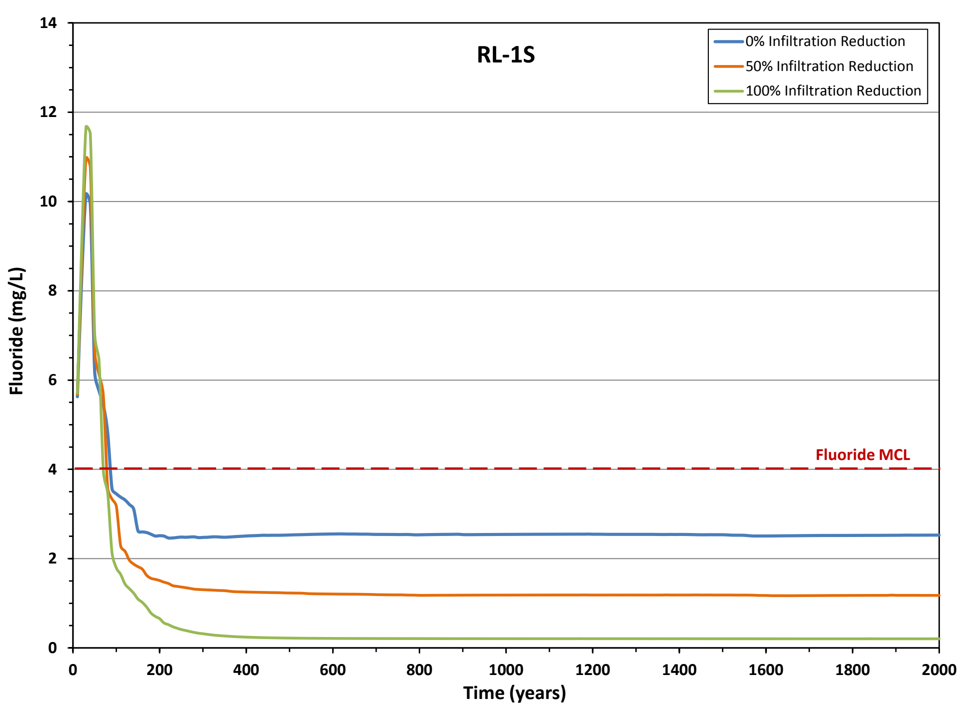

Figure 33

Fluoride Breakthrough Curves at Monitoring Well RL-1S for the Different Infiltration Reduction Scenarios

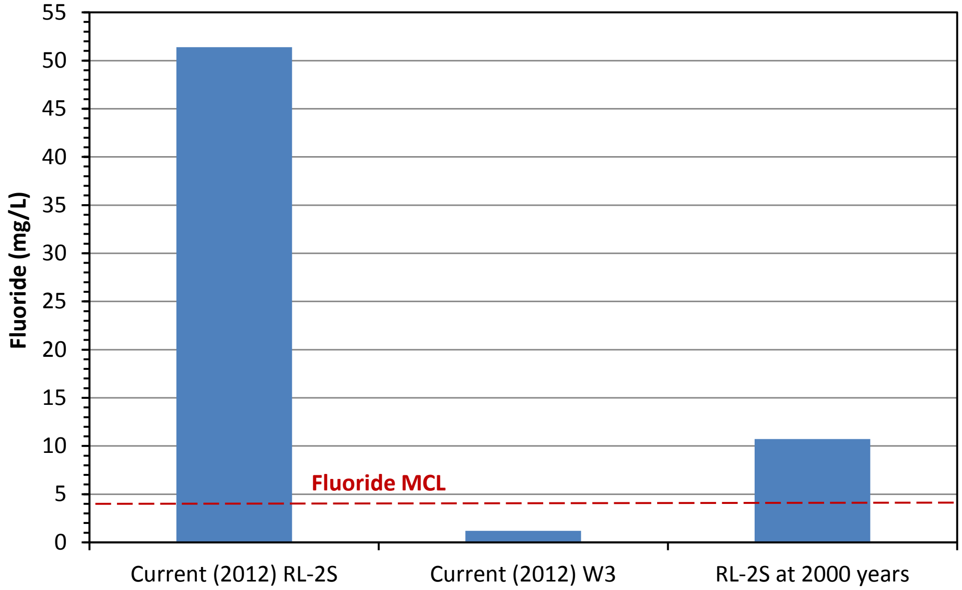

Figure 34
Current Measured Fluoride Concentrations at Well RL-2S and Surface Water Station W3 and Simulated Fluoride Concentration at Well RL-2S after 2,000 Years

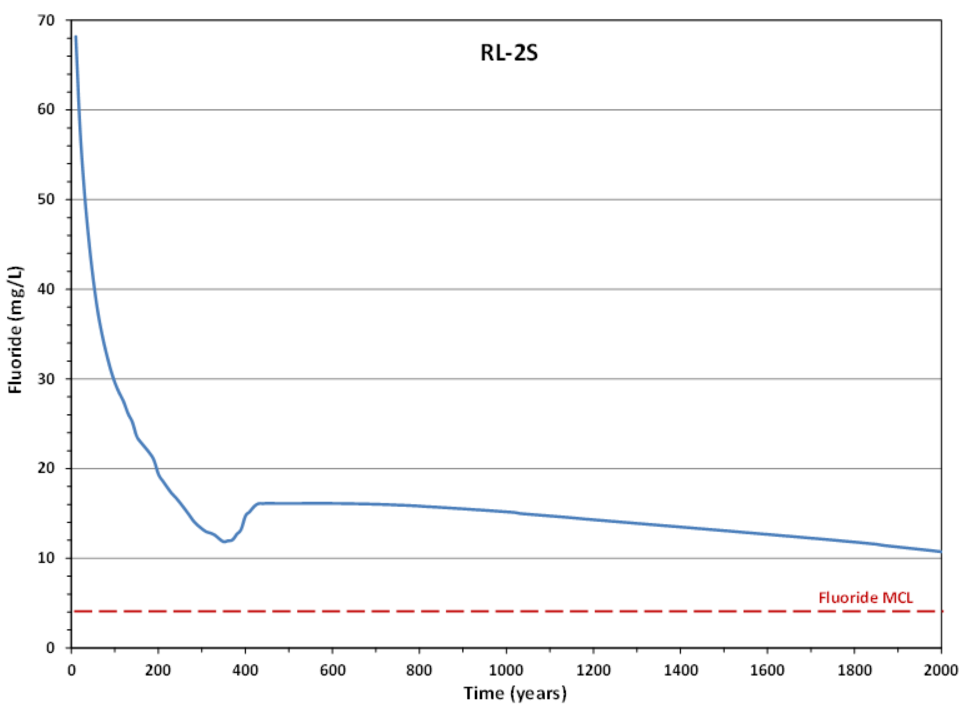

Figure 35
Fluoride Breakthrough Curve for Monitoring Well RL-2S

2.2.4 FS Remedial Alternative 4 Reactive Transport Simulations

The East and West Groundwater Area sub-models were also used to evaluate fluoride fate and transport in support of FS Remedial Alternative 4, which involves excavation of Fill Deposit B-2 (SU3), the Former Stockpile Area (SU5), and Landfill #1 (SU8) in the East Groundwater Area, and the eastern and western portions of Fill Deposit B-3 (SU2) in the West Groundwater Area. In addition to excavation, Alternative 4 also includes low-permeability capping of Fill Deposits A (SU7) and B-1 (SU6) in the East Groundwater Area and the unexcavated portion of Fill Deposit B-3 (SU2) and Landfill #2 (SU1) in the West Groundwater Area. As discussed in Section 9.3.1 of the RI/FS, infiltration is reduced by 80-95% for a low-permeability cap, as compared to present (base case) infiltration. FS Figure 10-3 shows the areas subject to excavation and capping. It should be noted that emplacement of reactive backfill below the waterline and permeable reactive barrier(s) were not included in the Alternative 4 reactive transport simulations. As such, the Alternative 4 simulations are very conservative.

The geochemical conditions (i.e., spatially distributed dissolved, adsorbed, and solid-phase concentrations) from the initial East and West Groundwater Area reactive transport simulations (representing present day) were used as the starting concentration distributions for the Alternative 4 reactive transport simulations, with the exception of the areas subject to excavation. In the excavation areas (i.e., SU3, SU5, SU8, and part of SU2), the simulated present day spatially distributed dissolved, adsorbed, and solid-phase concentrations were replaced with background aquifer geochemical conditions (see Table 13) to represent removal of the specified fill deposits. As previously discussed, the fill deposits do not extend below MSL; therefore, the background aquifer conditions were applied over the depth interval from the top of the model domain to 0 meters MSL in the areas subject to excavation. Recharge of precipitation (i.e., rainwater chemistry) was allowed over the excavated areas. The source-zone recharge flux (i.e., infiltration) through the low-permeability cap areas (i.e., SU6, SU7, SU1, and majority of SU2) was reduced by 80% (equaling 0.061 meter per year) to be conservative.

Figures 36, 37, and 38 illustrate the extent of the simulated East Groundwater Area fluoride plume (plan view and vertical x-sections) at 200, 1,000, and 2,000 years after excavation, respectively. Figures 39, 40, and 41 illustrate the extent of the simulated West Groundwater Area fluoride plume (plan view and vertical x-sections) 200, 1,000, and 2,000 years after excavation, respectively.

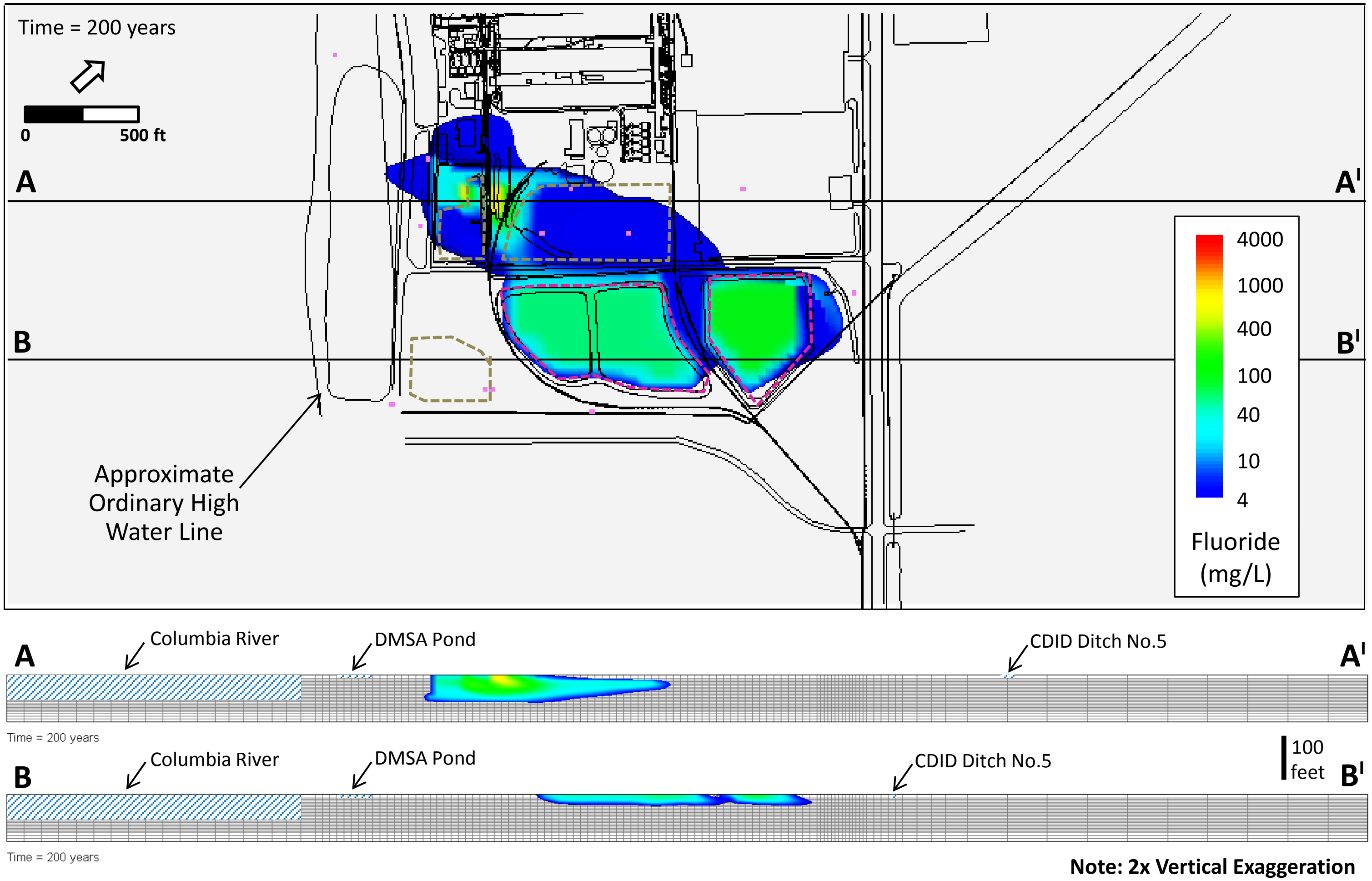

Figure 36

Remedial Alternative 4 Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume 200 Years after Excavation

Note: Pink squares denote monitoring well locations; pink dashed lines denote low-permeability cap boundaries; olive dashed lines denote excavation boundaries.

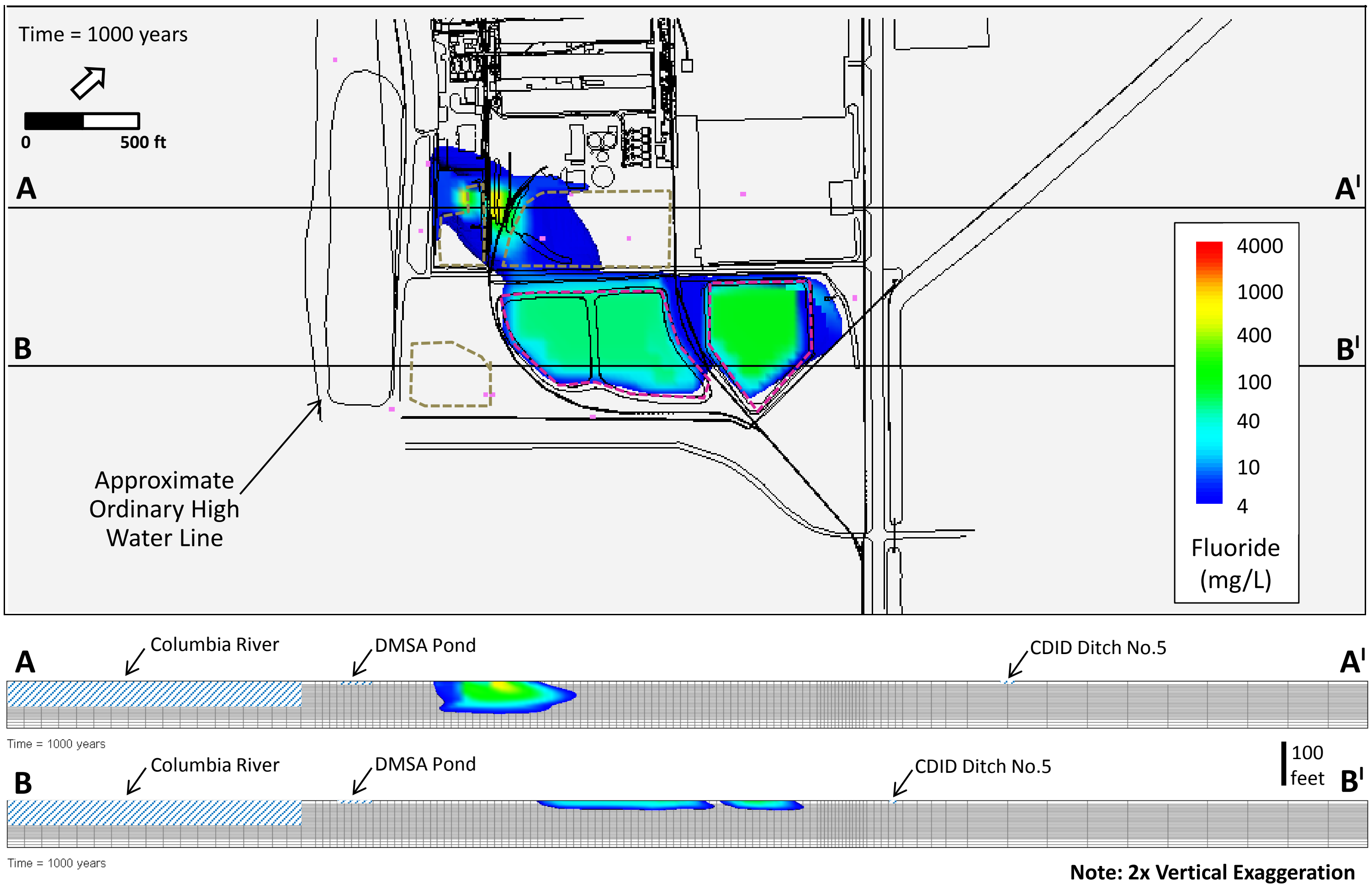

Figure 37

Remedial Alternative 4 Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume 1,000 Years after Excavation

Note: Pink squares denote monitoring well locations; pink dashed lines denote low-permeability cap boundaries; olive dashed lines denote excavation boundaries.

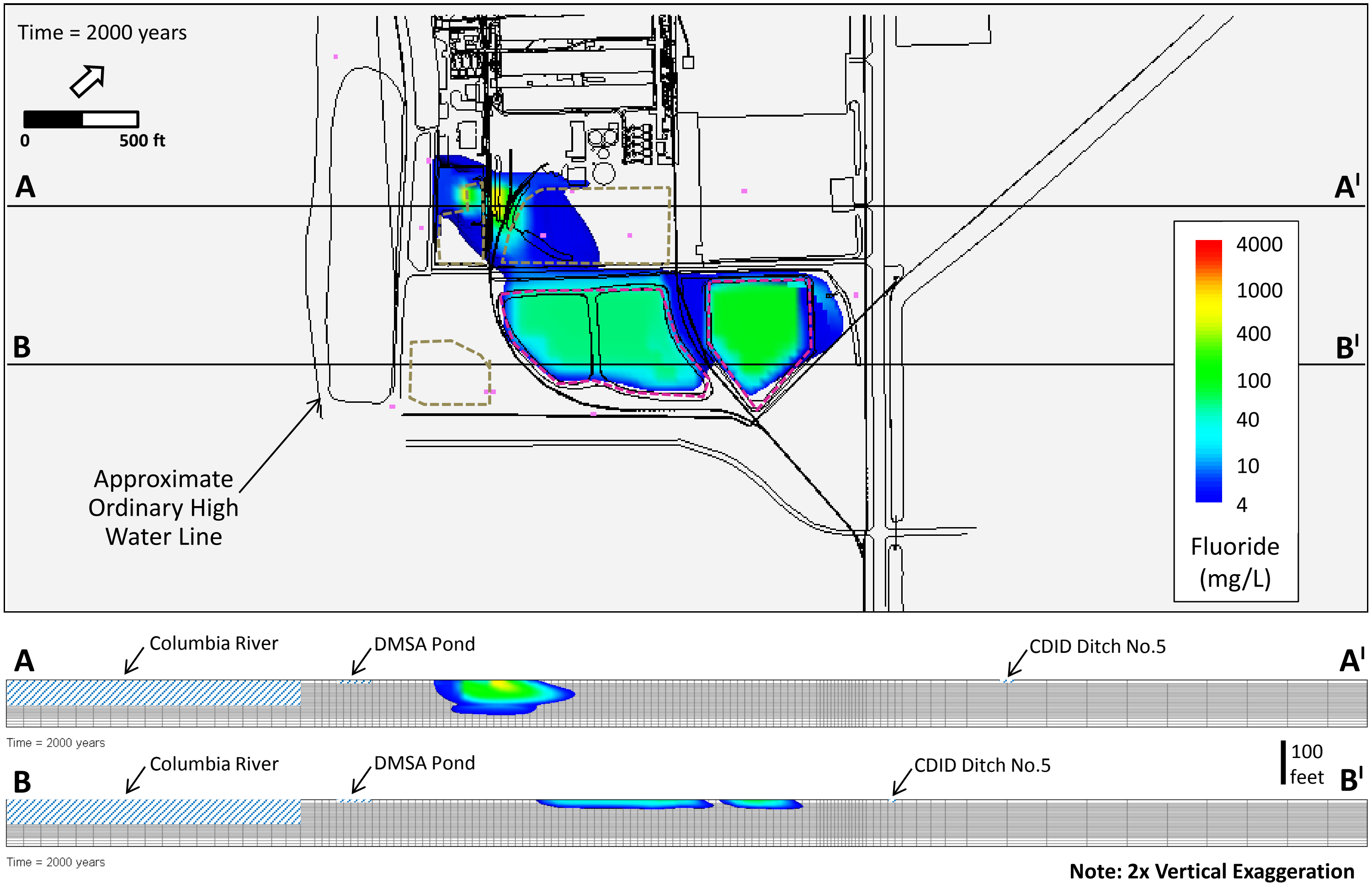

Figure 38

Remedial Alternative 4 Plan View and Vertical X-sections of the Simulated East Groundwater Area Fluoride Plume 2,000 Years after Excavation

Note: Pink squares denote monitoring well locations; pink dashed lines denote low-permeability cap boundaries; olive dashed lines denote excavation boundaries.

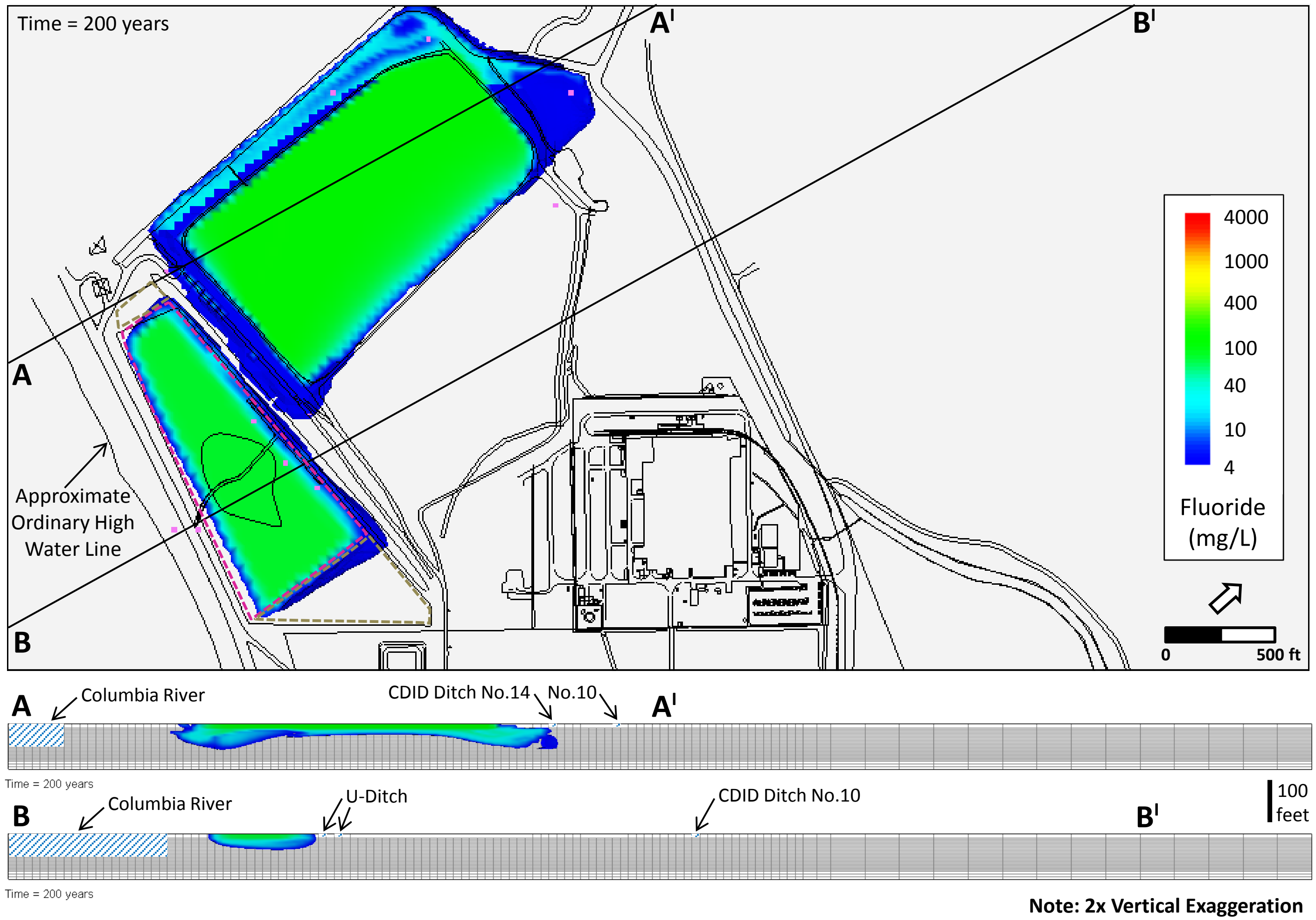

Figure 39

Remedial Alternative 4 Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume 200 Years after Excavation

Note: Pink squares denote monitoring well locations; pink dashed line denotes cap boundary; olive dashed lines denote excavation boundaries.

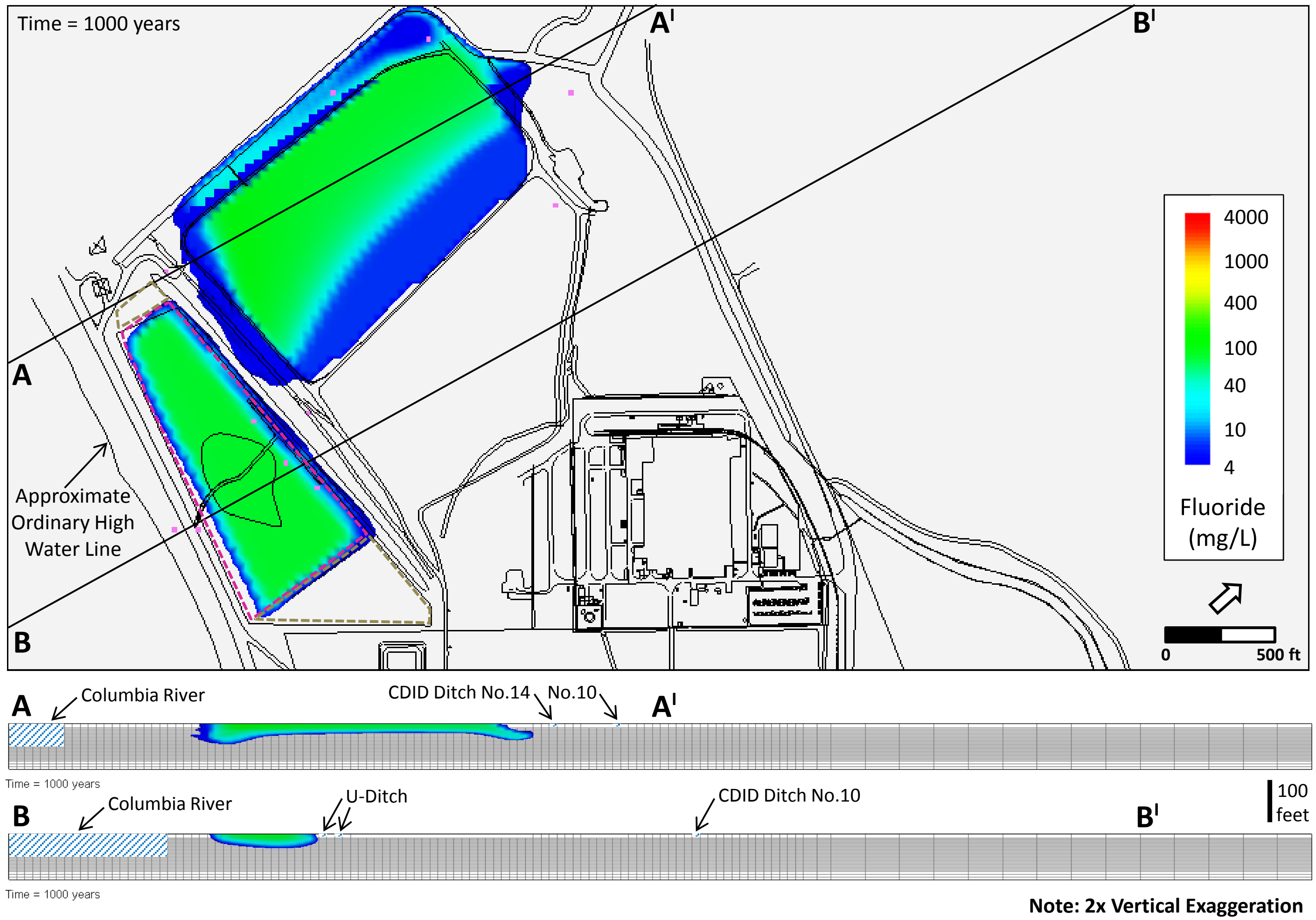

Figure 40

Remedial Alternative 4 Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume 1,000 Years after Excavation

Note: Pink squares denote monitoring well locations; pink dashed line denotes cap boundary; olive dashed lines denote excavation boundaries.

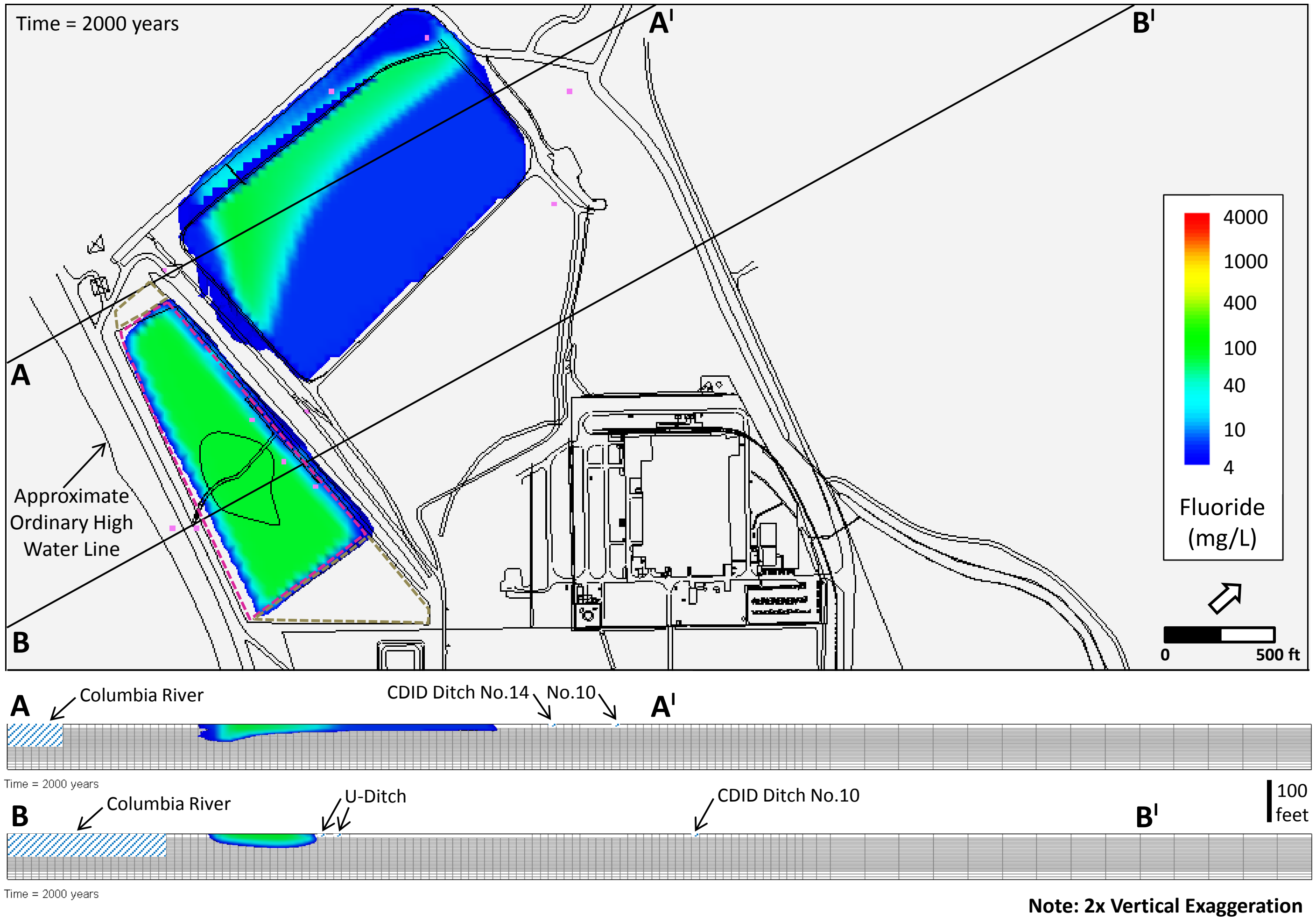

Figure 41

Remedial Alternative 4 Plan View and Vertical X-sections of the Simulated West Groundwater Area Fluoride Plume 2,000 Years after Excavation

Note: Pink squares denote monitoring well locations; pink dashed line denotes cap boundary; olive dashed lines denote excavation boundaries.

3 TIDAL ATTENUATION MODELING

Tidal attenuation modeling (TAM) was performed to evaluate potential Remediation Levels (RELs) for groundwater in shallow wells not containing perched groundwater, located along the Columbia River shoreline. The TAM results were used to calculate a physical attenuation factor for groundwater discharging to the Columbia River. The TAM was performed using data obtained from the tidal study presented in Section 4.3.2 of the RI/FS. Groundwater flow and non-reactive solute transport were simulated using MT3DMS (Zheng 2010). Pre- and post-processing of hydrogeologic data associated with the TAM were performed using iPHT3D (Atteia 2011), which provides a GUI for creating the input files needed to run MT3DMS, as well as a means for viewing output files.

Based on the tidal study conducted in late September/early October 2012, of the shoreline wells sampled, monitoring well SSA7-MW-01 exhibited the highest tidal efficiency. As compared to the Columbia River elevations measured at StillWell-03, groundwater elevations measured at SSA7-MW-01 indicated a tidal influence of 8 percent. The tidal attenuation model was set up by extracting a vertical two-dimensional (2-D) transect from the 3-D groundwater flow model. This vertical 2-D transect extends from the river boundary (approximate ordinary high water line [OHWL]) upland through SSA7-MW-01 to the Levee Road, representing an upland boundary with stable water levels. Since the tidal study was conducted during the dry season, the same hydrogeologic parameters used for the dry season groundwater flow model were used for the TAM. Table 14 lists the TAM input parameters while Figure 42 illustrates the extent of the vertical 2-D model domain.

Table 14
Tidal Attenuation Model Input Parameters

Hydrogeologic Parameters		Units	TAM
Model Domain (X × Z)		m	128 × 17
Grid Spacing (X × Z)		m	1 × 1
Porosity		-	0.35
Hydraulic Conductivity	Horizontal (K_x)	m/yr	556
	Vertical (K_z)	m/yr	55.6
Dispersivity	Longitudinal	m	1
	Transverse	m	0.1

Hydrogeologic Parameters		Units	TAM
Constant Head Boundaries	Upland Boundary	m	2.26[1]
	Columbia River	m	Time-varying[2]

Notes:
1. Based on the dry season groundwater flow model and SSA7-MW-01 October 2012 quarterly gauging data
2. Based on the 2012 tidal study data collected at StillWell-03. See Figure 43 for specific water elevations
m = meter
TAM = tidal attenuation model
yr = year

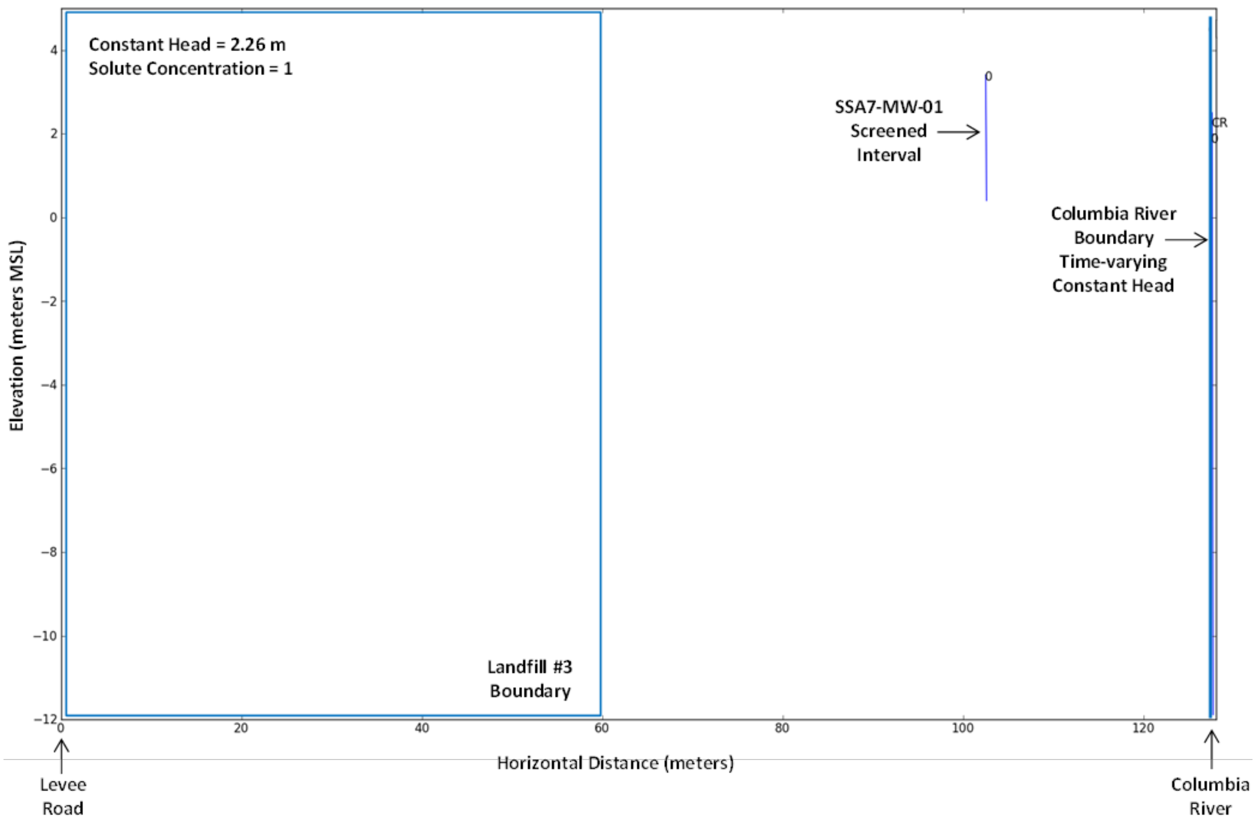

Figure 42
Tidal Attenuation Model Domain (2-D Vertical Transect) and Model Features

The 2012 tidal study was conducted over a 96-hour period, with water elevations recorded in 5-minute increments. A 3-day (i.e., 72-hour) record of Columbia River elevations, measured at StillWell-03 from 0820 on 9/29/12 to 0815 on 10/02/12, was selected from the tidal study data to use in the tidal attenuation model. This specific 72-hour river tidal record was selected because the measured starting and ending river stage were very similar (1.658 m at 0820 on 9/29/12 versus 1.687 m at 0815 on 10/2/12). A 30-day synthetic river stage record was generated from the 3-day river stage record by repeating it ten times. Figure 43 illustrates the 3-day Columbia River stage recorded at StillWell-03 from 0820 on 9/29/12 to 0815 on 10/02/12, and the synthetic 30-day river stage record. Also shown in Figure 43 are the groundwater elevations measured at SSA7-MW-01 during the same 72-hour period of the tidal study. The synthetic 30-day river stage record was used to define a time-varying constant head boundary in the model at the Columbia River.

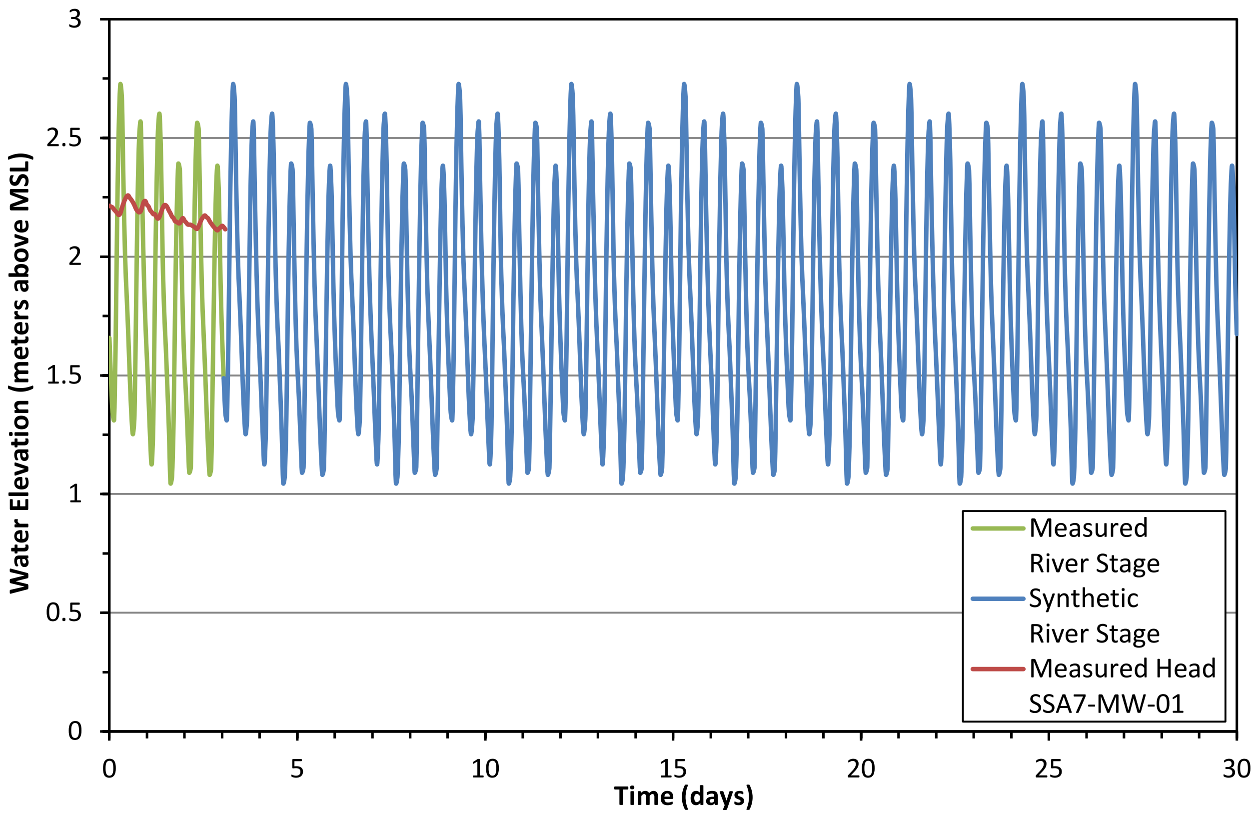

Figure 43
3-day Columbia River Stage Measured at StillWell-03 (green); Synthetic 30-day River Stage Record (blue); and Groundwater Elevations Measured at SSA7-MW-01 for the same 3-day Period (red)

As a calibration check, the average groundwater elevation at SSA7-MW-01 for the last 3 days of the 30-day simulation was compared to the average groundwater elevation measured at SSA7-MW-01 during the 72-hour period of the tidal study. The average modeled groundwater elevation matches the average measured groundwater elevation at SSA7-MW-01 within 8 percent. Figure 44 illustrates the 72-hour measured and 30-day modeled groundwater elevations at monitoring well SSA7-MW-01. Although the modeled groundwater elevation fluctuation shows less tidal response than observed at SSA7-MW-01, it does show the same overall trend observed during the 2012 tidal study.

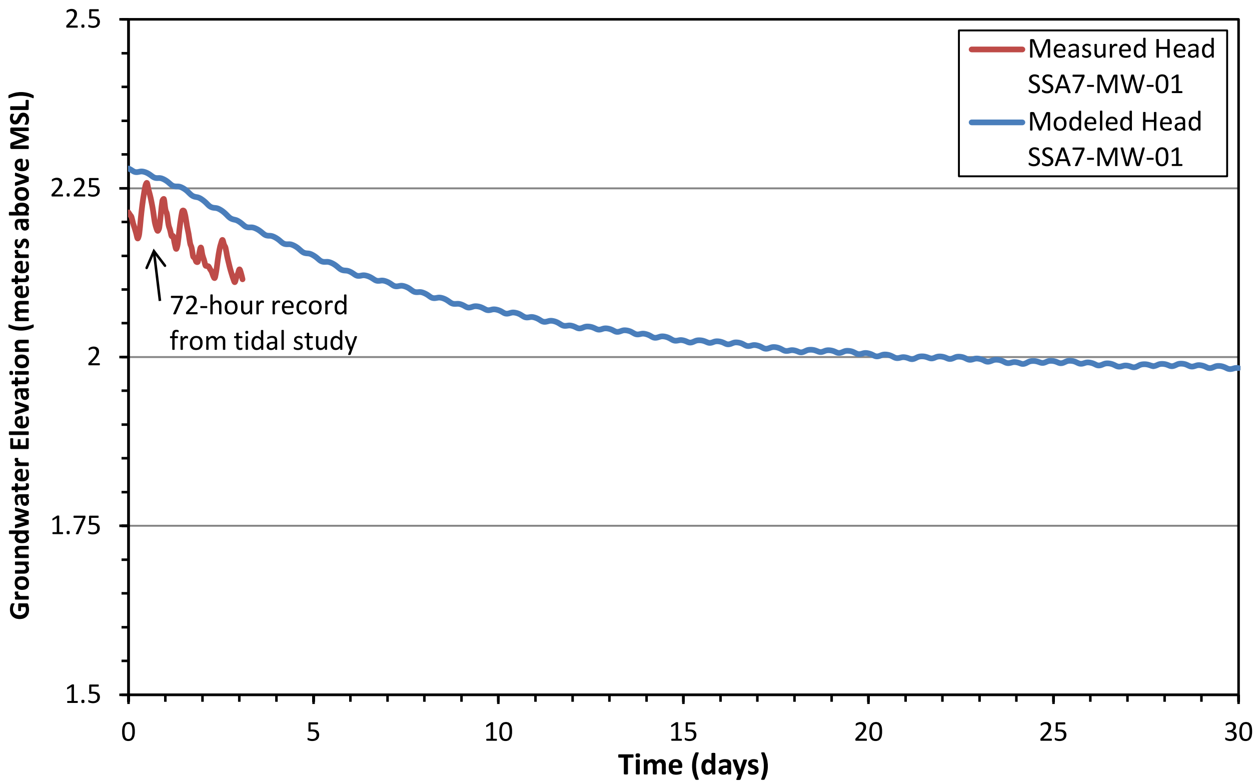

Figure 44
72-hour measured and 30-day modeled groundwater elevations at Monitoring Well SSA7-MW-01

The final groundwater elevations from the calibrated 30-day simulation were used as the initial groundwater elevations for a transient solute transport simulation (i.e., representing an upland source) to evaluate attenuation of solute concentrations downgradient from an upland source due to tidally influenced river stage fluctuations. In the transient simulation, Landfill #3 represents an upland source area with a solute concentration set to 1 (see Figure 42). The solute concentration at the river boundary (a fraction of 1), therefore, reflects the degree to which physical attenuation processes reduce solute concentrations as groundwater flows from the upland source towards the Columbia River.

The transient 30-day simulation was repeated multiple times, using the ending concentration distribution from the previous run as the starting concentration distribution for the next 30-day run until a steady-state concentration distribution was achieved.

Based on the stabilized solute concentrations in the cells adjacent to the Columbia River boundary, a tidal attenuation factor of 0.3 is found for groundwater discharging to the Columbia River. Using this attenuation factor, an REL of 13.3 mg/L fluoride in wells located along the Columbia River shoreline is protective of surface water.

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ATTACHMENT 1
X-RAY DIFFRACTION REPORT

12512002.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:31 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	No
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz

Formula	$Si\ O_2$
Pdf Number	000-83-0539
Figure of Merit	46%
Total Peaks	19
Peaks Matched	15
New Matches	15
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.734004
Concentration	0.451488
I / Icorundum	3.07

B Calcium Fluoride

Formula	$Ca\ F_2$
Pdf Number	000-87-0971
Figure of Merit	44%
Total Peaks	6
Peaks Matched	5
New Matches	5
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.411755
Concentration	0.338245
I / Icorundum	4.1

C Gibbsite

Formula	$Al\ (\ O\ H\ )_3$
Pdf Number	000-29-0041
Figure of Merit	45%
Total Peaks	39
Peaks Matched	29
New Matches	29

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.460181
Concentration	0.145678
I / Icorundum	1.58

D Aluminum Oxide

Formula	$Al_2 O_3$
Pdf Number	000-75-1865
Figure of Merit	45%
Total Peaks	15
Peaks Matched	11
New Matches	11
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.134669
Concentration	0.0275218
I / Icorundum	1.02

E beta-Sodium Aluminum Oxide

Formula	$Na Al_7 O_{11}$
Pdf Number	000-21-1095
Figure of Merit	36%
Total Peaks	21
Peaks Matched	12
New Matches	12
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.241708
Concentration	Not available

F Albite high

Formula	$Na (Al Si_3 O_8)$
Pdf Number	000-83-1607
Figure of Merit	28%
Total Peaks	198
Peaks Matched	105
New Matches	105
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.303282
Concentration	0.0370669
I / Icorundum	0.61

G Brushite

Formula	$Ca P O_3 (O H) !2 H_2 O$
Pdf Number	000-11-0293
Figure of Merit	19%
Total Peaks	38
Peaks Matched	18
New Matches	18

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.0529195
Concentration	Not available

H Montmorillonite (bentonite)

Formula	$(Na , Ca)_{0.3} (Al , Mg)_2 Si_4 O_{10} (O H)_2$!x $H_2 O$
Pdf Number	000-03-0015
Figure of Merit	9%
Total Peaks	10
Peaks Matched	7
New Matches	7
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.063675
Concentration	Not available

Peak List

Peak Search Settings

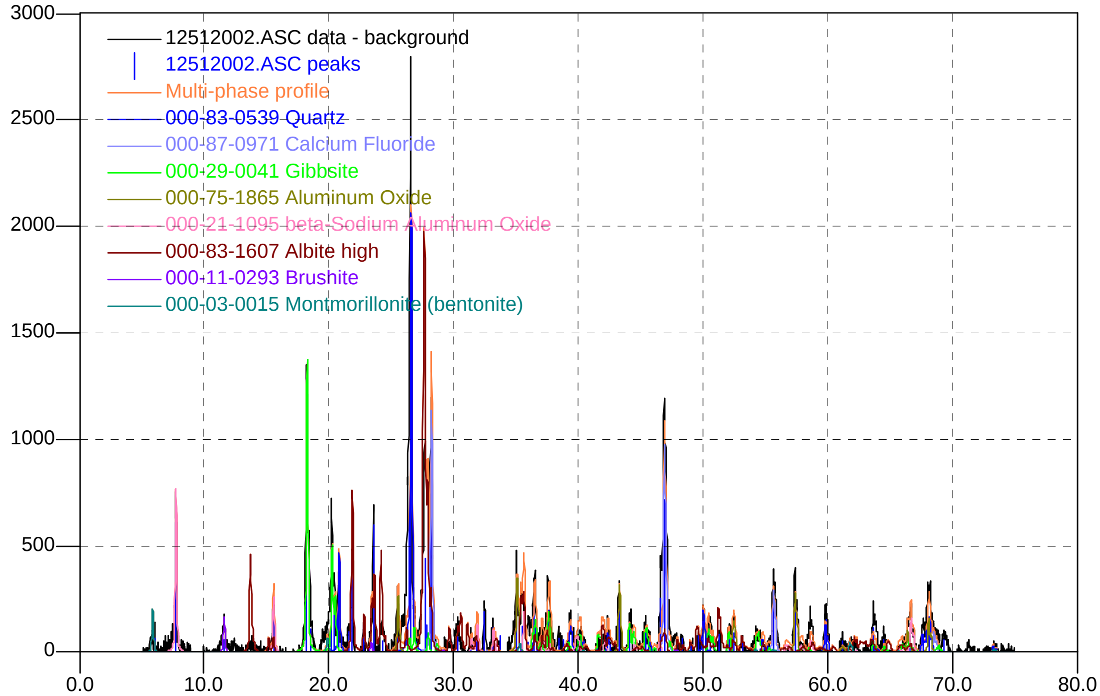
Confidence Threshold	90%
Matched / Total	58 / 64

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
6.016	14.6790	69	0.112	96.1%	H
7.745	11.4055	613	0.117	100%	E
11.584	7.6326	62	0.131	99.4%	G
15.559	5.6904	184	0.117	100%	EF
18.238	4.8602	961	0.122	100%	C
18.511	4.7891	108	0.127	96.2%	
20.219	4.3884	424	0.115	100%	C
20.479	4.3333	227	0.104	100%	C
20.791	4.2689	306	0.114	100%	AG
21.580	4.1145	99	0.112	99.9%	
21.892	4.0565	438	0.120	100%	F
22.796	3.8977	126	0.121	100%	F
23.596	3.7673	601	0.118	100%	F
24.363	3.6504	54	0.126	92.3%	F
25.507	3.4892	221	0.119	100%	DF
26.555	3.3539	1941	0.116	100%	AC
27.700	3.2178	442	0.122	100%	F
27.907	3.1944	131	0.132	98.5%	CF
28.235	3.1581	806	0.123	100%	BF
30.340	2.9435	73	0.166	99.9%	FG
31.400	2.8465	60	0.115	99.6%	EFG
31.859	2.8066	51	0.138	97.3%	EFG
32.490	2.7535	190	0.129	100%	
33.119	2.7026	116	0.128	100%	EF
33.704	2.6570	76	0.130	100%	
35.074	2.5563	303	0.121	100%	D
35.530	2.5246	121	0.148	100%	EFG
36.029	2.4908	46	0.103	95.7%	
36.504	2.4594	215	0.138	100%	ACFG

37.047	2.4246	38	0.122	92.1%	CEF
37.585	2.3911	196	0.141	100%	CDEF
38.419	2.3411	63	0.122	99.5%	F
38.771	2.3207	58	0.117	98.9%	F
39.348	2.2880	108	0.120	100%	ACF
40.519	2.2245	51	0.122	95.8%	FH
41.577	2.1703	43	0.125	93.8%	CDFG
42.403	2.1299	92	0.135	100%	AF
43.274	2.0890	235	0.127	100%	DG
44.154	2.0494	130	0.161	100%	CF
45.362	1.9976	89	0.123	100%	CF
46.604	1.9472	254	0.123	100%	EF
46.956	1.9335	719	0.140	100%	BF
47.844	1.8996	42	0.142	93.3%	FG
48.339	1.8813	64	0.138	99.8%	F
49.115	1.8534	47	0.128	98.3%	F
49.653	1.8346	81	0.123	100%	F
50.073	1.8202	164	0.137	100%	AFG
50.569	1.8035	80	0.135	100%	ACFG
51.351	1.7778	84	0.140	100%	FG
52.104	1.7539	62	0.154	97.5%	CF
52.501	1.7416	92	0.135	100%	DF
53.177	1.7210	40	0.177	95.9%	F
54.285	1.6885	42	0.114	94.5%	CFH
55.694	1.6490	254	0.156	100%	BFH
57.402	1.6039	235	0.124	100%	D
58.650	1.5728	87	0.159	100%	CEF
59.862	1.5438	151	0.151	100%	AF
61.191	1.5134	55	0.103	99.3%	DF
63.722	1.4592	117	0.191	100%	CFG
64.508	1.4434	62	0.166	99.7%	CF
66.669	1.4017	81	0.112	99.7%	CEF
67.637	1.3840	72	0.132	99.7%	A
68.147	1.3749	121	0.176	100%	AD
69.308	1.3553	59	0.116	90.4%	

Graphics


12512002.ASC data - background
12512002.ASC peaks
Multi-phase profile
000-83-0539 Quartz
000-87-0971 Calcium Fluoride
000-29-0041 Gibbsite
000-75-1865 Aluminum Oxide
000-21-1095 beta-Sodium Aluminum Oxide
000-83-1607 Albite high
000-11-0293 Brushite
000-03-0015 Montmorillonite (bentonite)
3000
2500
2000
1500
1000
500
0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0

12512004.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:42 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	No
Allow Zero Errors	No
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Labradorite

Formula	($Ca_{0.64}$ $Na_{0.31}$) ($Al_{1.775}$ $Si_{2.275}$) O_8
Pdf Number	000-83-1417
Figure of Merit	76%
Total Peaks	199
Peaks Matched	123
New Matches	123
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.275453
Concentration	0.0378191
I / Icorundum	0.53

B Quartz, syn

Formula	Si O_2
Pdf Number	000-46-1045
Figure of Merit	70%
Total Peaks	19
Peaks Matched	18
New Matches	18
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.947262
Concentration	0.836783
I / Icorundum	3.41

C Albite, ordered

Formula	Na Al Si_3 O_8
Pdf Number	000-19-1184
Figure of Merit	58%
Total Peaks	147
Peaks Matched	80
New Matches	80

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.230507
Concentration	0.125398
I / Icorundum	2.1

D Montmorillonite-14A

Formula	$Na_{0.3}$ (Al , Mg $)_2$ Si_4 O_{10} (O H $)_2$!x H_2 O
Pdf Number	000-13-0259
Figure of Merit	14%
Total Peaks	7
Peaks Matched	6
New Matches	6
Strong Unmatched	1
Peak Shift	0
Scale Factor	1.57773
Concentration	Not available

Peak List

Peak Search Settings

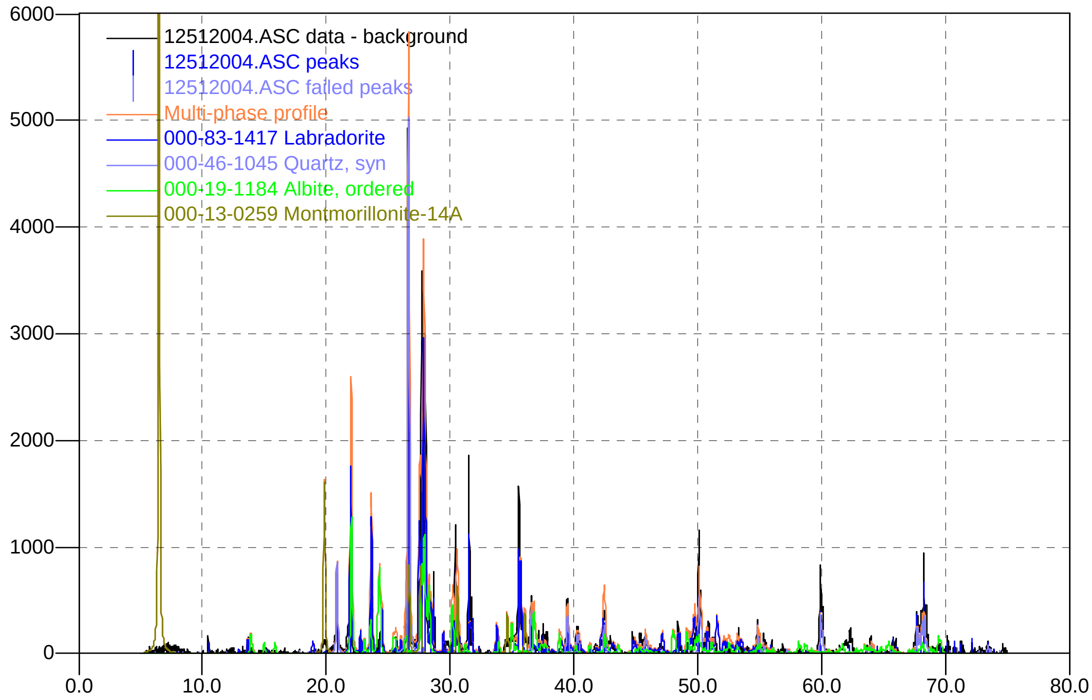
Confidence Threshold	80%
Matched / Total	0 / 69

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
10.492	8.4243	111	0.099	100%	
13.723	6.4473	78	0.095	100%	A
19.928	4.4518	33	0.111	81.6%	AD
20.863	4.2543	606	0.097	100%	AB
21.961	4.0440	834	0.106	100%	AC
22.823	3.8932	128	0.099	100%	A
23.660	3.7573	407	0.111	100%	AC
24.385	3.6472	114	0.115	100%	AC
25.656	3.4693	92	0.098	100%	AC
26.638	3.3436	3305	0.091	100%	BCD
27.733	3.2140	2360	0.095	100%	AC
28.024	3.1813	1748	0.091	100%	AC
28.421	3.1377	333	0.133	100%	AC
28.699	3.1080	516	0.091	100%	
29.563	3.0192	34	0.087	83.2%	A
29.805	2.9952	44	0.094	96.5%	A
30.201	2.9568	112	0.100	99.9%	AC
30.450	2.9331	804	0.095	100%	AC
31.544	2.8339	1122	0.089	100%	AC
31.825	2.8095	333	0.085	100%	A
32.349	2.7652	72	0.092	100%	A
33.753	2.6533	96	0.111	100%	A
34.457	2.6007	70	0.097	99.9%	
35.576	2.5214	982	0.102	100%	AC
36.561	2.4557	293	0.105	100%	AB
37.177	2.4164	113	0.102	100%	A
37.519	2.3952	173	0.100	100%	AC
37.853	2.3748	108	0.101	100%	AC

39.474	2.2809	358	0.104	100%	ABC
40.254	2.2385	201	0.118	100%	BC
41.713	2.1635	28	0.101	81.5%	A
42.144	2.1424	75	0.093	99.9%	AC
42.476	2.1264	232	0.128	100%	ABC
42.955	2.1038	34	0.137	90.0%	A
44.765	2.0228	126	0.097	100%	A
45.050	2.0107	47	0.084	97.7%	AC
45.340	1.9985	114	0.127	100%	AC
45.790	1.9799	95	0.104	100%	ABC
46.972	1.9328	31	0.079	88.9%	A
48.432	1.8779	165	0.132	100%	A
49.215	1.8499	34	0.098	91.7%	AC
50.128	1.8183	707	0.114	100%	ABC
50.681	1.7997	135	0.102	100%	ABC
50.899	1.7926	98	0.094	100%	AC
51.384	1.7767	59	0.116	99.4%	A
52.316	1.7473	84	0.114	100%	AC
53.339	1.7164	55	0.080	86.1%	AC
54.848	1.6728	284	0.101	100%	ABC
55.330	1.6592	118	0.102	100%	AB
55.947	1.6422	82	0.087	100%	AC
56.176	1.6360	38	0.069	97.2%	C
58.336	1.5805	33	0.087	93.8%	C
58.748	1.5704	26	0.089	85.0%	C
59.941	1.5422	396	0.095	100%	BC
62.300	1.4892	80	0.078	95.4%	C
63.986	1.4540	120	0.094	99.8%	BC
64.464	1.4442	63	0.087	99.9%	
65.788	1.4188	140	0.089	100%	BC
66.041	1.4141	68	0.080	93.0%	C
67.696	1.3829	363	0.096	100%	B
68.073	1.3762	165	0.076	99.8%	BC
68.294	1.3726	673	0.089	100%	BC
69.614	1.3497	65	0.087	93.9%	C
70.202	1.3399	111	0.091	100%	
70.699	1.3316	115	0.084	100%	
71.281	1.3221	97	0.088	99.8%	
72.166	1.3082	149	0.088	100%	
73.434	1.2886	104	0.100	100%	B
73.984	1.2802	42	0.081	93.2%	

Graphics



6000
5000
4000
3000
2000
1000
0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
12512004.ASC data - background
12512004.ASC peaks
12512004.ASC failed peaks
Multi-phase profile
000-83-1417 Labradorite
000-46-1045 Quartz, syn
000-19-1184 Albite, ordered
000-13-0259 Montmorillonite-14A

12512008.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:37 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	Yes
Figure of Merit	Single phase
Apply Restrictions	Yes

Matched Materials

A Gibbsite, syn

Formula	$Al(OH)_3$
Pdf Number	000-33-0018
Figure of Merit	49%
Total Peaks	47
Peaks Matched	36
New Matches	36
Strong Unmatched	0
Peak Shift	-0.0262793
Scale Factor	0.415144
Concentration	0.0784424
I / Icorundum	1

B Corundum, syn

Formula	Al_2O_3
Pdf Number	000-10-0173
Figure of Merit	39%
Total Peaks	15
Peaks Matched	11
New Matches	11
Strong Unmatched	0
Peak Shift	-0.0231195
Scale Factor	0.38935
Concentration	0.0735686
I / Icorundum	1

C Diaoyudaoite

Formula	$NaAl_{11}O_{17}$
Pdf Number	000-79-2288
Figure of Merit	38%
Total Peaks	75
Peaks Matched	46
New Matches	46

Strong Unmatched	0
Peak Shift	-0.0234527
Scale Factor	0.387849
Concentration	0.205931
I / Icorundum	2.81

D Fluorite

Formula	$Ca F_2$
Pdf Number	000-75-0097
Figure of Merit	27%
Total Peaks	6
Peaks Matched	5
New Matches	5
Strong Unmatched	0
Peak Shift	-0.00585805
Scale Factor	0.875233
Concentration	0.635048
I / Icorundum	3.84

E Brushite

Formula	$Ca P O_3 (O H) !2 H_2 O$
Pdf Number	000-11-0293
Figure of Merit	17%
Total Peaks	38
Peaks Matched	17
New Matches	17
Strong Unmatched	0
Peak Shift	0.0188326
Scale Factor	0.131386
Concentration	Not available

F Cryolite

Formula	$Na_3 (Al F_6)$
Pdf Number	000-82-0218
Figure of Merit	25%
Total Peaks	105
Peaks Matched	62
New Matches	62
Strong Unmatched	0
Peak Shift	0.160827
Scale Factor	0.0904847
Concentration	0.00700989
I / Icorundum	0.41

G Calcium Fluoride Phosphate Hydrate

Formula	$Ca F P O_3 !2 H_2 O$
Pdf Number	000-29-0323
Figure of Merit	12%
Total Peaks	46
Peaks Matched	30
New Matches	30

Strong Unmatched	1
Peak Shift	0.0516539
Scale Factor	0.118056
Concentration	Not available

H Thadeuite

Formula	Ca Mg (Mg , Fe , Mn $)_3$ (P O_4 $)_2$ (O H , F $)_2$
Pdf Number	000-33-0284
Figure of Merit	24%
Total Peaks	53
Peaks Matched	37
New Matches	37
Strong Unmatched	0
Peak Shift	0.0675863
Scale Factor	0.745428
Concentration	Not available

Peak List

Peak Search Settings

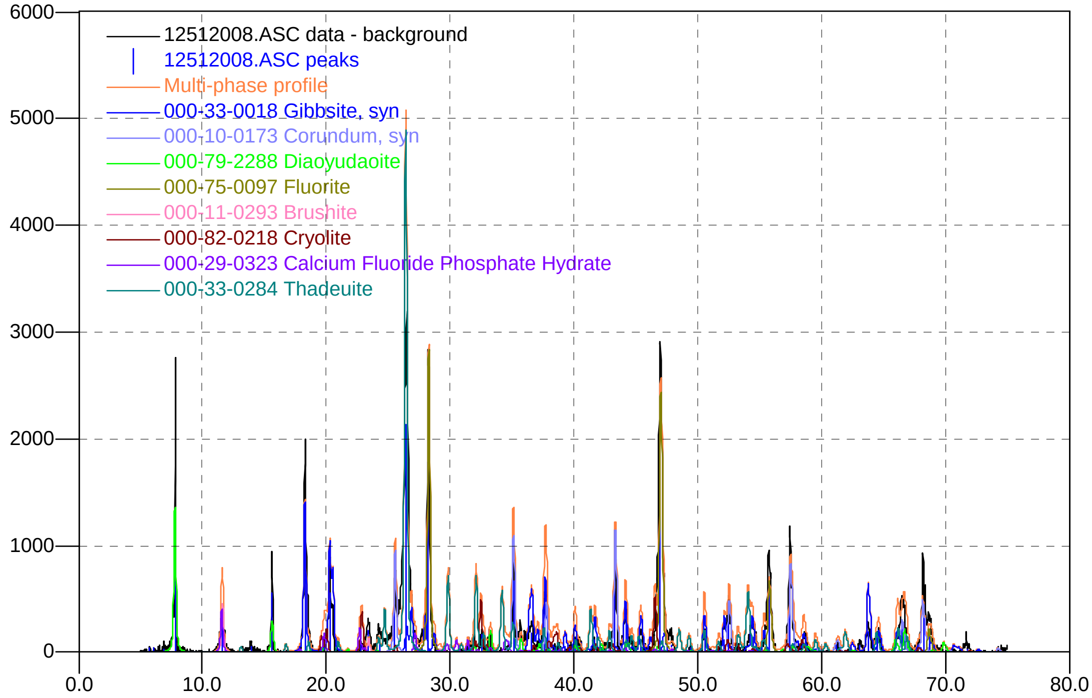
Confidence Threshold	80%
Matched / Total	51 / 56

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
5.764	15.3203	42	0.137	93.4%	
6.123	14.4236	41	0.139	92.4%	
6.905	12.7902	29	0.140	84.5%	
7.805	11.3181	1232	0.150	100%	C
11.626	7.6052	255	0.186	100%	EG
13.923	6.3551	61	0.164	100%	
15.632	5.6643	560	0.155	100%	C
18.295	4.8452	1197	0.165	100%	AC
19.478	4.5534	27	0.221	87.8%	F
20.293	4.3725	562	0.201	100%	A
22.811	3.8953	80	0.156	100%	FG
23.400	3.7985	205	0.192	100%	CE
24.283	3.6622	112	0.195	100%	CH
25.548	3.4838	424	0.170	100%	BFG
26.488	3.3622	2142	0.184	100%	AH
28.261	3.1552	1785	0.159	100%	D
31.492	2.8384	75	0.154	100%	CEG
31.913	2.8019	129	0.168	100%	CEFGH
32.550	2.7486	168	0.175	100%	DFH
33.186	2.6973	189	0.177	100%	CFG
35.131	2.5523	675	0.164	100%	BGH
35.646	2.5166	188	0.165	100%	CEG
36.065	2.4884	79	0.142	100%	F
36.554	2.4562	186	0.182	100%	ACEFG
37.103	2.4211	39	0.186	96.4%	ACG
37.694	2.3845	449	0.188	100%	ABCGH
38.450	2.3393	25	0.185	81.6%	AFG
38.836	2.3169	87	0.159	100%	CFGH
39.310	2.2901	51	0.143	98.8%	A

39.657	2.2709	45	0.136	98.0%	CEFG
40.071	2.2483	77	0.158	100%	ACH
40.536	2.2236	91	0.176	100%	CF
41.613	2.1685	120	0.175	100%	ABEF
43.330	2.0865	901	0.170	100%	ABEF
44.189	2.0479	280	0.209	100%	ACGH
45.408	1.9957	119	0.185	100%	ACH
47.008	1.9314	2083	0.182	100%	DEGH
47.840	1.8998	72	0.263	99.7%	CEFG
49.381	1.8440	46	0.161	99.8%	CFGH
50.557	1.8039	148	0.182	100%	ACEFH
52.118	1.7534	115	0.161	100%	AC
52.545	1.7402	339	0.175	100%	ABCFG
53.262	1.7184	43	0.166	99.2%	FGH
54.467	1.6832	139	0.283	100%	AFGH
55.762	1.6472	653	0.189	100%	CD
57.483	1.6019	746	0.182	100%	BFH
58.678	1.5721	115	0.201	100%	ACDFH
61.227	1.5126	66	0.195	100%	BF
63.111	1.4719	74	0.188	100%	
63.771	1.4582	189	0.197	100%	AEF
64.544	1.4426	130	0.216	100%	ACH
66.545	1.4040	295	0.203	100%	ABCF
68.219	1.3736	401	0.184	100%	BCE
68.767	1.3640	155	0.176	100%	ACDF
69.704	1.3479	44	0.171	99.1%	C
71.761	1.3143	34	0.129	93.0%	CF

Graphics



12512008.ASC data - background
12512008.ASC peaks
Multi-phase profile
000-33-0018 Gibbsite, syn
000-10-0173 Corundum, syn
000-79-2288 Diaoyudaoite
000-75-0097 Fluorite
000-11-0293 Brushite
000-82-0218 Cryolite
000-29-0323 Calcium Fluoride Phosphate Hydrate
000-33-0284 Thadeuite
6000
5000
4000
3000
2000
1000
0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0

12512009.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:38 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	Yes
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz, syn

Formula	$Si\ O_2$
Pdf Number	000-46-1045
Figure of Merit	60%
Total Peaks	19
Peaks Matched	18
New Matches	18
Strong Unmatched	0
Peak Shift	-0.0243247
Scale Factor	0.956594
Concentration	0.471145
I / Icorundum	3.41

B Corundum

Formula	$Al_2\ O_3$
Pdf Number	000-71-1124
Figure of Merit	55%
Total Peaks	15
Peaks Matched	12
New Matches	12
Strong Unmatched	0
Peak Shift	-0.0565175
Scale Factor	0.176361
Concentration	0.0257274
I / Icorundum	1.01

C Fluorite

Formula	$Ca\ F_2$
Pdf Number	000-75-0097
Figure of Merit	45%
Total Peaks	6
Peaks Matched	5
New Matches	5

Strong Unmatched	0
Peak Shift	-0.000442628
Scale Factor	0.447995
Concentration	0.248472
I / Icorundum	3.84

D Albite high

Formula	$Na (Al Si_3 O_8)$
Pdf Number	000-71-1151
Figure of Merit	39%
Total Peaks	198
Peaks Matched	123
New Matches	123
Strong Unmatched	0
Peak Shift	-0.0141505
Scale Factor	0.408332
Concentration	0.0383353
I / Icorundum	0.65

E Gibbsite

Formula	$Al (O H)_3$
Pdf Number	000-29-0041
Figure of Merit	36%
Total Peaks	39
Peaks Matched	28
New Matches	28
Strong Unmatched	0
Peak Shift	-0.00428454
Scale Factor	0.277034
Concentration	0.0632212
I / Icorundum	1.58

F Sodium Aluminum Oxide

Formula	$Na_2 Al_{22} O_{34}$
Pdf Number	000-72-1406
Figure of Merit	15%
Total Peaks	70
Peaks Matched	27
New Matches	27
Strong Unmatched	0
Peak Shift	-0.0640491
Scale Factor	0.143448
Concentration	0.146068
I / Icorundum	7.05

G Cryolite, syn

Formula	$Na_3 Al F_6$
Pdf Number	000-25-0772
Figure of Merit	37%
Total Peaks	49
Peaks Matched	31

New Matches	31
Strong Unmatched	0
Peak Shift	-0.0285192
Scale Factor	0.131578
Concentration	0.00703166
I / Icorundum	0.37

Peak List

Peak Search Settings

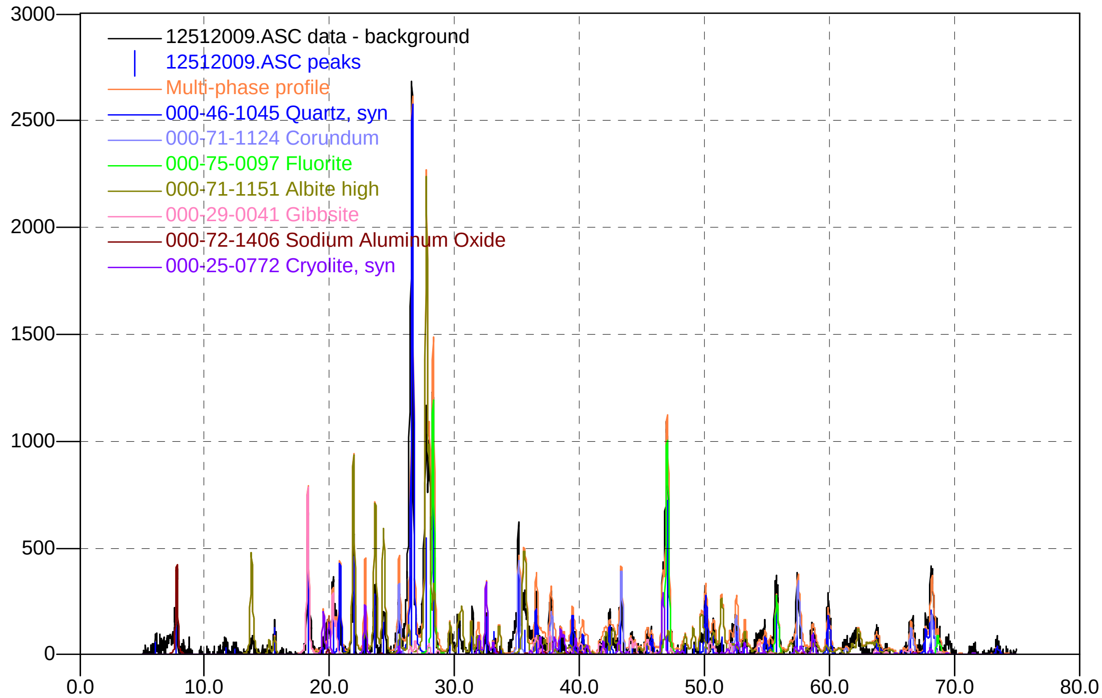
Confidence Threshold	80%
Matched / Total	61 / 64

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
6.051	14.5947	61	0.141	99.1%	
7.765	11.3762	293	0.149	100%	F
11.665	7.5802	34	0.161	94.7%	
12.410	7.1264	28	0.149	90.7%	
15.601	5.6754	128	0.148	100%	DF
18.286	4.8476	489	0.150	100%	EF
19.485	4.5519	31	0.112	83.2%	G
19.851	4.4688	69	0.136	99.9%	FG
20.280	4.3752	208	0.159	100%	DE
20.845	4.2580	277	0.140	100%	A
21.940	4.0479	458	0.153	100%	D
22.852	3.8883	171	0.144	100%	DG
23.626	3.7627	285	0.154	100%	DF
24.346	3.6529	156	0.181	100%	D
25.573	3.4803	154	0.148	100%	BDG
26.582	3.3505	1843	0.153	100%	AE
27.710	3.2167	549	0.185	100%	D
28.306	3.1503	855	0.145	100%	CD
29.647	3.0108	39	0.184	92.7%	D
30.340	2.9435	123	0.164	100%	D
31.448	2.8424	163	0.147	100%	D
31.953	2.7986	75	0.159	100%	DFG
32.542	2.7492	177	0.154	100%	G
33.153	2.6999	108	0.164	100%	DFG
33.736	2.6546	66	0.151	100%	D
35.136	2.5520	407	0.145	100%	B
35.593	2.5203	117	0.168	100%	DF
36.536	2.4573	199	0.149	100%	ADE
37.702	2.3840	190	0.171	100%	BDEF
38.483	2.3374	93	0.136	100%	DG
39.421	2.2839	102	0.146	100%	ADE
39.700	2.2685	43	0.128	88.5%	DG
40.218	2.2404	47	0.160	98.9%	ADEF
42.449	2.1277	129	0.145	100%	A
43.337	2.0861	271	0.154	100%	B
44.218	2.0466	60	0.169	99.9%	DEF
44.710	2.0252	24	0.112	84.6%	D
45.436	1.9945	50	0.127	99.4%	DEF
45.784	1.9802	57	0.127	99.6%	ADF
46.640	1.9458	215	0.137	100%	DFG

47.023	1.9308	724	0.156	100%	CDF
48.476	1.8763	49	0.164	99.4%	DF
49.226	1.8495	48	0.165	99.7%	D
49.708	1.8327	62	0.144	99.8%	DFG
50.128	1.8183	233	0.150	100%	AD
50.765	1.7969	97	0.182	100%	ADEG
51.426	1.7754	87	0.156	100%	DFG
52.214	1.7505	57	0.150	98.2%	DEF
52.556	1.7399	108	0.162	100%	BDFG
53.251	1.7188	85	0.169	100%	DG
54.341	1.6868	36	0.171	93.9%	DE
54.822	1.6732	72	0.152	100%	ADG
55.771	1.6469	247	0.171	100%	CDF
57.467	1.6023	215	0.177	100%	BDFG
58.178	1.5844	37	0.139	95.7%	DE
58.757	1.5701	102	0.217	100%	DFG
59.948	1.5418	199	0.158	100%	ADF
61.250	1.5121	26	0.150	82.2%	BG
63.816	1.4573	76	0.206	100%	ADEG
64.708	1.4394	27	0.128	86.0%	DEF
66.568	1.4036	105	0.203	100%	BEF
67.681	1.3832	106	0.151	100%	A
68.196	1.3740	208	0.173	100%	ABG
73.366	1.2894	26	0.132	88.4%	A

Graphics



12512009.ASC data - background
12512009.ASC peaks
Multi-phase profile
000-46-1045 Quartz, syn
000-71-1124 Corundum
000-75-0097 Fluorite
000-71-1151 Albite high
000-29-0041 Gibbsite
000-72-1406 Sodium Aluminum Oxide
000-25-0772 Cryolite, syn
3000
2500
2000
1500
1000
500
0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0

12512010.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:51 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	Yes
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz, syn

Formula	$Si\ O_2$
Pdf Number	000-46-1045
Figure of Merit	65%
Total Peaks	19
Peaks Matched	18
New Matches	18
Strong Unmatched	0
Peak Shift	-0.0210753
Scale Factor	0.946177
Concentration	0.881743
I / Icorundum	3.41

B Andesine

Formula	$Na_{.499}\ Ca_{.491}\ (\ Al_{1.488}\ Si_{2.506}\ O_8\ )$
Pdf Number	000-79-1148
Figure of Merit	56%
Total Peaks	198
Peaks Matched	128
New Matches	128
Strong Unmatched	0
Peak Shift	-0.0109527
Scale Factor	0.345213
Concentration	0.0528312
I / Icorundum	0.56

C Albite high

Formula	$Na\ (\ Al\ Si_3\ O_8\ )$
Pdf Number	000-71-1152
Figure of Merit	36%
Total Peaks	199
Peaks Matched	108
New Matches	108

Strong Unmatched	0
Peak Shift	0.0392312
Scale Factor	0.368313
Concentration	0.0654253
I / Icorundum	0.65

D Montmorillonite

Formula	$(Na , Ca)_{0.3} (Al , Mg)_2 Si_4 O_{16} (O H)_2$!x $H_2 O$
Pdf Number	000-12-0232
Figure of Merit	18%
Total Peaks	14
Peaks Matched	9
New Matches	9
Strong Unmatched	0
Peak Shift	0.123016
Scale Factor	0.190554
Concentration	Not available

Peak List

Peak Search Settings

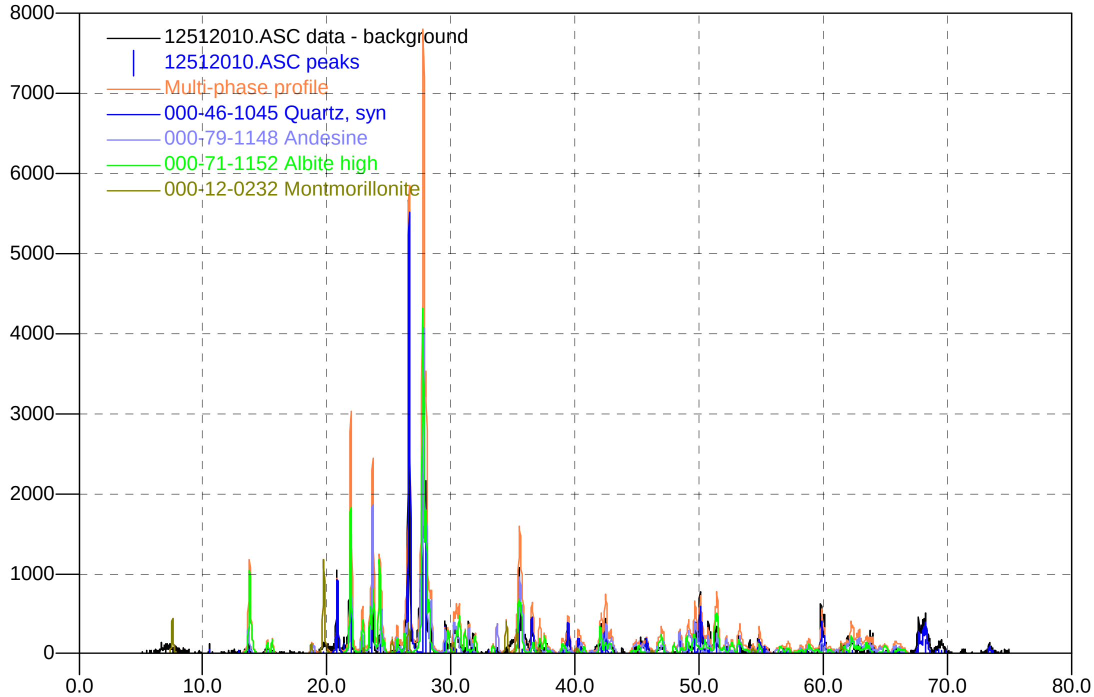
Confidence Threshold	80%
Matched / Total	64 / 71

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
10.522	8.4009	65	0.101	99.7%	
12.959	6.8260	35	0.101	93.1%	
13.688	6.4640	65	0.097	99.8%	BC
19.771	4.4867	32	0.097	81.7%	D
20.820	4.2629	747	0.103	100%	A
21.358	4.1568	127	0.125	100%	
21.933	4.0491	1135	0.118	100%	BC
22.823	3.8931	207	0.109	100%	BC
23.640	3.7604	907	0.111	100%	BC
24.357	3.6513	214	0.133	100%	BC
25.289	3.5189	31	0.079	83.2%	CD
25.579	3.4796	136	0.101	100%	BC
25.837	3.4454	67	0.098	99.0%	BC
26.609	3.3472	3626	0.099	100%	AD
27.734	3.2140	1471	0.107	100%	BC
28.010	3.1828	1498	0.106	100%	BC
28.387	3.1415	501	0.116	100%	B
29.558	3.0196	346	0.110	100%	B
30.247	2.9524	177	0.108	100%	BD
30.479	2.9313	65	0.082	86.3%	BC
31.454	2.8418	259	0.112	100%	BC
31.808	2.8110	181	0.116	100%	BC
33.041	2.7088	47	0.138	99.2%	BC
33.683	2.6586	76	0.135	100%	B
35.515	2.5256	741	0.108	100%	BC
35.807	2.5057	63	0.095	94.8%	B
36.512	2.4589	270	0.111	100%	ABC
36.783	2.4414	82	0.100	99.0%	B

37.140	2.4187	78	0.116	100%	BCD
37.740	2.3817	68	0.124	99.9%	B
38.754	2.3217	28	0.081	87.2%	BC
39.043	2.3051	35	0.096	91.0%	BC
39.419	2.2840	247	0.114	100%	ABC
40.275	2.2374	79	0.112	100%	ACD
41.244	2.1871	26	0.089	80.5%	BC
41.687	2.1648	52	0.129	99.5%	B
42.153	2.1420	192	0.107	100%	BC
42.479	2.1263	223	0.129	100%	ABC
42.893	2.1067	31	0.090	85.9%	BC
45.343	1.9992	148	0.105	100%	BC
45.775	1.9806	122	0.126	100%	AB
47.173	1.9250	75	0.113	100%	B
47.935	1.8962	35	0.110	96.1%	BC
48.431	1.8780	172	0.146	100%	BC
49.177	1.8512	87	0.120	100%	BC
49.687	1.8334	188	0.195	100%	BC
50.101	1.8192	484	0.127	100%	ABC
50.793	1.7960	191	0.132	100%	BC
51.414	1.7758	234	0.123	100%	BC
52.306	1.7476	67	0.123	100%	B
53.255	1.7187	129	0.132	100%	BC
54.117	1.6933	91	0.104	100%	BC
54.818	1.6733	159	0.126	100%	ABC
55.309	1.6596	43	0.099	97.5%	AC
56.909	1.6167	28	0.118	85.1%	BC
58.217	1.5834	36	0.128	95.7%	BC
58.686	1.5719	51	0.107	99.2%	BC
59.883	1.5436	549	0.110	100%	ABC
60.894	1.5206	37	0.091	89.6%	BC
61.968	1.4963	60	0.095	98.3%	B
62.393	1.4871	43	0.113	87.4%	BC
63.823	1.4577	194	0.102	100%	BC
65.725	1.4199	65	0.101	99.0%	AB
66.203	1.4105	34	0.104	93.6%	BC
67.678	1.3833	270	0.111	100%	A
68.306	1.3725	172	0.105	100%	A
69.058	1.3592	42	0.090	85.4%	
69.357	1.3540	58	0.088	80.4%	
69.603	1.3496	47	0.103	85.9%	
69.921	1.3445	40	0.081	88.7%	
73.389	1.2893	82	0.103	99.4%	A

Graphics



12512010.ASC data - background
12512010.ASC peaks
Multi-phase profile
000-46-1045 Quartz, syn
000-79-1148 Andesine
000-71-1152 Albite high
000-12-0232 Montmorillonite
8000
7000
6000
5000
4000
3000
2000
1000
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10.0
20.0
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80.0

12512011.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:55 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	Yes
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz, syn

Formula	$Si\ O_2$
Pdf Number	000-46-1045
Figure of Merit	56%
Total Peaks	19
Peaks Matched	18
New Matches	18
Strong Unmatched	0
Peak Shift	-0.0204701
Scale Factor	0.469431
Concentration	0.750786
I / Icorundum	3.41

B Albite, calcian, ordered

Formula	$(Na , Ca) (Si , Al)_4 O_8$
Pdf Number	000-20-0548
Figure of Merit	34%
Total Peaks	84
Peaks Matched	57
New Matches	57
Strong Unmatched	0
Peak Shift	-0.00989998
Scale Factor	0.661184
Concentration	Not available

C Albite high

Formula	$Na (Al\ Si_3 O_8)$
Pdf Number	000-71-1150
Figure of Merit	48%
Total Peaks	199
Peaks Matched	116
New Matches	116
Strong Unmatched	0

Peak Shift	-0.062312
Scale Factor	0.460767
Concentration	0.140471
I / Icorundum	0.65

D Anorthite, ordered

Formula	Ca Al_2 Si_2 O_8
Pdf Number	000-41-1486
Figure of Merit	34%
Total Peaks	73
Peaks Matched	44
New Matches	44
Strong Unmatched	0
Peak Shift	-0.00068964
Scale Factor	0.565495
Concentration	0.108743
I / Icorundum	0.41

E Montmorillonite

Formula	Al Si_2 O_6 (O H $)_2$
Pdf Number	000-02-0037
Figure of Merit	12%
Total Peaks	9
Peaks Matched	6
New Matches	6
Strong Unmatched	1
Peak Shift	0.0280546
Scale Factor	0.0202426
Concentration	Not available

Peak List

Peak Search Settings

Confidence Threshold	80%
Matched / Total	70 / 84

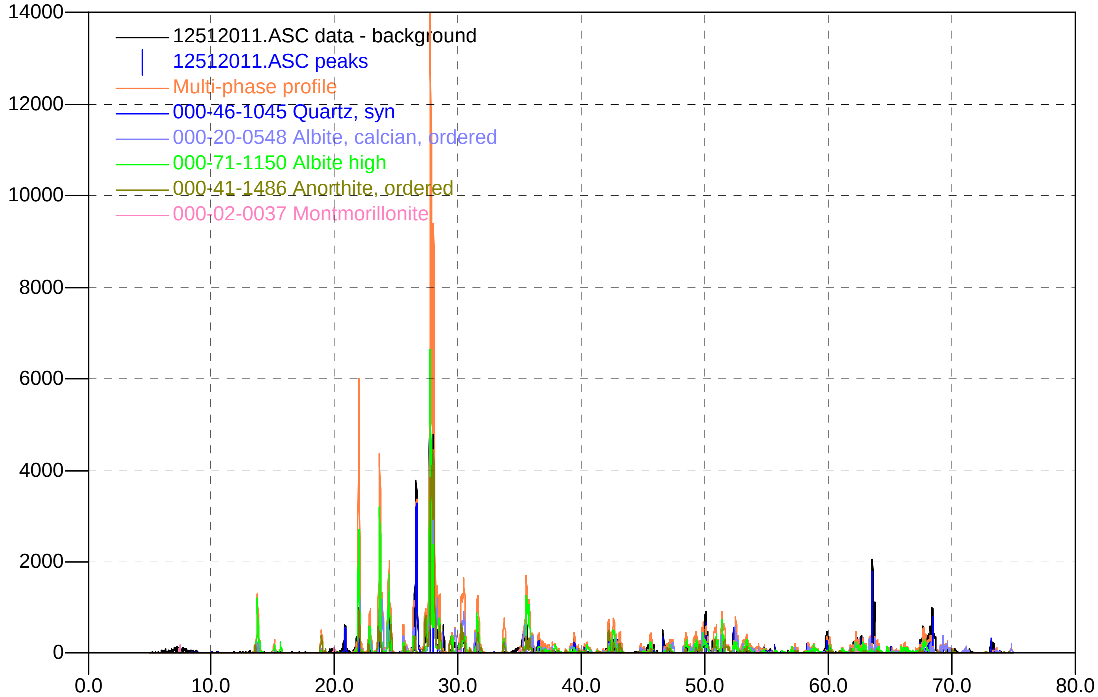
List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
8.432	10.4773	36	0.060	80.5%	
8.784	10.0583	43	0.077	87.9%	
10.055	8.7899	36	0.069	80.8%	
10.555	8.3743	36	0.067	84.4%	
13.855	6.3863	50	0.067	90.5%	BC
15.668	5.6511	26	0.063	80.0%	C
20.839	4.2592	461	0.082	100%	A
21.950	4.0460	652	0.089	100%	BCD
22.874	3.8846	538	0.077	100%	BC
23.636	3.7611	585	0.105	100%	BCD
24.408	3.6438	665	0.079	100%	C
25.311	3.5159	33	0.063	85.8%	
25.590	3.4781	69	0.086	99.4%	BC
26.610	3.3471	2612	0.086	100%	A
27.733	3.2140	3785	0.092	100%	BCD

28.019	3.1819	4355	0.073	100%	BCD
28.367	3.1437	180	0.108	100%	B
28.841	3.0931	472	0.076	100%	
29.525	3.0229	59	0.083	97.7%	C
29.811	2.9946	93	0.092	100%	B
30.244	2.9527	271	0.078	100%	CD
30.471	2.9312	111	0.071	99.9%	BCD
31.449	2.8422	280	0.096	100%	B
32.878	2.7219	32	0.068	88.9%	
35.240	2.5447	151	0.073	100%	D
35.526	2.5248	300	0.090	100%	CD
36.529	2.4578	225	0.088	100%	AC
37.123	2.4198	28	0.079	81.7%	BC
37.891	2.3725	34	0.070	86.0%	C
38.140	2.3576	31	0.070	87.1%	CD
39.433	2.2832	176	0.096	100%	ABC
40.241	2.2392	74	0.080	99.8%	ACD
41.256	2.1864	31	0.076	88.7%	CD
41.704	2.1640	30	0.079	87.6%	BC
42.181	2.1406	322	0.078	100%	BCD
42.469	2.1268	126	0.170	99.9%	A
42.989	2.1022	123	0.071	100%	C
44.820	2.0205	50	0.069	98.4%	BCD
45.377	1.9970	84	0.070	99.9%	C
45.736	1.9829	135	0.071	100%	AD
46.631	1.9462	358	0.072	100%	
46.803	1.9394	83	0.058	99.8%	BC
47.146	1.9261	163	0.087	100%	CD
48.365	1.8804	58	0.082	95.7%	BCD
49.189	1.8514	159	0.066	100%	BC
49.678	1.8337	84	0.100	99.9%	CD
50.092	1.8196	696	0.083	100%	AC
50.690	1.7998	145	0.065	99.8%	AB
51.393	1.7767	92	0.079	94.5%	BC
52.354	1.7467	562	0.073	100%	C
53.652	1.7072	74	0.064	99.4%	BC
53.841	1.7016	65	0.062	84.0%	B
54.032	1.6962	81	0.065	96.6%	B
54.815	1.6738	135	0.081	100%	AC
55.299	1.6600	53	0.070	95.3%	AB
55.700	1.6492	187	0.069	100%	C
56.168	1.6364	57	0.067	97.8%	C
58.266	1.5824	215	0.070	100%	C
58.720	1.5711	104	0.079	99.9%	BCD
59.906	1.5429	244	0.078	100%	ACD
61.869	1.4987	60	0.071	89.0%	BD
62.131	1.4931	107	0.084	94.4%	B
62.399	1.4877	164	0.074	99.5%	CE
62.671	1.4816	323	0.072	100%	BC
63.611	1.4617	1795	0.063	100%	
63.802	1.4578	267	0.062	99.2%	BC
64.194	1.4501	63	0.072	94.8%	C
64.894	1.4358	49	0.064	88.4%	B
65.140	1.4310	162	0.072	100%	BC
66.019	1.4140	114	0.067	100%	C
66.224	1.4103	117	0.065	99.8%	BCD

67.160	1.3928	55	0.070	90.0%	BC
67.492	1.3867	248	0.069	100%	CD
67.693	1.3831	364	0.073	100%	ABC
68.087	1.3759	183	0.066	100%	A
68.279	1.3726	327	0.064	100%	AB
68.492	1.3690	807	0.073	100%	
69.393	1.3531	64	0.066	92.2%	B
69.575	1.3502	57	0.067	85.0%	D
70.251	1.3385	58	0.072	91.8%	
71.513	1.3183	64	0.076	98.5%	
73.195	1.2920	344	0.072	100%	
73.432	1.2888	90	0.071	83.8%	AE
73.913	1.2812	59	0.064	97.9%	

Graphics



12512012.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:57 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	Yes
Figure of Merit	Multi-phase
Apply Restrictions	No

Matched Materials

A Andesine

Formula	$Na_{.499}\ Ca_{.491}\ (\ Al_{1.488}\ Si_{2.506}\ O_8\ )$
Pdf Number	000-79-1148
Figure of Merit	50%
Total Peaks	198
Peaks Matched	128
New Matches	128
Strong Unmatched	0
Peak Shift	-0.0133507
Scale Factor	0.571559
Concentration	0.08564
I / Icorundum	0.56

B Quartz, syn

Formula	$Si\ O_2$
Pdf Number	000-33-1161
Figure of Merit	54%
Total Peaks	19
Peaks Matched	17
New Matches	17
Strong Unmatched	0
Peak Shift	-0.014557
Scale Factor	0.871417
Concentration	0.839375
I / Icorundum	3.6

C Albite high

Formula	$Na\ (\ Al\ Si_3\ O_8\ )$
Pdf Number	000-83-1607
Figure of Merit	30%
Total Peaks	198
Peaks Matched	110
New Matches	110

Strong Unmatched	0
Peak Shift	0.06559
Scale Factor	0.459425
Concentration	0.0749847
I / Icorundum	0.61

Peak List

Peak Search Settings

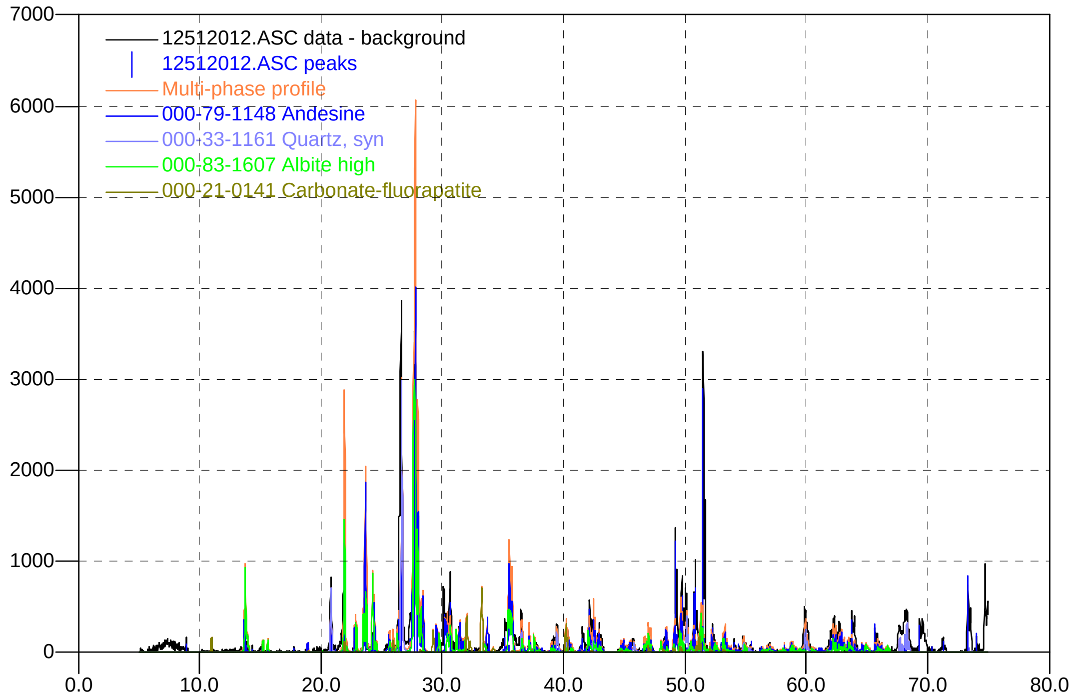
Confidence Threshold	80%
Matched / Total	55 / 70

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
8.897	9.9308	100	0.059	99.9%	
13.720	6.4491	86	0.066	99.9%	AC
13.926	6.3541	86	0.061	99.9%	AC
14.334	6.1739	33	0.053	88.0%	
17.798	4.9794	49	0.060	98.0%	
20.843	4.2584	513	0.069	100%	B
21.254	4.1768	30	0.056	82.3%	
21.945	4.0469	499	0.090	100%	AC
22.835	3.8911	74	0.078	99.8%	AC
23.665	3.7565	370	0.078	100%	AC
24.428	3.6408	202	0.082	100%	A
26.442	3.3680	359	0.075	100%	A
26.624	3.3453	2216	0.074	100%	B
27.345	3.2588	158	0.069	100%	
27.759	3.2110	1849	0.071	100%	AC
27.997	3.1843	661	0.079	100%	AC
28.382	3.1421	276	0.090	100%	A
29.554	3.0200	130	0.071	100%	A
30.154	2.9613	416	0.076	100%	
30.650	2.9145	548	0.073	100%	AC
30.957	2.8863	38	0.110	90.4%	
31.438	2.8432	123	0.078	100%	AC
31.745	2.8164	82	0.072	100%	AC
32.693	2.7368	35	0.051	91.5%	
33.712	2.6564	42	0.063	96.4%	A
35.020	2.5601	39	0.047	87.7%	
35.203	2.5472	166	0.070	100%	
35.502	2.5265	84	0.063	93.9%	AC
36.519	2.4584	238	0.094	100%	ABC
39.002	2.3074	58	0.050	90.8%	AC
39.456	2.2819	152	0.077	100%	BC
40.293	2.2372	89	0.055	97.1%	BC
41.372	2.1813	84	0.060	99.5%	A
41.574	2.1712	157	0.061	100%	C
41.845	2.1570	32	0.054	83.3%	A
42.165	2.1421	474	0.063	100%	AC
42.437	2.1281	140	0.057	99.9%	ABC
42.950	2.1040	140	0.072	100%	AC
47.223	1.9238	105	0.055	99.8%	A
48.367	1.8806	148	0.060	100%	A
49.226	1.8499	1228	0.055	100%	A
49.608	1.8362	143	0.073	99.0%	AC

49.764	1.8311	621	0.059	100%	AC
50.736	1.7981	650	0.055	100%	AC
50.885	1.7933	714	0.055	100%	C
51.511	1.7730	2899	0.053	100%	AC
52.293	1.7482	265	0.060	100%	A
53.004	1.7266	109	0.057	99.9%	A
54.070	1.6947	116	0.060	100%	AC
54.465	1.6835	94	0.064	99.9%	A
54.840	1.6728	121	0.065	100%	ABC
55.461	1.6557	122	0.057	100%	A
56.177	1.6363	43	0.058	91.8%	A
59.927	1.5430	294	0.084	100%	ABC
60.629	1.5262	46	0.053	93.2%	A
62.311	1.4892	211	0.080	100%	AC
62.738	1.4801	205	0.070	100%	AC
63.788	1.4581	356	0.064	100%	AC
63.993	1.4540	118	0.063	96.8%	AB
65.651	1.4208	315	0.062	100%	A
66.005	1.4143	100	0.057	99.5%	AC
66.206	1.4104	69	0.064	84.2%	AC
67.653	1.3837	146	0.092	99.0%	B
68.085	1.3760	176	0.062	100%	B
68.283	1.3725	102	0.066	80.4%	B
69.361	1.3540	305	0.065	100%	
70.405	1.3361	72	0.058	98.9%	
71.274	1.3221	123	0.061	100%	
73.335	1.2900	838	0.069	100%	
74.060	1.2789	216	0.062	100%	

Graphics



12512012.ASC data - background
12512012.ASC peaks
Multi-phase profile
000-79-1148 Andesine
000-33-1161 Quartz, syn
000-83-1607 Albite high
000-21-0141 Carbonate-fluorapatite
7000
6000
5000
4000
3000
2000
1000
0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0

12512015.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 14:58 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	Yes
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A alpha-Corundum

Formula	$Al_2 O_3$
Pdf Number	000-05-0712
Figure of Merit	62%
Total Peaks	12
Peaks Matched	9
New Matches	9
Strong Unmatched	0
Peak Shift	-0.0729585
Scale Factor	0.29762
Concentration	Not available

B Fluorite, syn

Formula	$Ca F_2$
Pdf Number	000-35-0816
Figure of Merit	57%
Total Peaks	6
Peaks Matched	6
New Matches	6
Strong Unmatched	0
Peak Shift	-0.0530581
Scale Factor	0.746276
Concentration	Not available

C Graphite

Formula	C
Pdf Number	000-12-0212
Figure of Merit	48%
Total Peaks	6
Peaks Matched	6
New Matches	6
Strong Unmatched	0
Peak Shift	-0.00687902

Scale Factor	0.997309
Concentration	Not available

D Gibbsite

Formula	$Al (O H)_3$
Pdf Number	000-29-0041
Figure of Merit	41%
Total Peaks	39
Peaks Matched	32
New Matches	32
Strong Unmatched	0
Peak Shift	-0.0284809
Scale Factor	0.216174
Concentration	0.617928
I / Icorundum	1.58

E Diaoyudaoite, syn

Formula	$Na Al_{11} O_{17}$
Pdf Number	000-21-1096
Figure of Merit	38%
Total Peaks	40
Peaks Matched	29
New Matches	29
Strong Unmatched	0
Peak Shift	-0.114184
Scale Factor	0.193975
Concentration	Not available

F Sodium Aluminum Silicate Hydroxide

Formula	$Na_4 (Si_3 Al_3 O_{12}) (O H)$
Pdf Number	000-76-0717
Figure of Merit	27%
Total Peaks	34
Peaks Matched	19
New Matches	19
Strong Unmatched	0
Peak Shift	-0.177653
Scale Factor	0.0841384
Concentration	0.382072
I / Icorundum	2.51

G Brushite

Formula	$Ca P O_3 (O H)$!2 $H_2 O$
Pdf Number	000-11-0293
Figure of Merit	28%
Total Peaks	38
Peaks Matched	18
New Matches	18
Strong Unmatched	0
Peak Shift	-0.0729981
Scale Factor	0.13932

Concentration	Not available

Peak List

Peak Search Settings

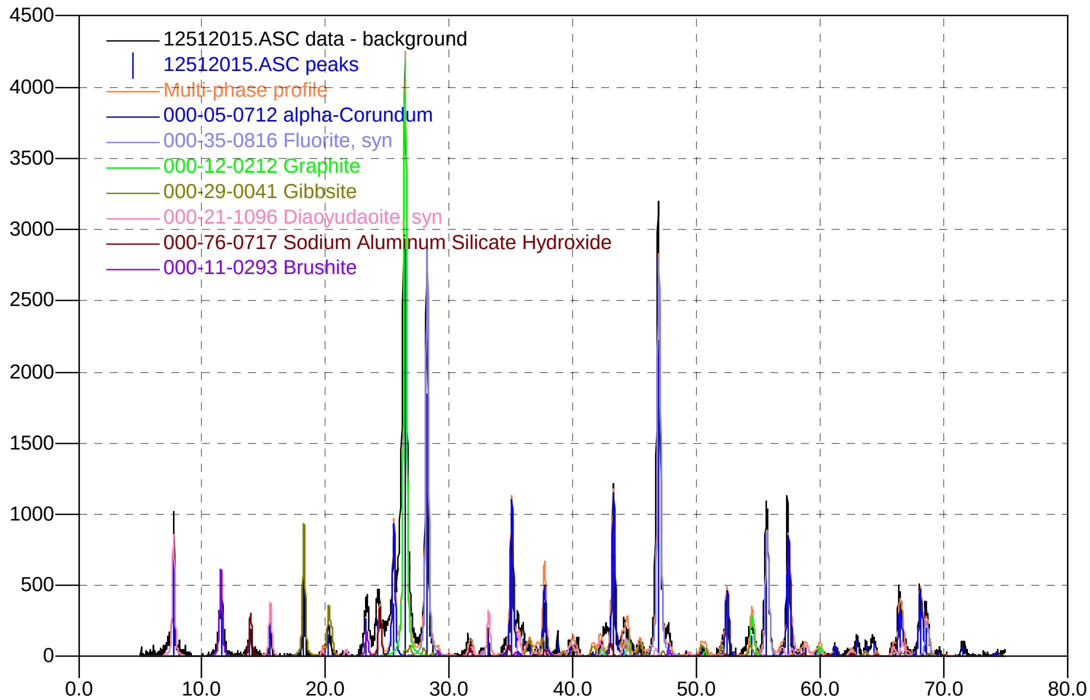
Confidence Threshold	80%
Matched / Total	46 / 50

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
7.707	11.4622	798	0.189	100%	E
11.552	7.6539	372	0.208	100%	G
13.874	6.3778	136	0.186	100%	F
15.538	5.6981	298	0.186	100%	E
18.234	4.8612	458	0.191	100%	D
20.217	4.3888	151	0.200	100%	D
21.761	4.0808	33	0.174	94.6%	E
23.327	3.8101	266	0.214	100%	G
24.247	3.6677	261	0.215	100%	F
25.479	3.4931	376	0.190	100%	A
26.419	3.3708	2860	0.201	100%	CD
28.198	3.1621	1845	0.176	100%	BF
31.556	2.8328	49	0.157	99.1%	EF
32.596	2.7448	31	0.262	92.2%	B
33.126	2.7021	155	0.187	100%	E
35.076	2.5562	703	0.183	100%	AF
35.571	2.5218	178	0.171	100%	EG
36.017	2.4915	129	0.177	100%	
36.527	2.4579	76	0.181	100%	DEF
37.070	2.4231	31	0.208	91.8%	DE
37.688	2.3848	304	0.201	100%	ADEF
38.781	2.3201	120	0.183	100%	E
39.748	2.2658	98	0.185	100%	EG
40.395	2.2310	102	0.203	100%	DEF
42.067	2.1461	47	0.168	94.6%	EG
42.610	2.1201	61	0.318	97.5%	C
43.281	2.0887	877	0.189	100%	AFG
44.163	2.0490	113	0.289	100%	DE
45.327	1.9991	48	0.159	99.0%	DEF
45.677	1.9846	41	0.161	93.6%	DFG
46.942	1.9340	2217	0.195	100%	BEFG
47.783	1.9019	86	0.295	99.9%	EFG
50.513	1.8053	51	0.194	99.9%	CDEG
52.470	1.7425	337	0.195	100%	AEF
54.529	1.6815	146	0.260	100%	CD
55.703	1.6488	823	0.207	100%	BF
56.783	1.6200	31	0.273	85.0%	EFG
57.422	1.6034	852	0.195	100%	A
58.645	1.5729	65	0.206	100%	BDEF
59.832	1.5445	33	0.202	96.1%	ACE
61.225	1.5126	84	0.200	100%	A
63.015	1.4739	121	0.208	100%	
63.744	1.4588	78	0.192	100%	DFG
64.359	1.4463	97	0.230	100%	DF
65.818	1.4178	50	0.265	99.0%	DE

66.469	1.4054	339	0.224	100%	ADEF
68.103	1.3757	325	0.195	100%	AFG
68.651	1.3660	207	0.216	100%	BD
69.566	1.3503	36	0.230	98.9%	
71.600	1.3168	67	0.225	100%	

Graphics



12512016.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 15:02 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	No
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz

Formula	$Si\ O_2$
Pdf Number	000-83-0539
Figure of Merit	59%
Total Peaks	19
Peaks Matched	15
New Matches	15
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.99981
Concentration	0.623545
I / Icorundum	3.07

B Corundum

Formula	$Al_2\ O_3$
Pdf Number	000-71-1123
Figure of Merit	57%
Total Peaks	15
Peaks Matched	10
New Matches	10
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.196338
Concentration	0.0398856
I / Icorundum	1

C Fluorite

Formula	$Ca\ F_2$
Pdf Number	000-75-0097
Figure of Merit	50%
Total Peaks	6
Peaks Matched	4
New Matches	4

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.431451
Concentration	0.33657
I / Icorundum	3.84

D Albite, calcian, ordered

Formula	$(Na , Ca) (Si , Al)_4 O_8$
Pdf Number	000-20-0548
Figure of Merit	37%
Total Peaks	84
Peaks Matched	47
New Matches	47
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.436739
Concentration	Not available

E Gibbsite

Formula	$Al (O H)_3$
Pdf Number	000-07-0324
Figure of Merit	23%
Total Peaks	38
Peaks Matched	22
New Matches	22
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.142872
Concentration	Not available

F Brushite

Formula	$Ca P O_3 (O H) !2 H_2 O$
Pdf Number	000-11-0293
Figure of Merit	18%
Total Peaks	38
Peaks Matched	17
New Matches	17
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.0876261
Concentration	Not available

G beta-Sodium Aluminum Oxide

Formula	$Na Al_7 O_{11}$
Pdf Number	000-21-1095
Figure of Merit	23%
Total Peaks	21
Peaks Matched	9
New Matches	9
Strong Unmatched	0
Peak Shift	0

Scale Factor	0.1406
Concentration	Not available

H Montmorillonite

Formula	(Na , Ca)$_{0.3}$ (Al , Mg)$_2$ Si$_4$ O$_{16}$ (O H)$_2$!x H$_2$ O
Pdf Number	000-12-0232
Figure of Merit	9%
Total Peaks	14
Peaks Matched	6
New Matches	6
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.179169
Concentration	Not available

Peak List

Peak Search Settings

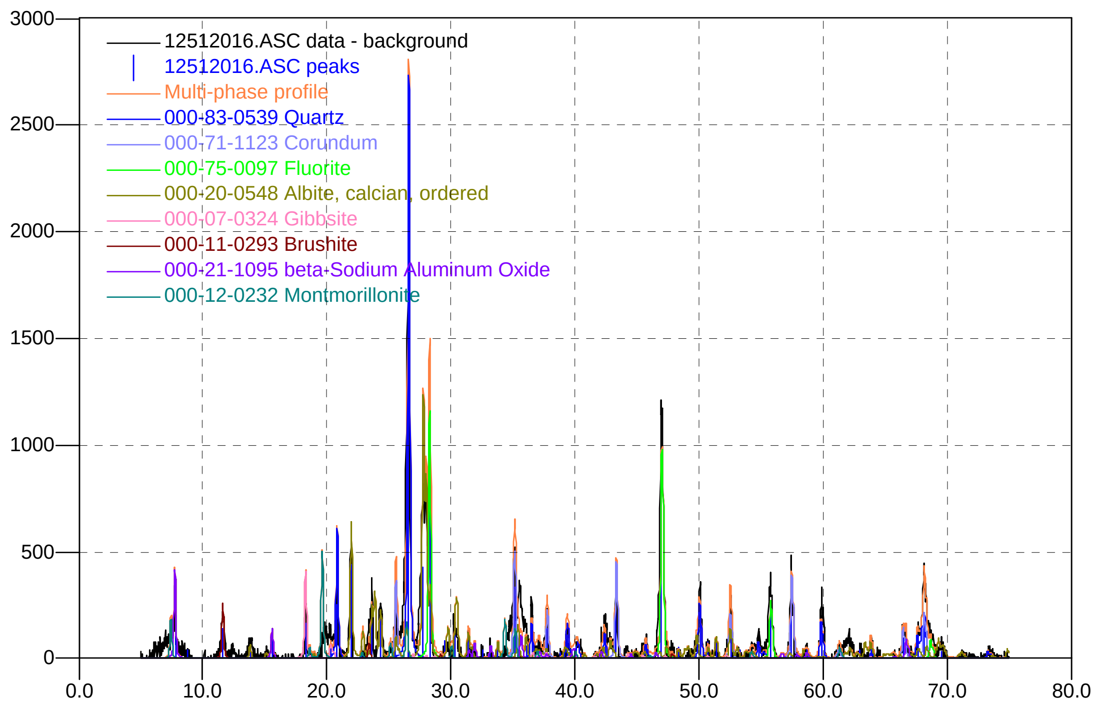
Confidence Threshold	90%
Matched / Total	47 / 51

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
7.780	11.3537	206	0.146	100%	G
8.815	10.0231	40	0.140	92.6%	
11.601	7.6219	138	0.158	100%	F
13.877	6.3764	43	0.160	98.5%	D
15.597	5.6767	90	0.143	100%	G
18.284	4.8483	168	0.146	100%	E
20.277	4.3759	49	0.146	98.6%	E
20.822	4.2625	257	0.144	100%	AF
21.925	4.0505	444	0.150	100%	D
22.788	3.8991	55	0.147	99.0%	DH
23.615	3.7644	254	0.175	100%	D
24.320	3.6568	191	0.189	100%	D
25.549	3.4837	229	0.144	100%	BD
26.580	3.3508	1831	0.151	100%	ADH
27.710	3.2167	430	0.162	100%	D
28.293	3.1516	867	0.147	100%	CD
29.547	3.0207	82	0.196	100%	
30.335	2.9441	107	0.164	100%	DF
31.409	2.8458	102	0.139	100%	DFG
32.555	2.7482	42	0.149	98.9%	
33.177	2.6980	48	0.151	99.5%	G
33.717	2.6560	51	0.153	99.7%	DF
35.121	2.5531	333	0.143	100%	BH
35.558	2.5227	137	0.151	100%	DFG
36.054	2.4891	59	0.137	98.7%	D
36.530	2.4577	180	0.149	100%	ADEF
37.731	2.3822	142	0.165	100%	BDEG
38.827	2.3174	29	0.151	92.5%	
39.428	2.2835	112	0.147	100%	ADE
41.666	2.1659	30	0.144	90.2%	BDEF
42.439	2.1282	94	0.138	100%	AD

43.318	2.0870	289	0.151	100%	BDEF
45.761	1.9811	77	0.138	100%	ADF
47.009	1.9314	848	0.165	100%	CD
48.413	1.8786	52	0.171	99.7%	D
50.124	1.8184	263	0.158	100%	AF
50.706	1.7989	76	0.174	100%	ADEF
51.415	1.7758	70	0.166	100%	DF
52.550	1.7400	174	0.152	100%	BD
53.255	1.7187	41	0.170	99.1%	D
54.829	1.6730	65	0.153	100%	A
55.758	1.6473	248	0.174	100%	C
57.482	1.6019	274	0.160	100%	BD
58.678	1.5721	49	0.165	99.6%	CDEG
59.944	1.5419	186	0.177	100%	AD
62.993	1.4744	39	0.165	97.2%	E
63.888	1.4559	54	0.171	99.8%	ADEF
66.529	1.4043	100	0.170	100%	BG
67.673	1.3833	85	0.151	100%	ADE
68.174	1.3744	204	0.173	100%	ABD
69.568	1.3502	36	0.161	96.9%	D

Graphics



12512018.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 15:05 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	No
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz

Formula	$Si\ O_2$
Pdf Number	000-83-0539
Figure of Merit	60%
Total Peaks	19
Peaks Matched	18
New Matches	18
Strong Unmatched	0
Peak Shift	0
Scale Factor	1.02109
Concentration	0.869781
I / Icorundum	3.07

B Andesine

Formula	$Na_{.499}\ Ca_{.491}\ (\ Al_{1.488}\ Si_{2.506}\ O_8\ )$
Pdf Number	000-79-1149
Figure of Merit	57%
Total Peaks	198
Peaks Matched	120
New Matches	120
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.527463
Concentration	0.0819576
I / Icorundum	0.56

C Sanidine

Formula	$K_{0.42}\ Na_{0.58}\ Ca_{0.03}\ (\ Al\ Si_3\ O_8\ )$
Pdf Number	000-89-1455
Figure of Merit	26%
Total Peaks	173
Peaks Matched	88
New Matches	88

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.289896
Concentration	0.0482617
I / Icorundum	0.6

D Montmorillonite

Formula	$Nax (Al , Mg)_2 Si_4 O_{10} (O H)_2$!z $H_2 O$
Pdf Number	000-12-0204
Figure of Merit	8%
Total Peaks	12
Peaks Matched	10
New Matches	10
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.0404821
Concentration	Not available

Peak List

Peak Search Settings

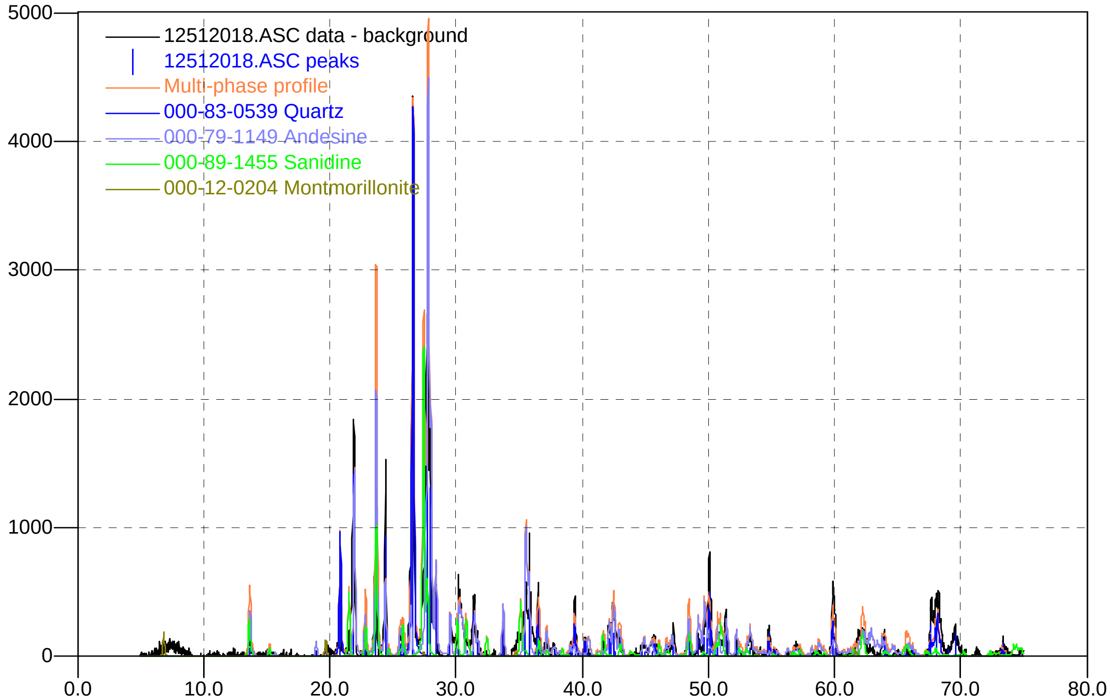
Confidence Threshold	90%
Matched / Total	56 / 56

List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
13.635	6.4887	72	0.112	99.9%	BCD
18.888	4.6943	35	0.093	93.1%	B
19.755	4.4903	44	0.118	94.4%	D
20.817	4.2636	700	0.109	100%	A
21.925	4.0505	1417	0.115	100%	B
22.815	3.8945	266	0.116	100%	BC
23.667	3.7562	1060	0.111	100%	BC
24.429	3.6407	939	0.104	100%	B
25.620	3.4742	101	0.122	100%	BC
26.609	3.3472	2849	0.102	100%	A
27.723	3.2152	1430	0.112	100%	BC
27.997	3.1843	1317	0.104	100%	B
28.392	3.1409	470	0.120	100%	B
29.557	3.0198	147	0.120	100%	B
30.246	2.9525	331	0.113	100%	B
30.948	2.8871	43	0.111	90.6%	C
31.423	2.8446	320	0.114	100%	B
31.737	2.8171	123	0.098	100%	B
33.718	2.6560	232	0.111	100%	B
35.528	2.5247	316	0.113	100%	BC
35.867	2.5016	417	0.108	100%	B
36.533	2.4575	368	0.115	100%	ABC
37.138	2.4189	55	0.142	99.1%	BC
37.783	2.3790	46	0.118	97.1%	B
39.065	2.3039	58	0.108	98.9%	BC
39.426	2.2836	322	0.113	100%	ABC
40.253	2.2386	102	0.112	100%	ACD
41.673	2.1655	57	0.122	99.4%	BC

42.137	2.1427	137	0.107	100%	BC
42.471	2.1267	181	0.137	100%	AB
44.693	2.0259	54	0.102	98.8%	BC
44.976	2.0138	41	0.108	95.3%	B
45.773	1.9806	63	0.129	98.9%	A
46.616	1.9468	56	0.114	99.0%	BC
47.250	1.9221	104	0.117	100%	BC
48.469	1.8766	114	0.149	100%	BCD
49.184	1.8509	137	0.122	100%	BC
49.704	1.8328	154	0.121	100%	BC
50.096	1.8194	492	0.130	100%	AB
50.723	1.7983	112	0.137	100%	BC
51.402	1.7762	214	0.119	100%	B
52.259	1.7491	67	0.137	99.7%	B
53.328	1.7165	70	0.111	99.5%	BC
54.834	1.6728	181	0.121	100%	AB
55.276	1.6611	45	0.088	91.9%	AC
57.276	1.6072	41	0.089	94.3%	ABC
58.677	1.5721	37	0.105	95.3%	BC
59.888	1.5432	390	0.135	100%	ABC
61.920	1.4973	52	0.103	93.3%	B
63.981	1.4543	139	0.107	99.9%	ABC
66.215	1.4102	77	0.099	100%	BC
67.665	1.3835	246	0.113	100%	AC
68.075	1.3761	195	0.095	100%	AC
69.049	1.3595	55	0.101	92.5%	C
69.608	1.3500	180	0.100	100%	C
73.408	1.2890	94	0.093	99.8%	AC

Graphics



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12512018.ASC peaks
Multi-phase profile
000-83-0539 Quartz
000-79-1149 Andesine
000-89-1455 Sanidine
000-12-0204 Montmorillonite

12512022.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 15:06 Wednesday, March 07, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	No
Figure of Merit	Multi-phase
Apply Restrictions	Yes

Matched Materials

A Quartz

Formula	$Si\ O_2$
Pdf Number	000-83-0539
Figure of Merit	41%
Total Peaks	19
Peaks Matched	19
New Matches	19
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.655033
Concentration	0.837978
I / Icorundum	3.07

B Andesine

Formula	$Na_{.499}\ Ca_{.491}\ (\ Al_{1.488}\ Si_{2.506}\ O_8\ )$
Pdf Number	000-79-1148
Figure of Merit	37%
Total Peaks	198
Peaks Matched	115
New Matches	115
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.2897
Concentration	0.0676033
I / Icorundum	0.56

C Anorthoclase

Formula	$(\ Na_{0.667}\ K_{0.333}\ )\ (\ Al\ Si_3\ O_8\ )$
Pdf Number	000-75-1631
Figure of Merit	23%
Total Peaks	168
Peaks Matched	84
New Matches	84

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.284319
Concentration	0.0639779
I / Icorundum	0.54

D Enstatite ferroan

Formula	$Fe_{.155}\ Mg_{.845}\ Si\ O_3$
Pdf Number	000-74-1393
Figure of Merit	18%
Total Peaks	155
Peaks Matched	73
New Matches	73
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.105872
Concentration	0.0304411
I / Icorundum	0.69

E Opal- A

Formula	$Si\ O_2$!x $H_2\ O$
Pdf Number	000-38-0448
Figure of Merit	19%
Total Peaks	8
Peaks Matched	6
New Matches	6
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.114893
Concentration	Not available

F Illite-Montmorillonite, regular

Formula	$K - Al_4\ (\ Si\ Al\ )_8\ O_{20}\ (\ O\ H\ )_4$!x $H_2\ O$
Pdf Number	000-07-0330
Figure of Merit	16%
Total Peaks	18
Peaks Matched	13
New Matches	13
Strong Unmatched	1
Peak Shift	0
Scale Factor	0.0626616
Concentration	Not available

Peak List

Peak Search Settings

Confidence Threshold	90%
Matched / Total	62 / 66

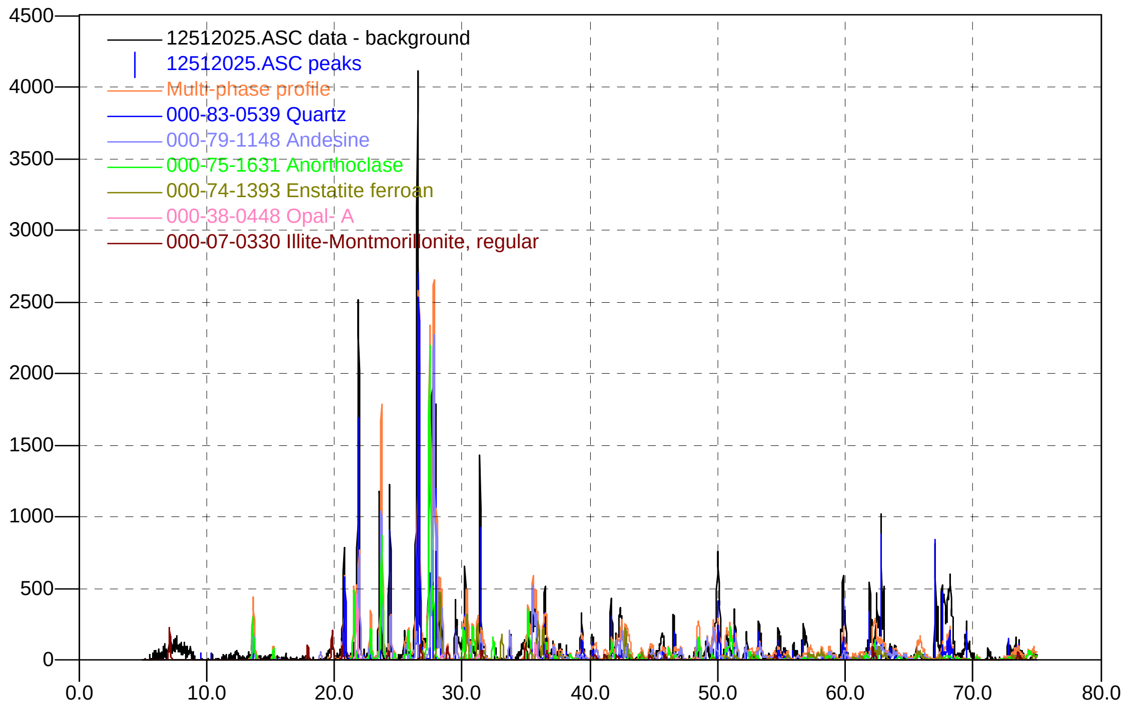
List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
9.609	9.1968	48	0.100	93.2%	

10.427	8.4769	52	0.088	97.9%	
13.615	6.4984	65	0.092	99.7%	BC
17.981	4.9293	63	0.087	99.9%	F
20.773	4.2725	575	0.102	100%	A
21.912	4.0530	1691	0.092	100%	B
22.348	3.9749	47	0.112	97.6%	
22.782	3.9000	90	0.097	100%	BC
23.580	3.7698	909	0.098	100%	B
24.357	3.6513	915	0.097	100%	B
25.535	3.4856	119	0.093	100%	BC
26.554	3.3540	2707	0.096	100%	ABD
27.456	3.2459	610	0.100	100%	C
27.691	3.2188	769	0.090	100%	BC
27.951	3.1894	1201	0.098	100%	BD
28.339	3.1467	375	0.110	100%	BDE
29.526	3.0228	215	0.104	100%	B
30.241	2.9530	326	0.105	100%	B
31.443	2.8428	932	0.093	100%	BF
32.640	2.7412	44	0.094	98.9%	
33.042	2.7088	34	0.090	95.1%	BD
33.801	2.6497	117	0.101	100%	B
35.447	2.5303	123	0.106	100%	BCD
35.717	2.5118	89	0.096	99.8%	BDE
36.469	2.4617	334	0.108	100%	ABCD
37.105	2.4210	42	0.108	96.5%	B
38.210	2.3534	61	0.098	99.9%	BCD
38.978	2.3088	37	0.098	93.9%	BCD
39.376	2.2864	214	0.102	100%	ABC
40.227	2.2400	121	0.112	100%	AD
41.682	2.1651	308	0.112	100%	BC
42.072	2.1459	92	0.093	100%	BCDF
42.397	2.1302	145	0.139	100%	ABCE
42.914	2.1057	46	0.170	92.1%	BD
44.723	2.0247	35	0.094	93.0%	BCDEF
45.684	1.9843	73	0.129	99.9%	ABD
46.590	1.9478	202	0.101	100%	BC
49.116	1.8534	58	0.108	98.8%	BD
49.673	1.8339	78	0.110	99.2%	BCD
50.037	1.8214	417	0.118	100%	ABD
50.710	1.7988	108	0.099	100%	BCD
51.347	1.7779	211	0.117	100%	BD
52.263	1.7489	106	0.092	100%	B
53.243	1.7190	200	0.112	100%	BCD
54.759	1.6749	146	0.121	100%	ABD
55.224	1.6622	66	0.082	98.3%	AC
55.952	1.6420	70	0.093	99.9%	BD
56.772	1.6210	146	0.116	100%	BCD
58.270	1.5821	43	0.092	98.4%	BCD
59.102	1.5618	45	0.092	98.7%	BC
59.841	1.5443	431	0.113	100%	ABCD
61.913	1.4975	340	0.091	100%	BD
62.172	1.4924	128	0.083	99.9%	BCF
62.472	1.4854	233	0.104	100%	BD
62.848	1.4778	880	0.084	100%	BD
63.506	1.4640	86	0.084	99.8%	B
63.912	1.4554	74	0.089	99.0%	ABCD

65.632	1.4217	106	0.090	100%	ABCD
67.066	1.3948	842	0.087	100%	CD
67.585	1.3848	483	0.102	100%	AC
68.036	1.3767	175	0.083	99.9%	ACD
68.222	1.3738	188	0.101	99.3%	ACD
69.502	1.3519	200	0.094	100%	CD
72.754	1.2989	153	0.088	100%	CD
73.363	1.2896	95	0.101	99.9%	ACD
73.628	1.2859	114	0.088	99.8%	CDF

Graphics



12512025.csm

Crystallographica Search-Match Version 3, 1, 0, 2

Report Compiled at 13:52 Thursday, March 08, 2012

Search-Match

Settings

Search Range	5.01 to 74.99
Data Source	Raw data
Trust Intensities	Yes
Allow Zero Errors	No
Figure of Merit	Multi-phase
Apply Restrictions	No

Matched Materials

A Quartz

Formula	$Si\ O_2$
Pdf Number	000-83-0539
Figure of Merit	41%
Total Peaks	19
Peaks Matched	19
New Matches	19
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.655033
Concentration	0.891576
I / Icorundum	3.07

B Albite high

Formula	$Na\ (\ Al\ Si_3\ O_8\ )$
Pdf Number	000-71-1151
Figure of Merit	39%
Total Peaks	198
Peaks Matched	109
New Matches	109
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.376232
Concentration	0.108424
I / Icorundum	0.65

C Sanidine, K-rich, disordered, syn

Formula	$(\ Na\ ,\ K\ )\ (\ Si_3\ Al\ )\ O_8$
Pdf Number	000-10-0357
Figure of Merit	23%
Total Peaks	17
Peaks Matched	10
New Matches	10

Strong Unmatched	0
Peak Shift	0
Scale Factor	0.307951
Concentration	Not available

D Aluminum Phosphate

Formula	$Al\ P\ O_4$
Pdf Number	000-11-0500
Figure of Merit	15%
Total Peaks	32
Peaks Matched	16
New Matches	16
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.150407
Concentration	Not available

E Sodium Calcium Oxide Fluoride Phosphate

Formula	$Ca_6\ Na_4\ (\ P\ O_3\ F\ )_6\ O_2$
Pdf Number	000-28-1065
Figure of Merit	15%
Total Peaks	19
Peaks Matched	9
New Matches	9
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.107508
Concentration	Not available

F Montmorillonite-22A

Formula	$Na_{0.3}\ (\ Al\ ,\ Mg\ )_2\ Si_4\ O_{10}\ (\ O\ H\ )_2$!8 $H_2\ O$
Pdf Number	000-29-1499
Figure of Merit	10%
Total Peaks	6
Peaks Matched	3
New Matches	3
Strong Unmatched	0
Peak Shift	0
Scale Factor	0.0406359
Concentration	Not available

Peak List

Peak Search Settings

Confidence Threshold	90%
Matched / Total	56 / 66

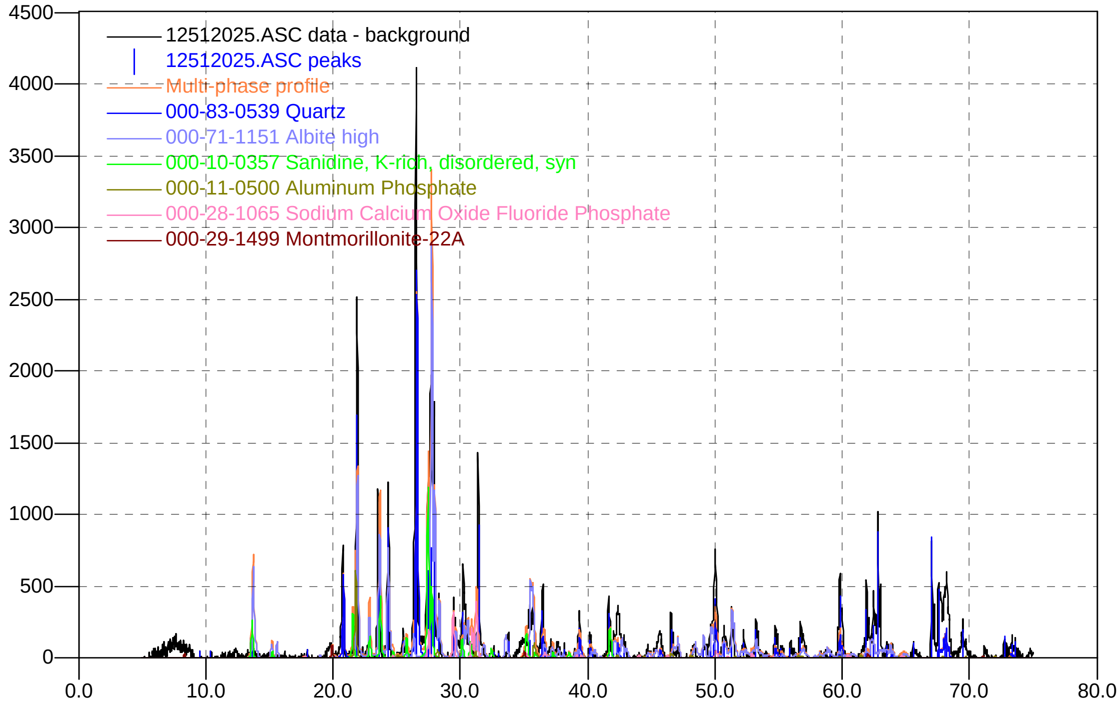
List of Peaks

2-Theta	*D-Spacing*	*Intensity*	*Width*	*Confidence*	*Matches*
9.609	9.1968	48	0.100	93.2%	
10.427	8.4769	52	0.088	97.9%	
13.615	6.4984	65	0.092	99.7%	C

17.981	4.9293	63	0.087	99.9%	
20.773	4.2725	575	0.102	100%	A
21.912	4.0530	1691	0.092	100%	B
22.348	3.9749	47	0.112	97.6%	
22.782	3.9000	90	0.097	100%	B
23.580	3.7698	909	0.098	100%	B
24.357	3.6513	915	0.097	100%	B
25.535	3.4856	119	0.093	100%	BD
26.554	3.3540	2707	0.096	100%	A
27.456	3.2459	610	0.100	100%	CE
27.691	3.2188	769	0.090	100%	BC
27.951	3.1894	1201	0.098	100%	B
28.339	3.1467	375	0.110	100%	B
29.526	3.0228	215	0.104	100%	E
30.241	2.9530	326	0.105	100%	BC
31.443	2.8428	932	0.093	100%	B
32.640	2.7412	44	0.094	98.9%	
33.042	2.7088	34	0.090	95.1%	
33.801	2.6497	117	0.101	100%	B
35.447	2.5303	123	0.106	100%	B
35.717	2.5118	89	0.096	99.8%	BD
36.469	2.4617	334	0.108	100%	AB
37.105	2.4210	42	0.108	96.5%	B
38.210	2.3534	61	0.098	99.9%	B
38.978	2.3088	37	0.098	93.9%	B
39.376	2.2864	214	0.102	100%	ABE
40.227	2.2400	121	0.112	100%	AB
41.682	2.1651	308	0.112	100%	BC
42.072	2.1459	92	0.093	100%	B
42.397	2.1302	145	0.139	100%	AD
42.914	2.1057	46	0.170	92.1%	B
44.723	2.0247	35	0.094	93.0%	B
45.684	1.9843	73	0.129	99.9%	AB
46.590	1.9478	202	0.101	100%	D
49.116	1.8534	58	0.108	98.8%	B
49.673	1.8339	78	0.110	99.2%	B
50.037	1.8214	417	0.118	100%	ABE
50.710	1.7988	108	0.099	100%	B
51.347	1.7779	211	0.117	100%	BD
52.263	1.7489	106	0.092	100%	BD
53.243	1.7190	200	0.112	100%	B
54.759	1.6749	146	0.121	100%	AB
55.224	1.6622	66	0.082	98.3%	AB
55.952	1.6420	70	0.093	99.9%	B
56.772	1.6210	146	0.116	100%	B
58.270	1.5821	43	0.092	98.4%	BD
59.102	1.5618	45	0.092	98.7%	B
59.841	1.5443	431	0.113	100%	ABD
61.913	1.4975	340	0.091	100%	BF
62.172	1.4924	128	0.083	99.9%	B
62.472	1.4854	233	0.104	100%	B
62.848	1.4778	880	0.084	100%	B
63.506	1.4640	86	0.084	99.8%	B
63.912	1.4554	74	0.089	99.0%	AB
65.632	1.4217	106	0.090	100%	A
67.066	1.3948	842	0.087	100%	

67.585	1.3848	483	0.102	100%	A
68.036	1.3767	175	0.083	99.9%	AD
68.222	1.3738	188	0.101	99.3%	A
69.502	1.3519	200	0.094	100%	
72.754	1.2989	153	0.088	100%	
73.363	1.2896	95	0.101	99.9%	AD
73.628	1.2859	114	0.088	99.8%	

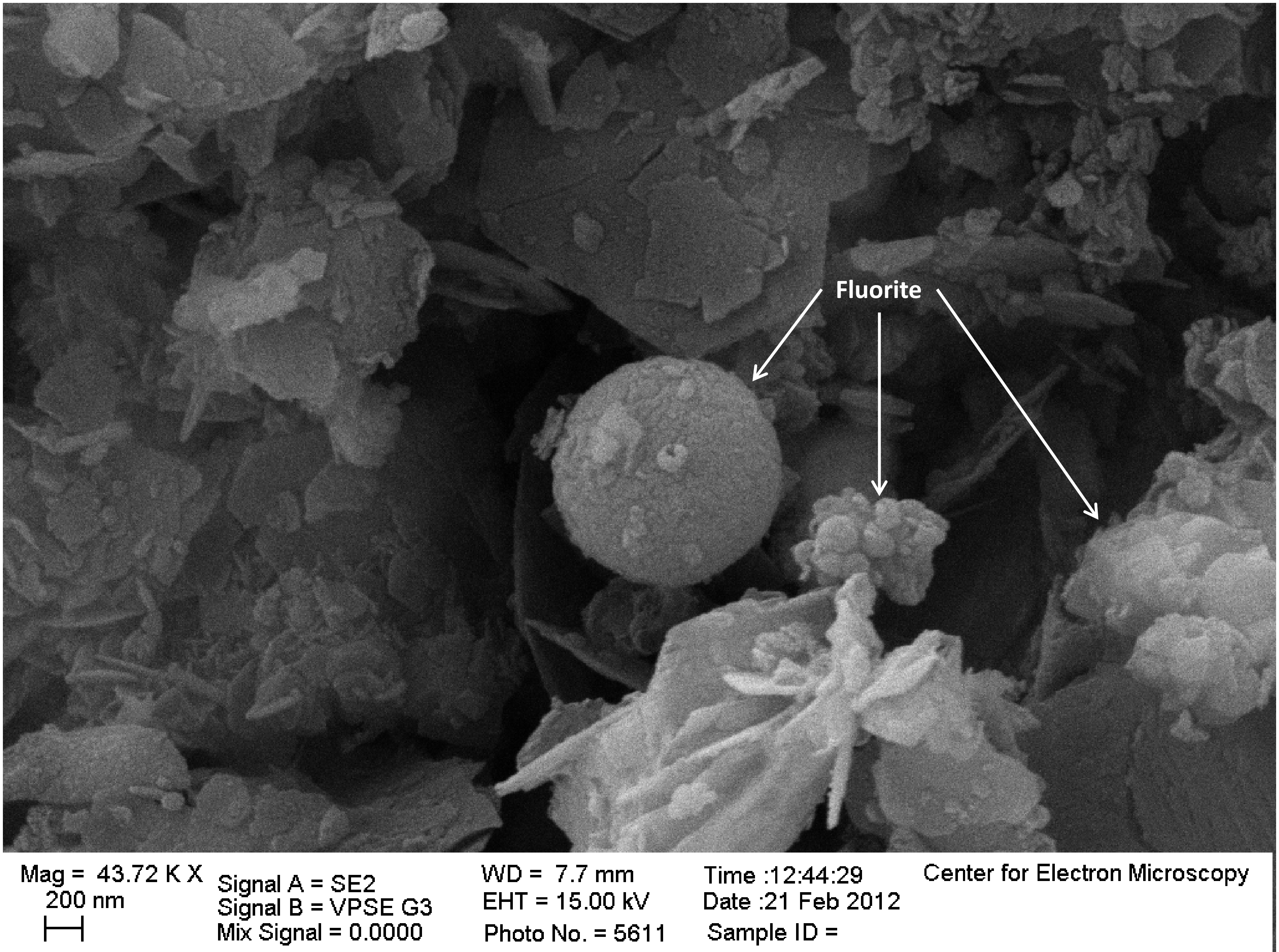
Graphics



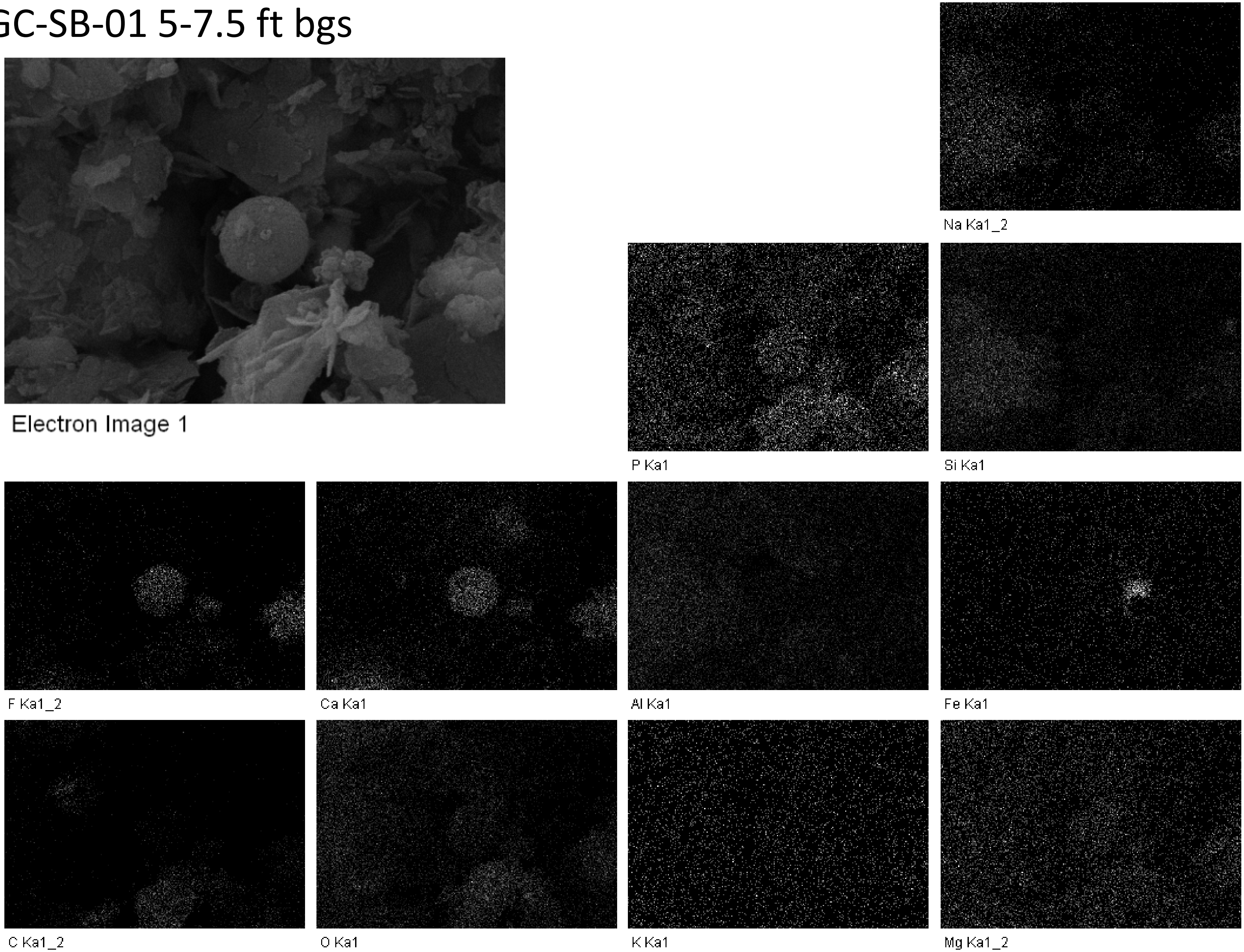
ATTACHMENT 2
SCANNING ELECTRON MICROSCOPY IMAGES

High Resolution Scanning Electron Microscope Images and EDS Element Maps

GC-SB-01 5-7.5 ft bgs



GC-SB-01 5-7.5 ft bgs



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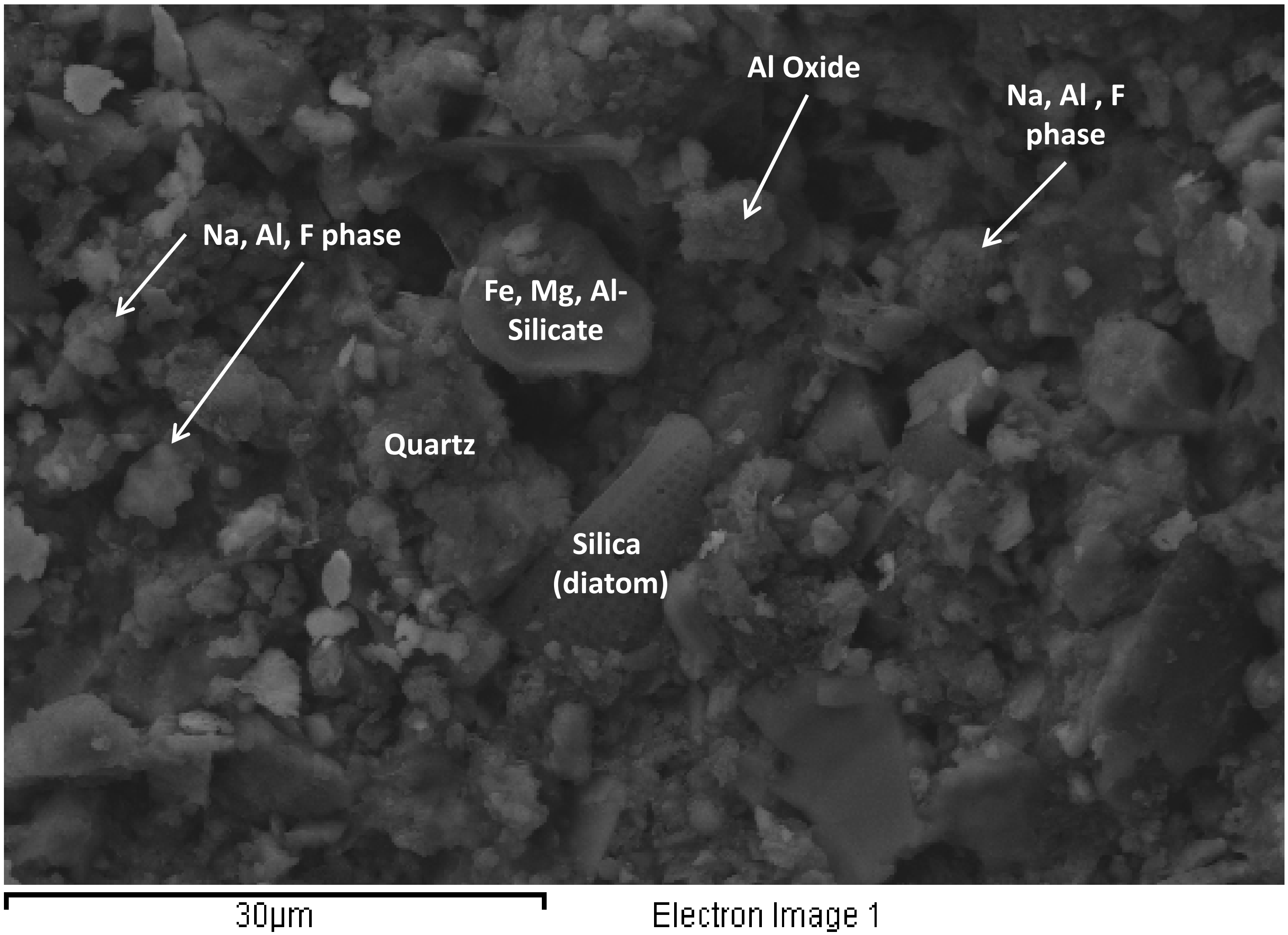
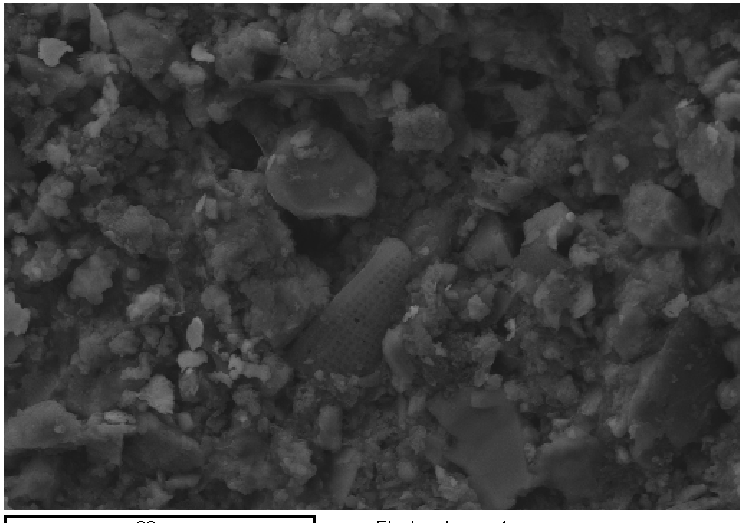
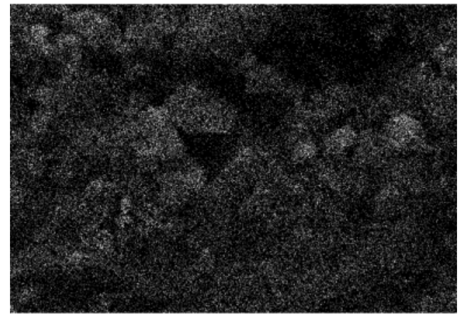


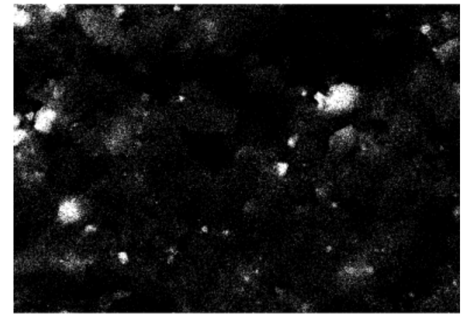
GC-SB-01 5-7.5 ft bgs



Electron Image 1



S Ka1



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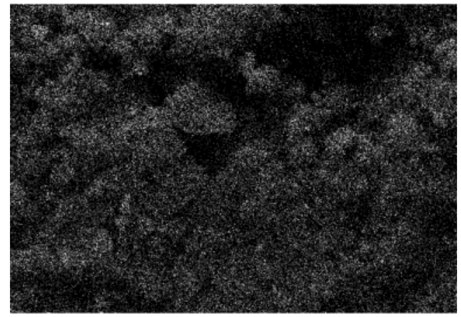

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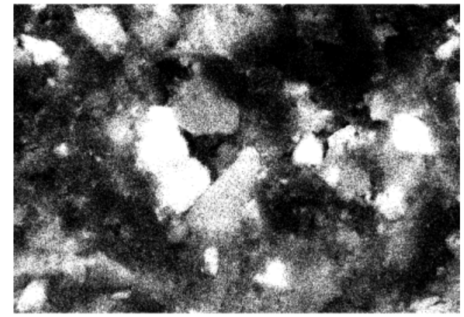

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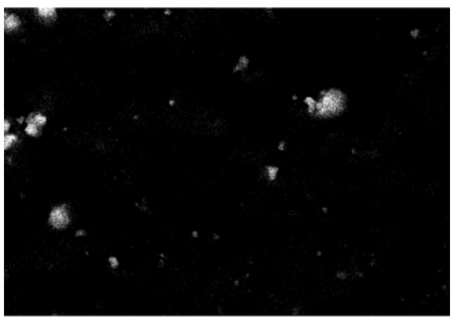

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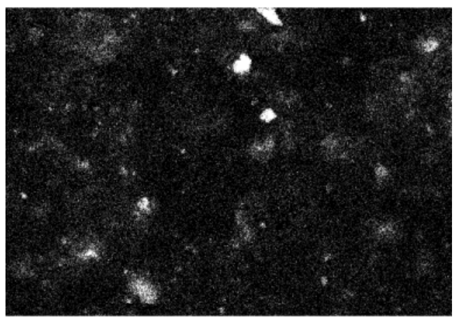

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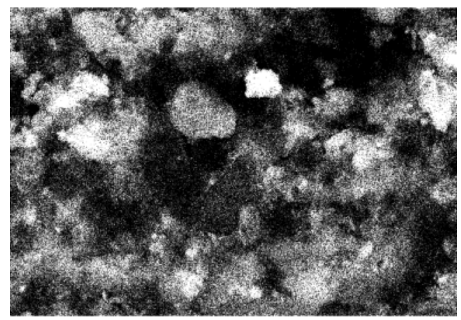

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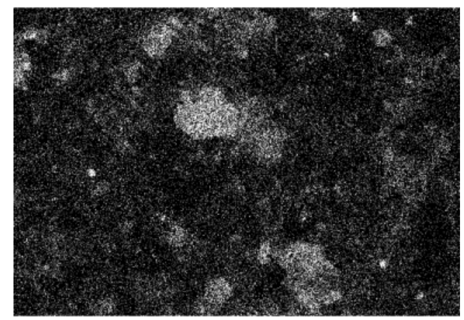

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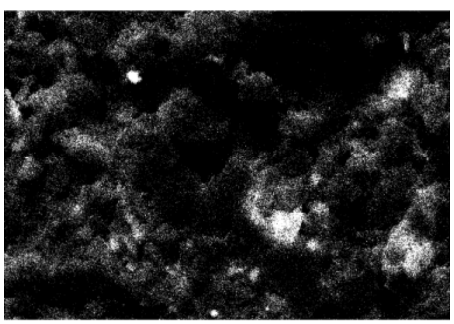

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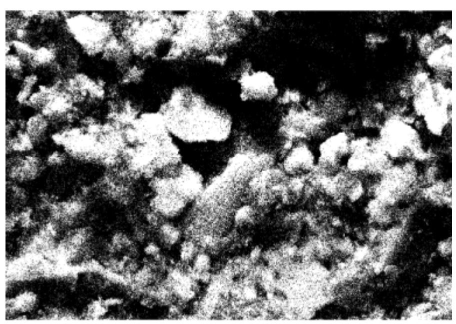

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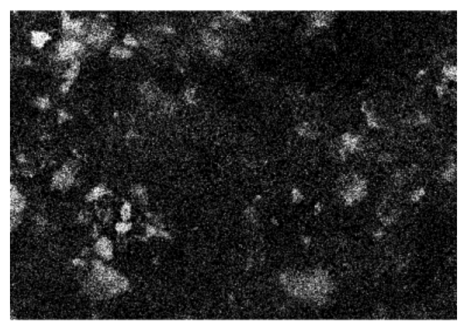

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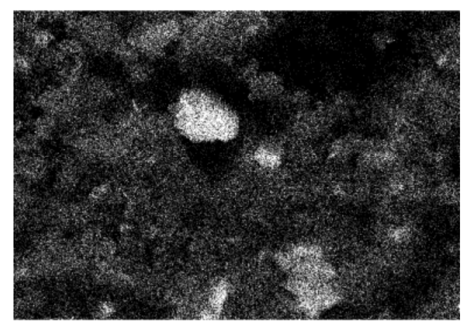
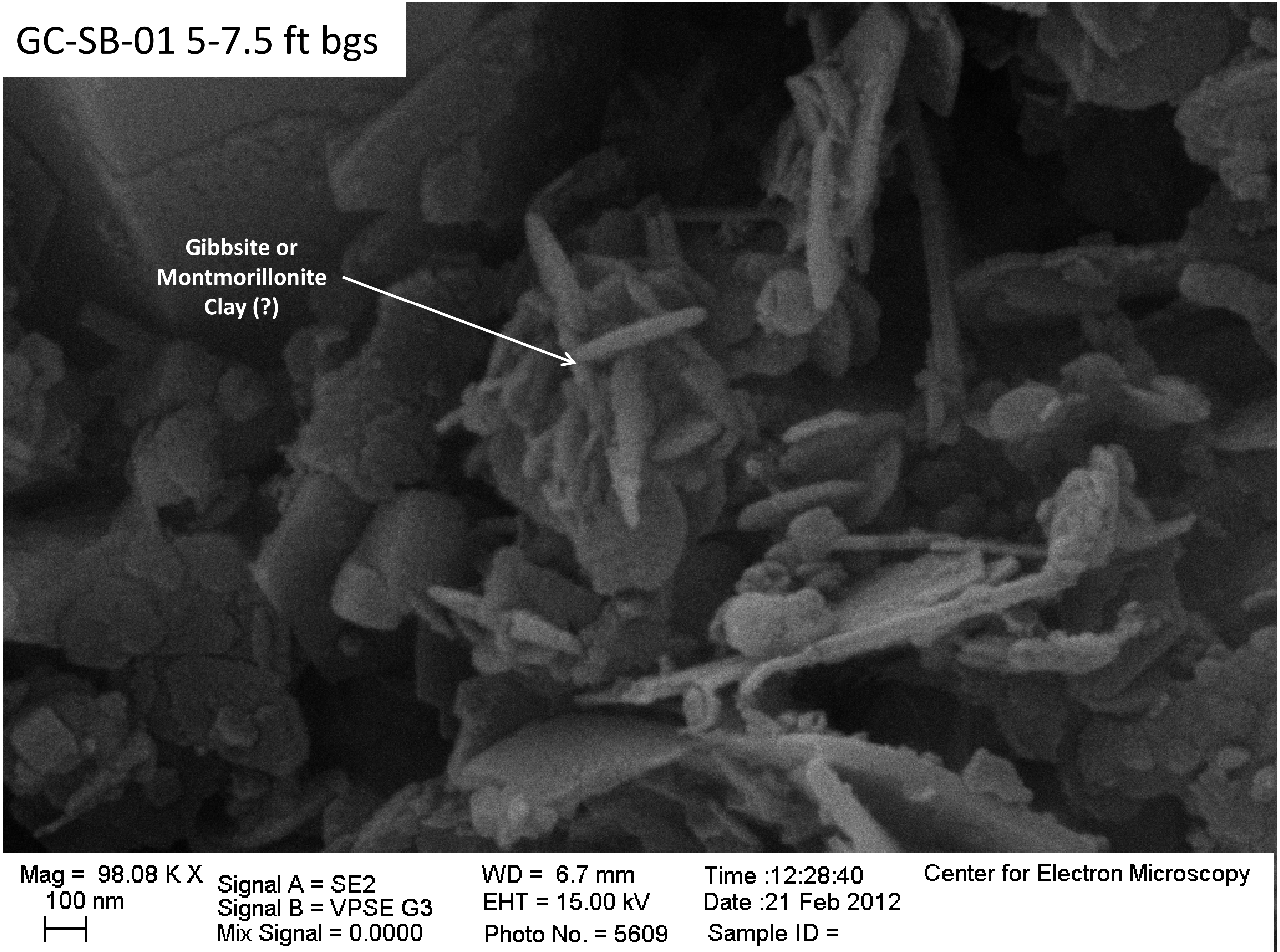


Mg Ka1_2

GC-SB-01 5-7.5 ft bgs



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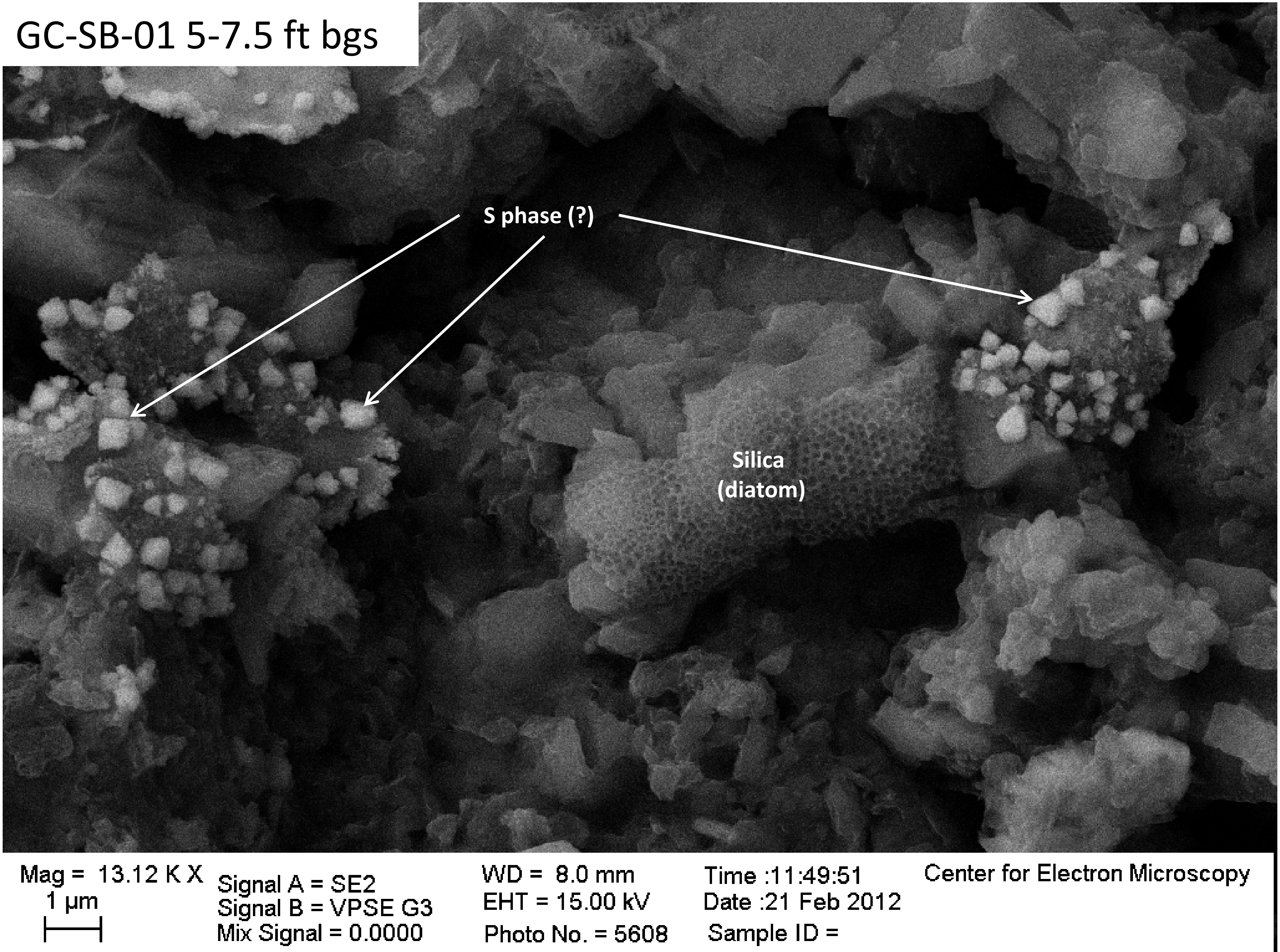

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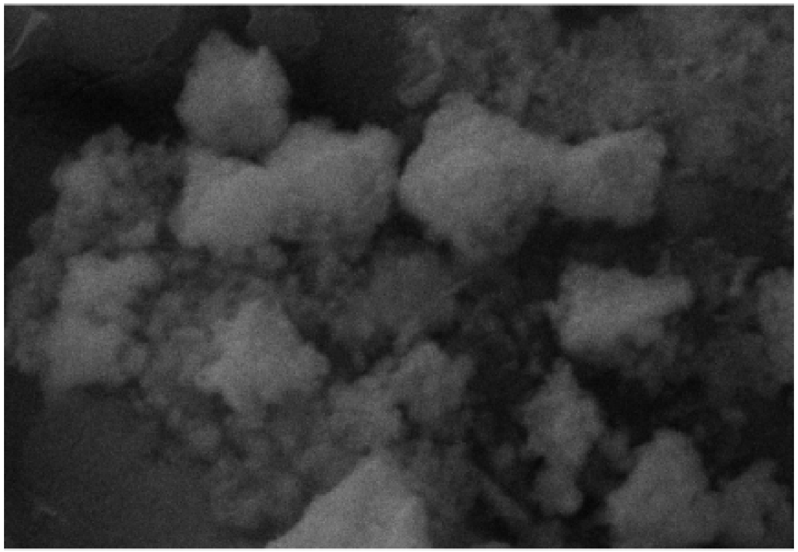
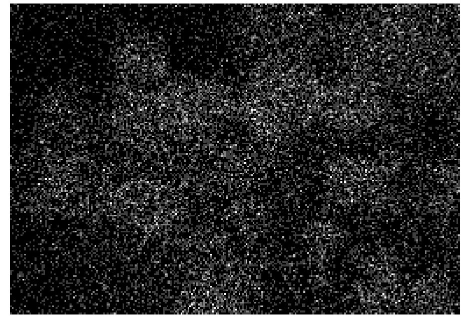


Electron Image 1



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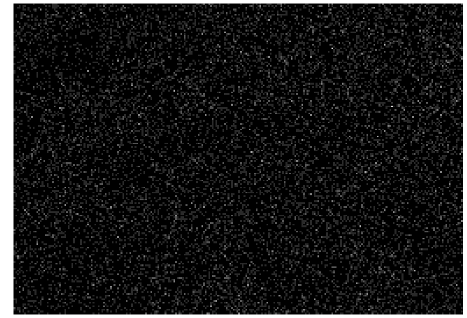

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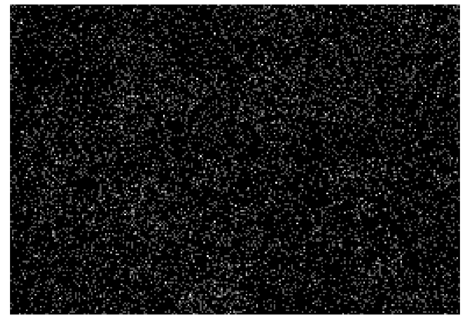

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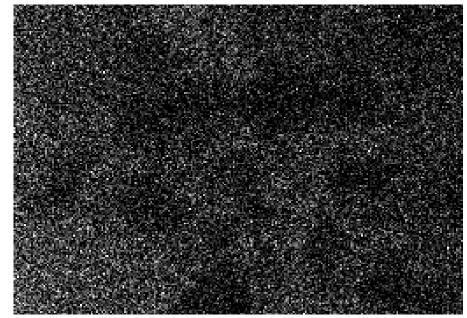

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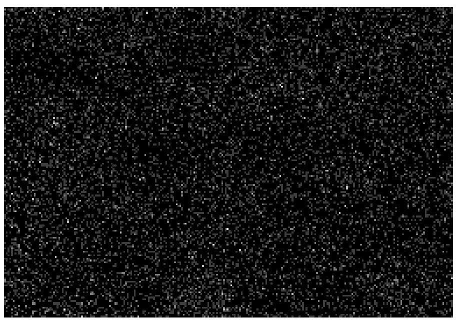
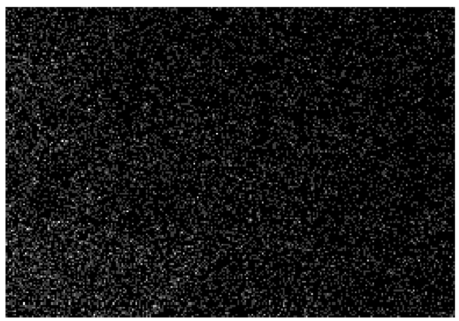


F Ka1_2



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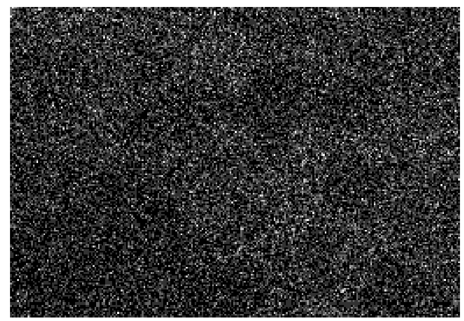

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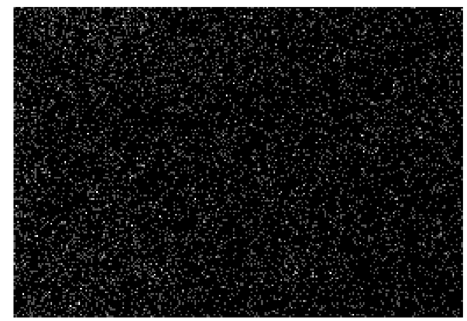

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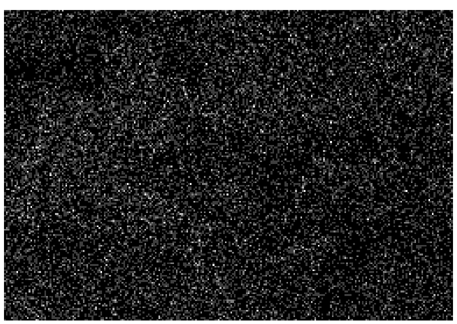

C Ka1_2

O Ka1

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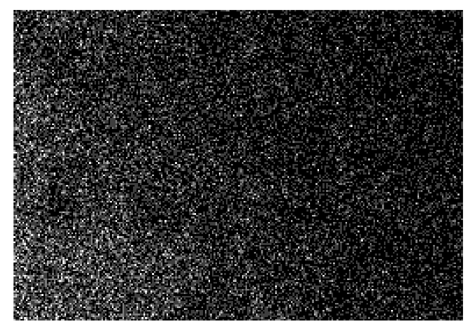
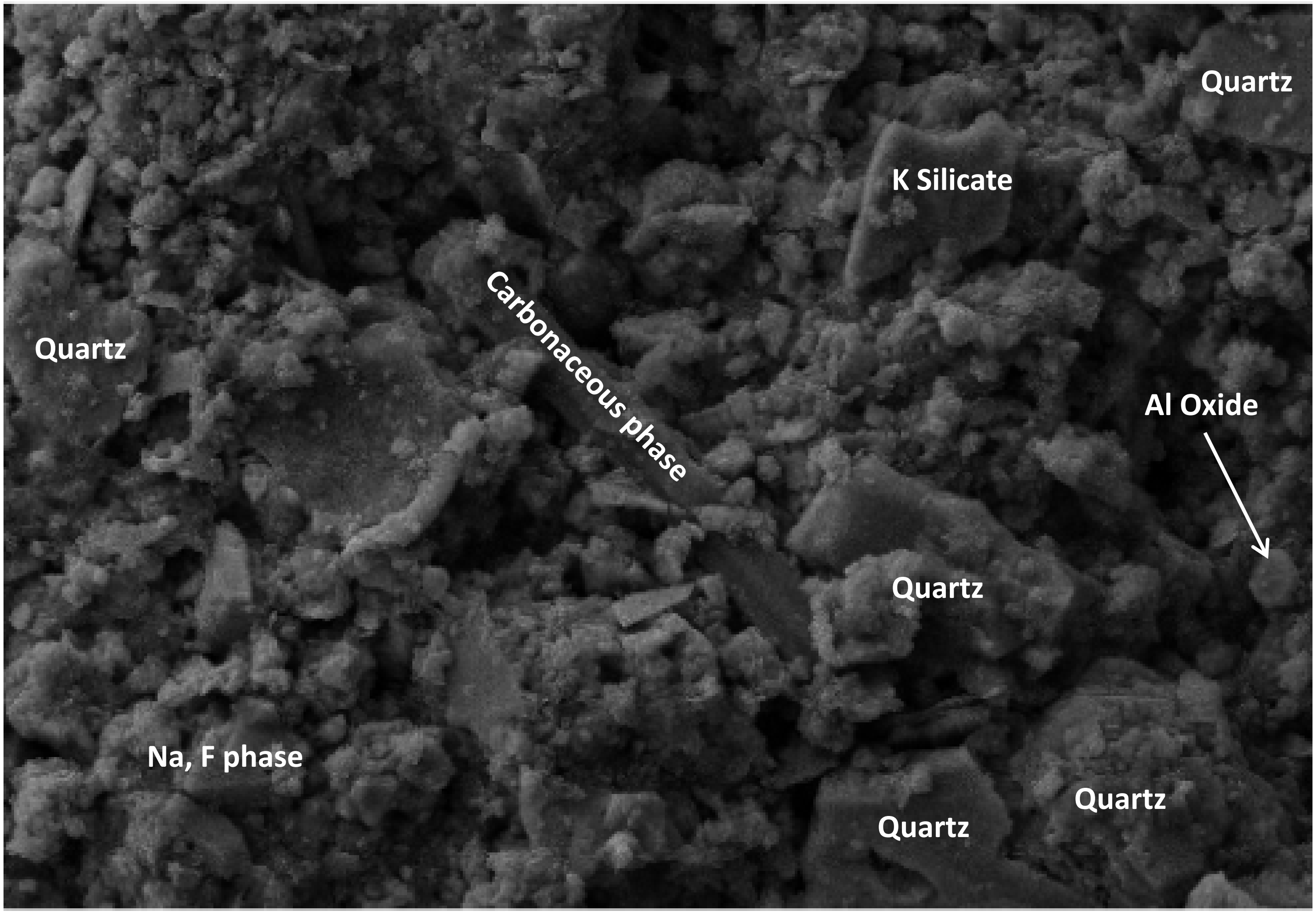


Mg Ka1_2

GC-SB-01 5-7.5 ft bgs



Electron Image 1

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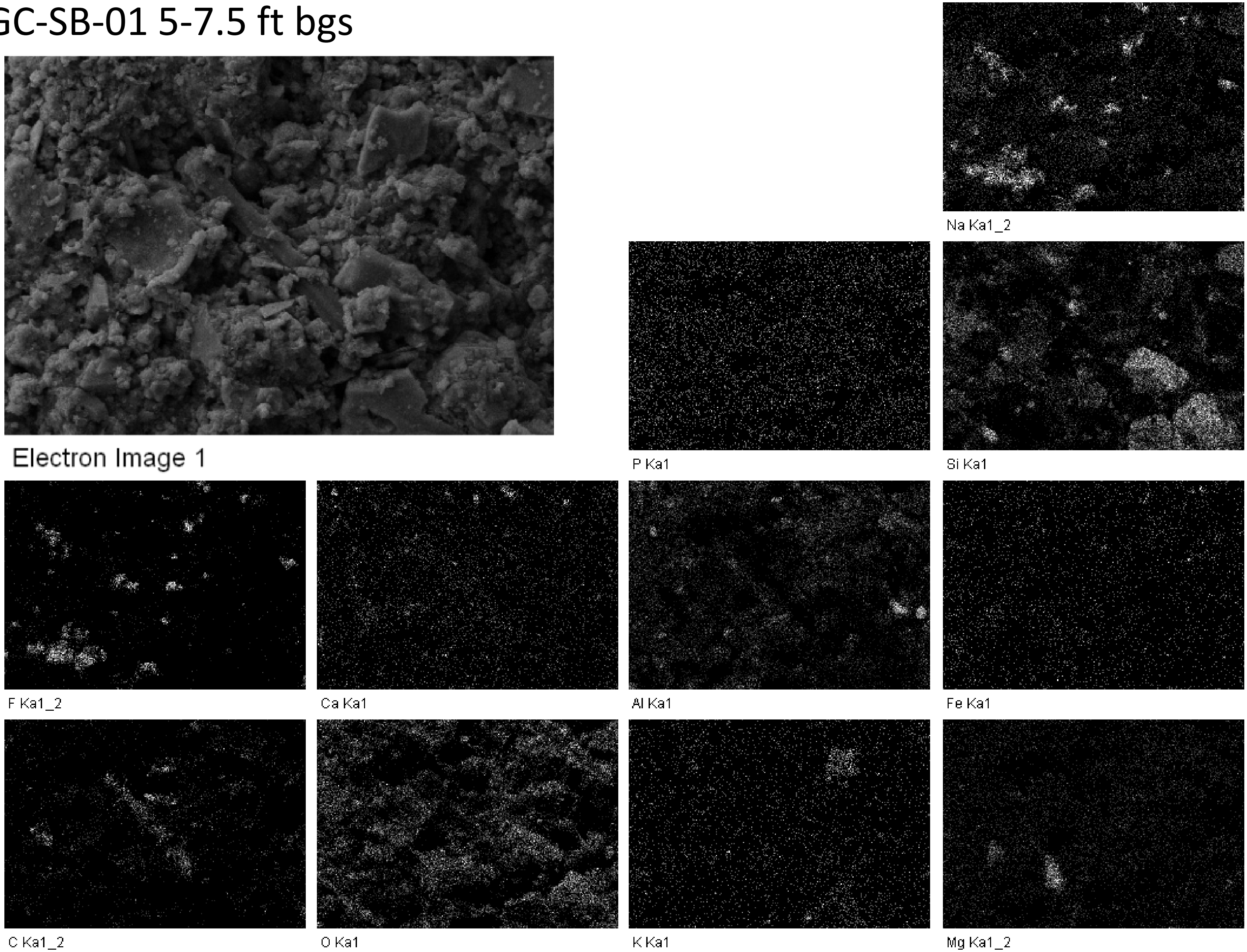

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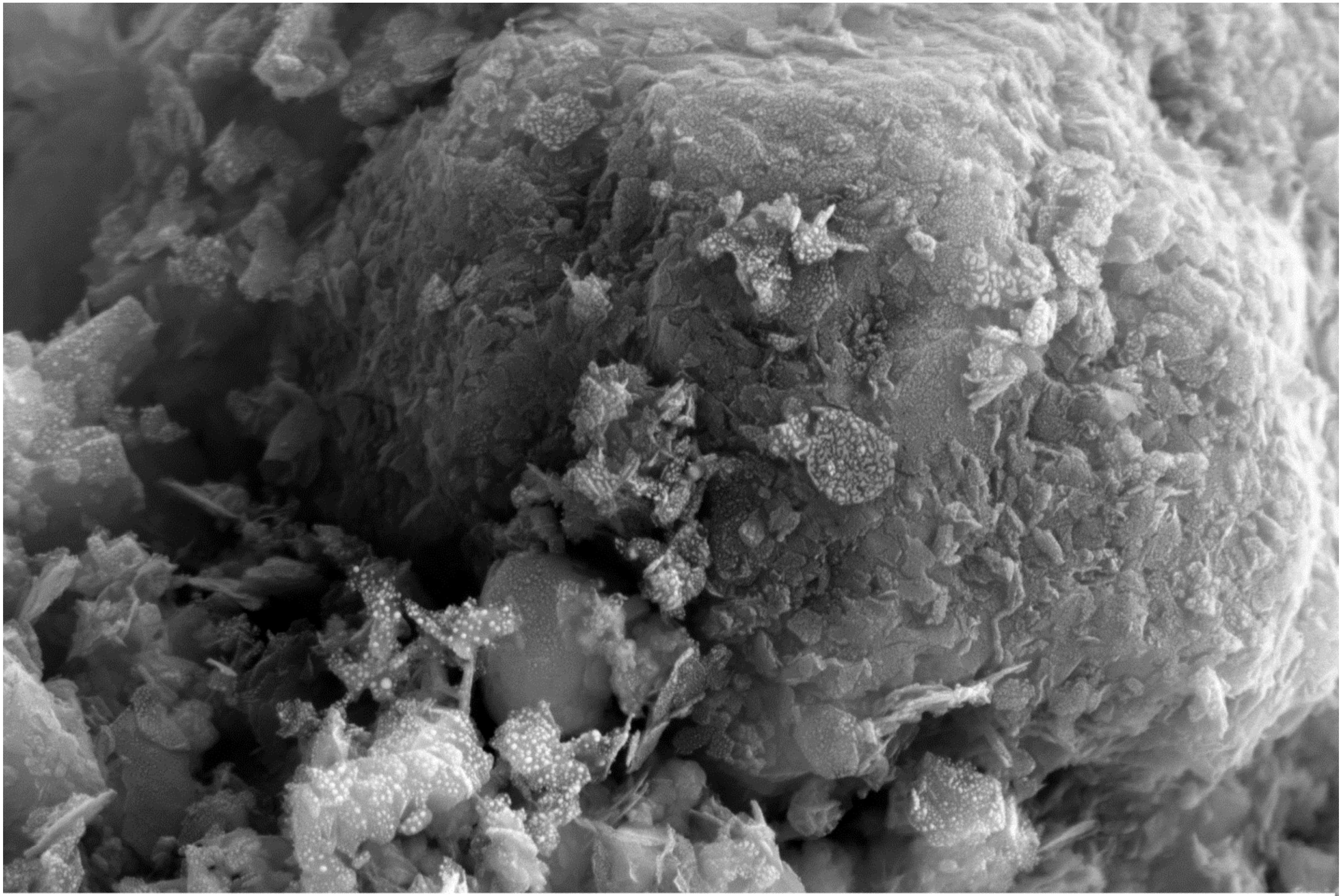

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Signal B = InLens
Mix Signal = 0.0000
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EHT = 15.00 kV
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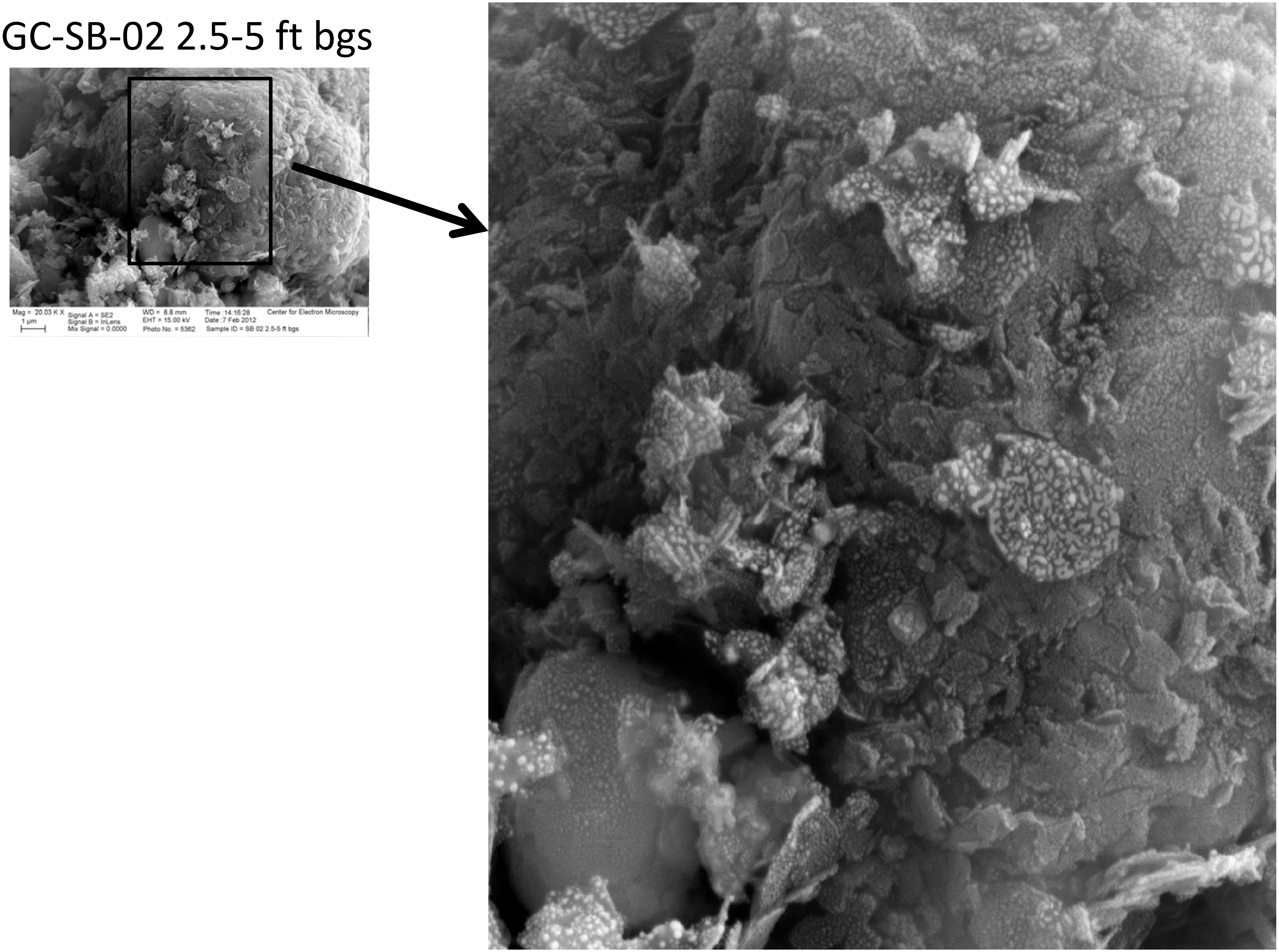
Date :7 Feb 2012
Sample ID = SB 02 2.5-5 ft bgs
Center for Electron Microscopy

GC-SB-02 2.5-5 ft bgs



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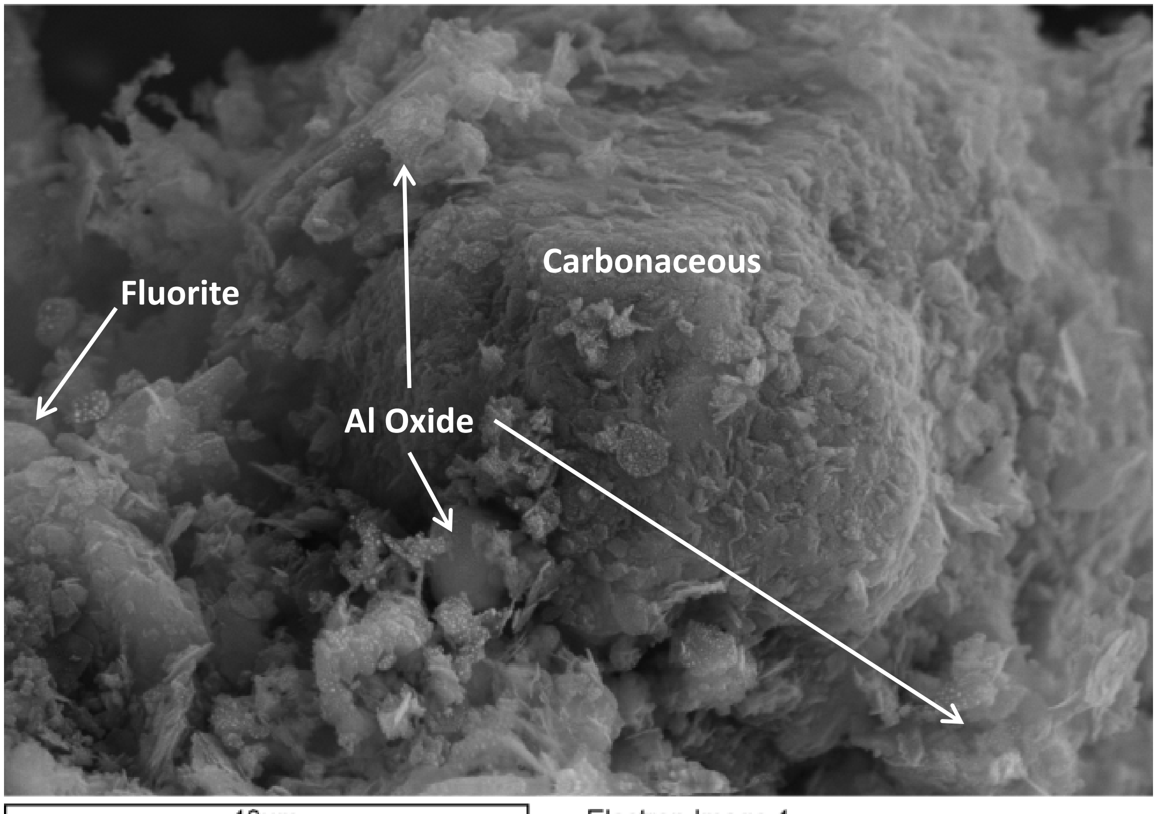
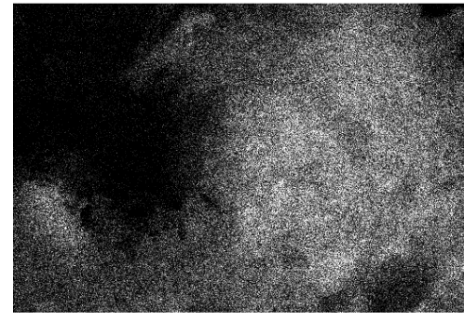


Electron Image 1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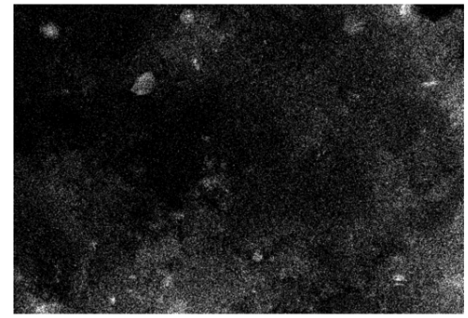
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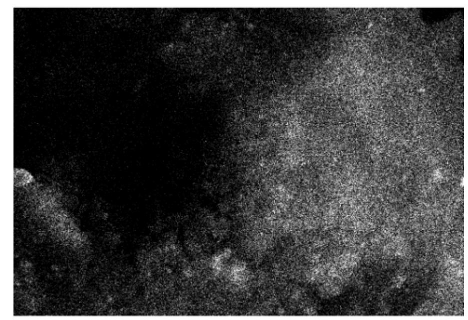
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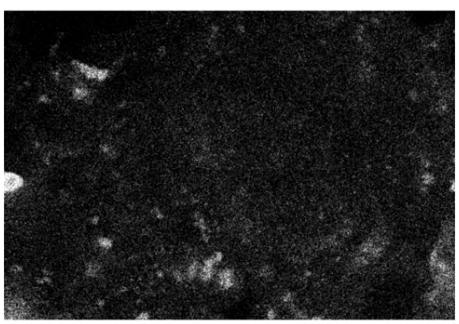
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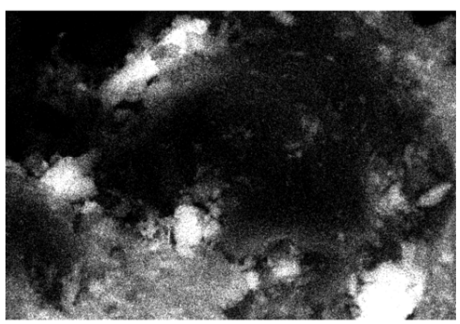
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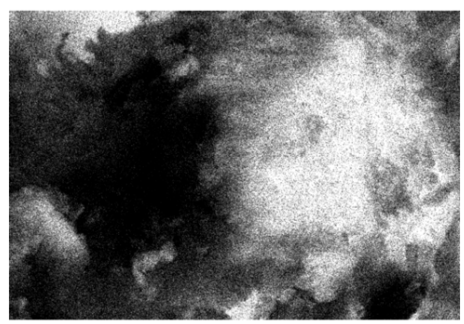
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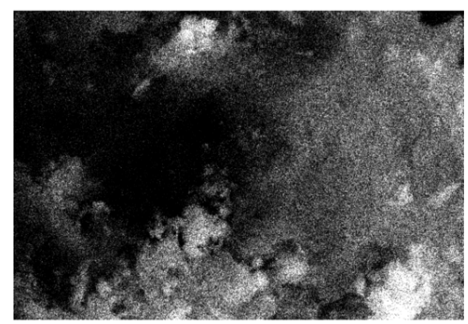
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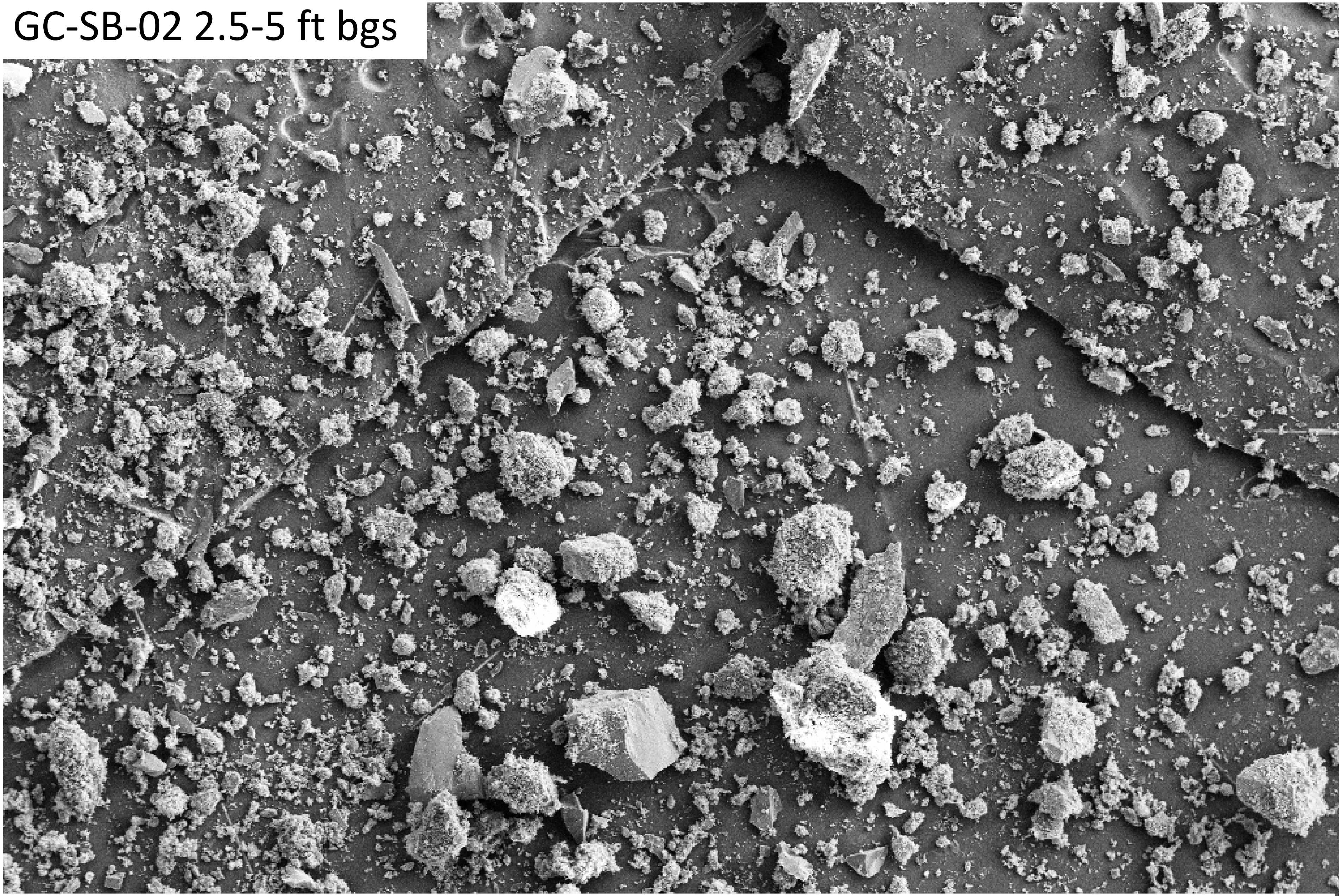

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Mix Signal = 0.0000

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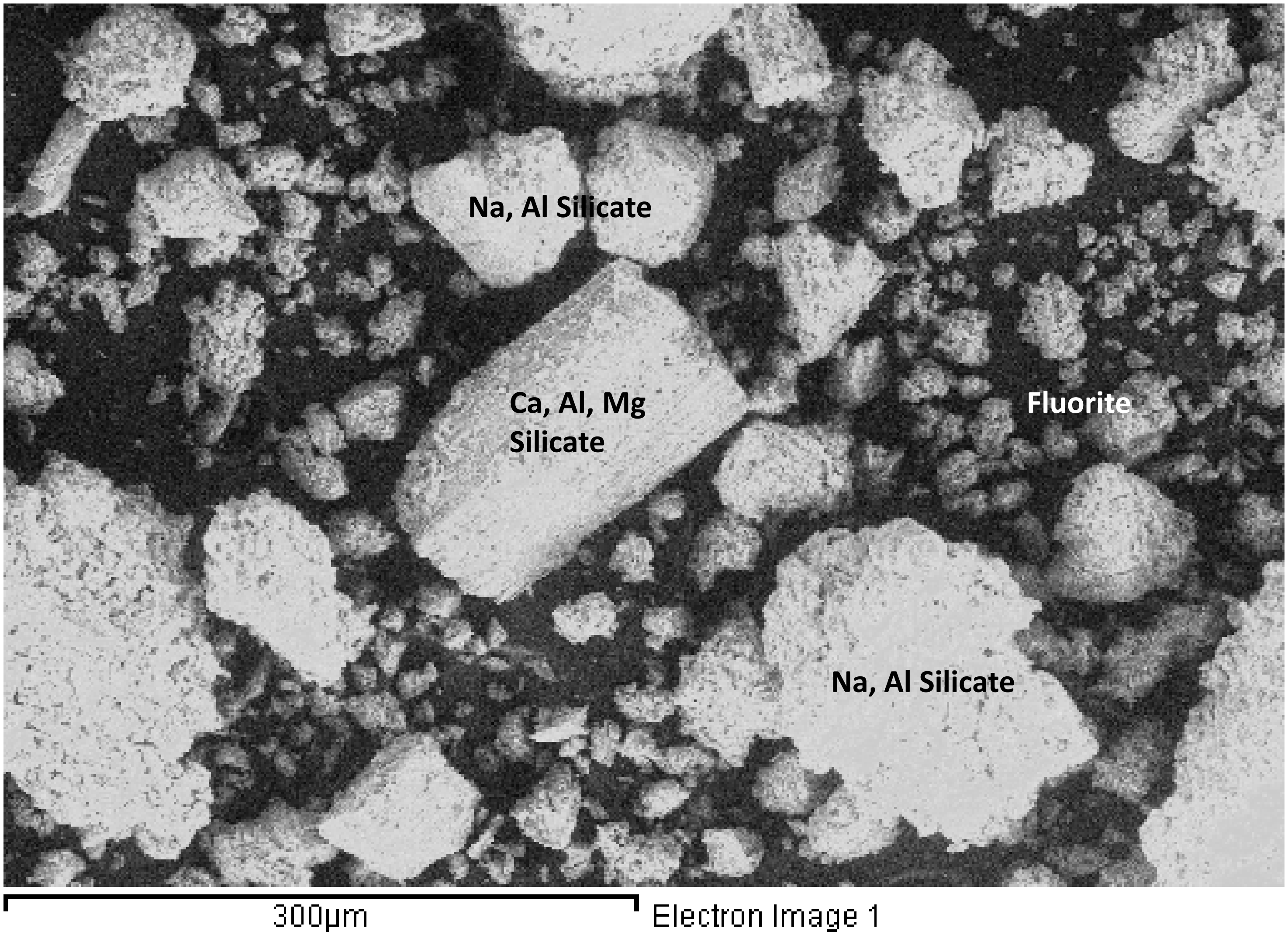
Center for Electron Microscopy

GC-SB-02 2.5-5 ft bgs



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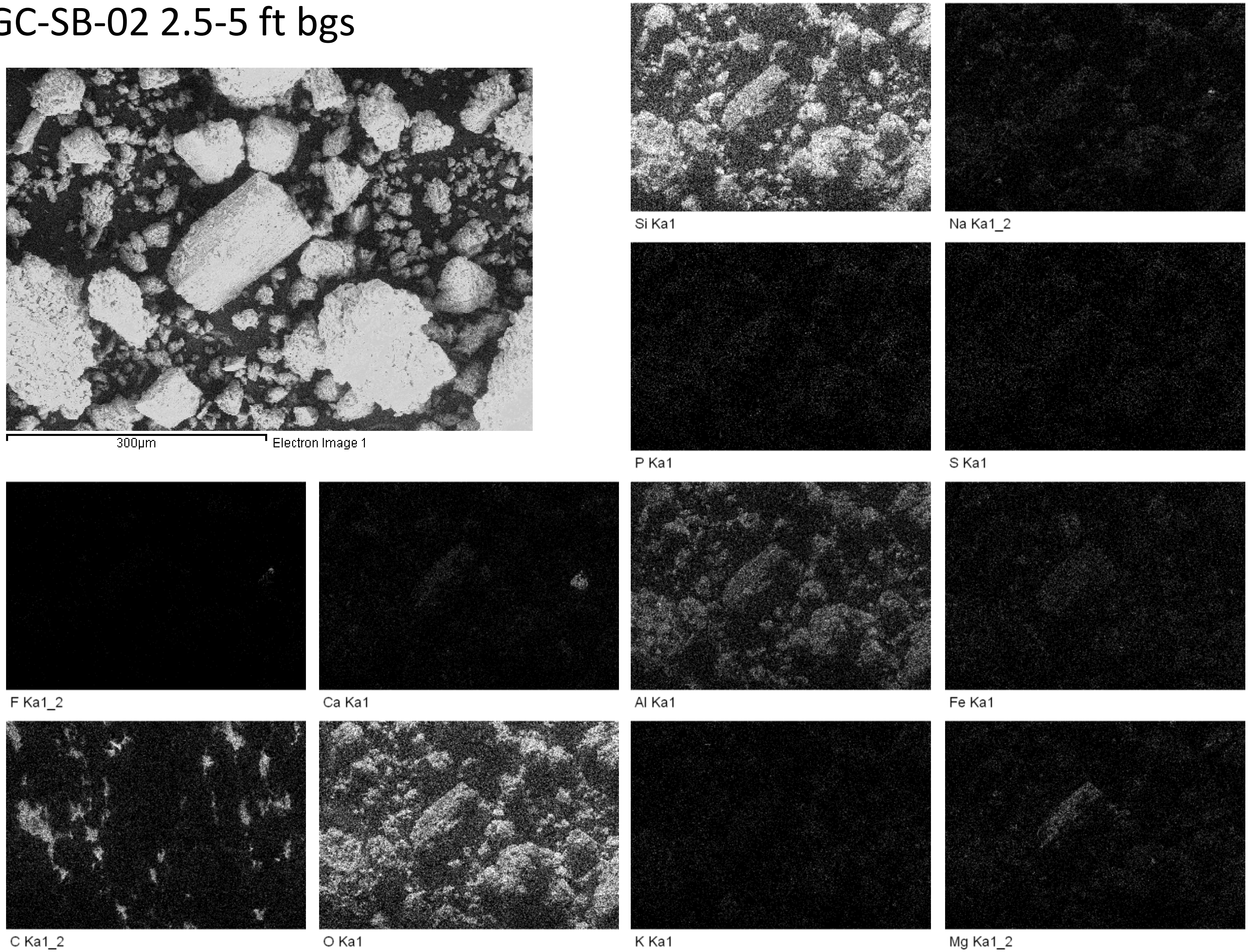

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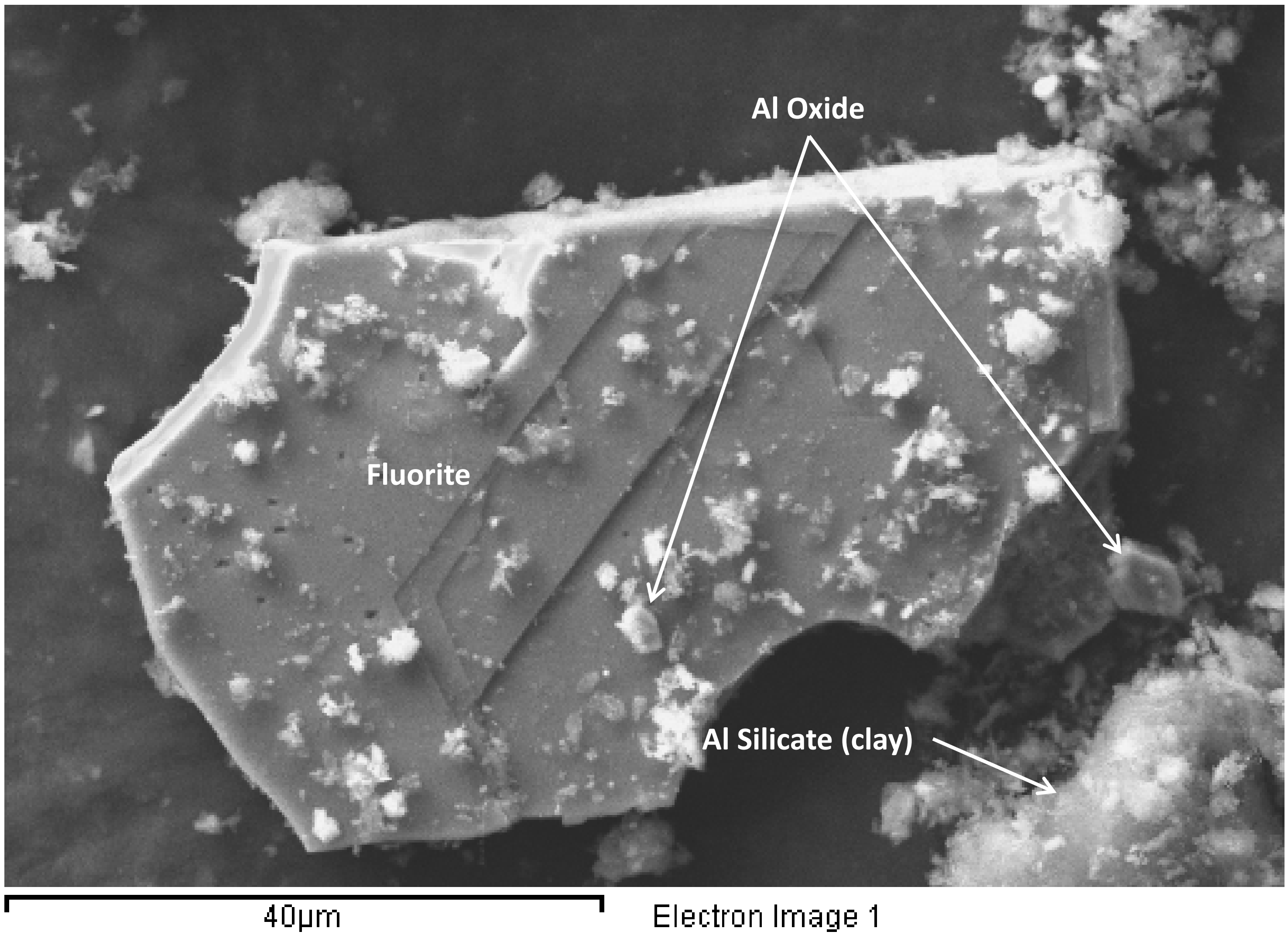

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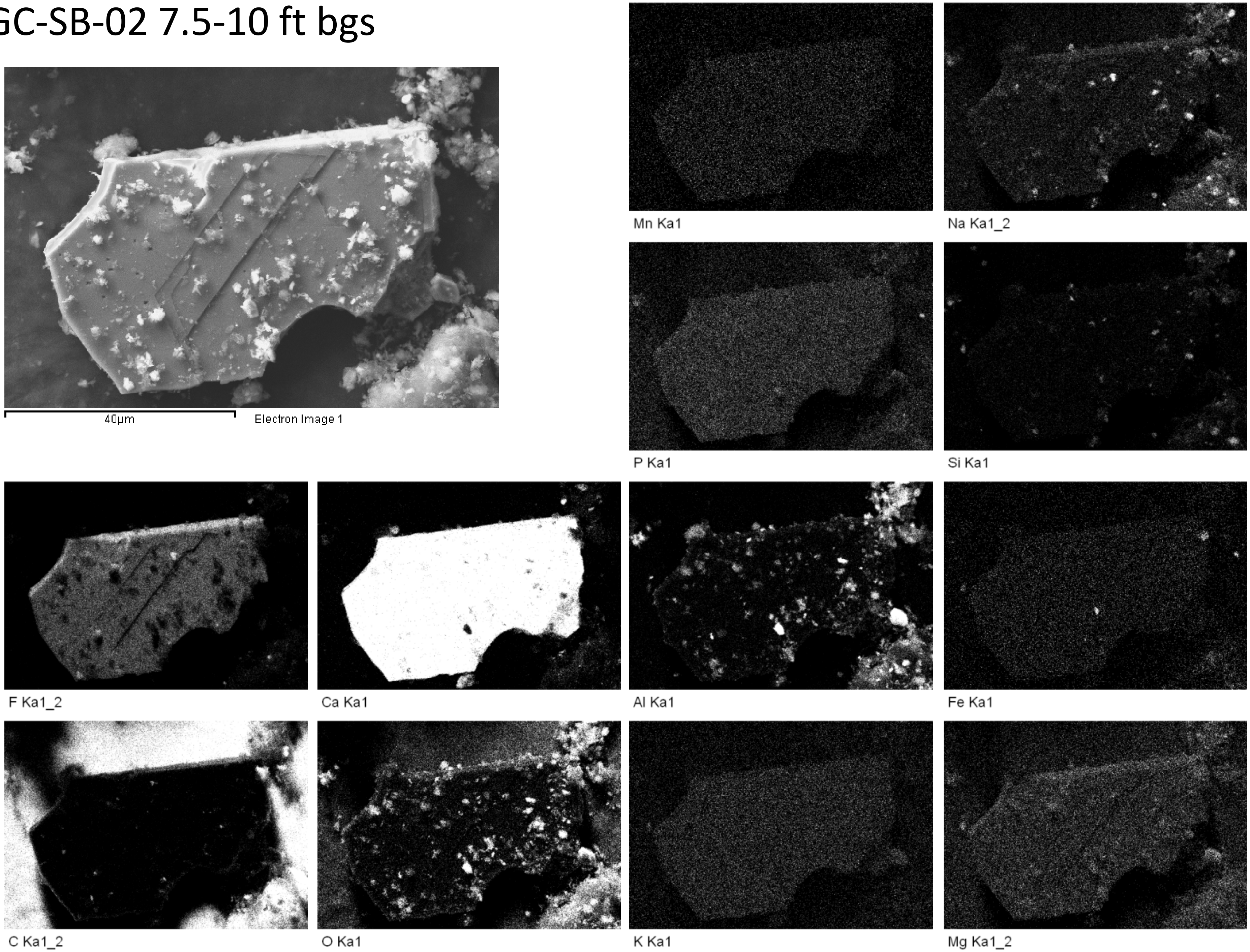

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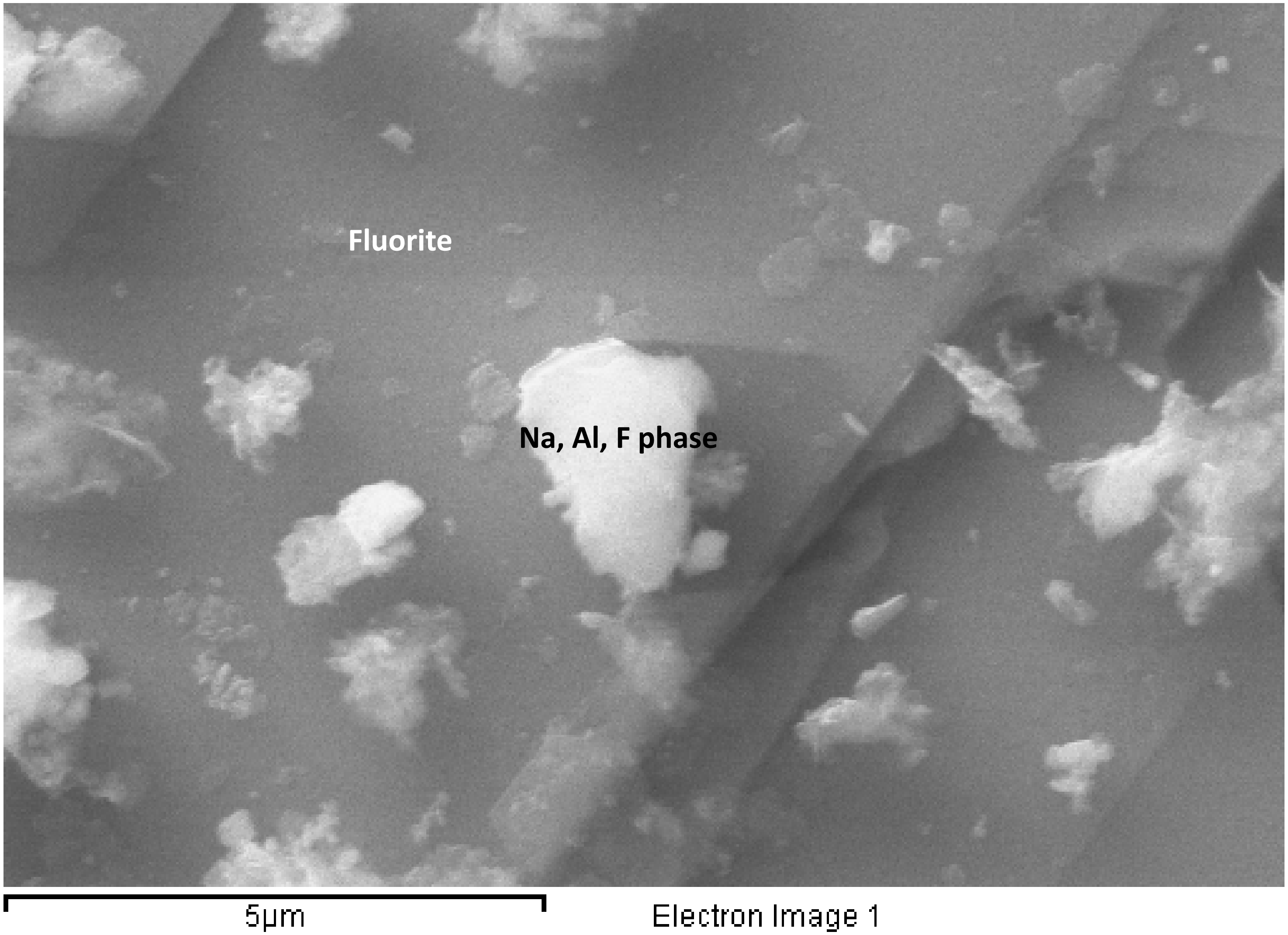

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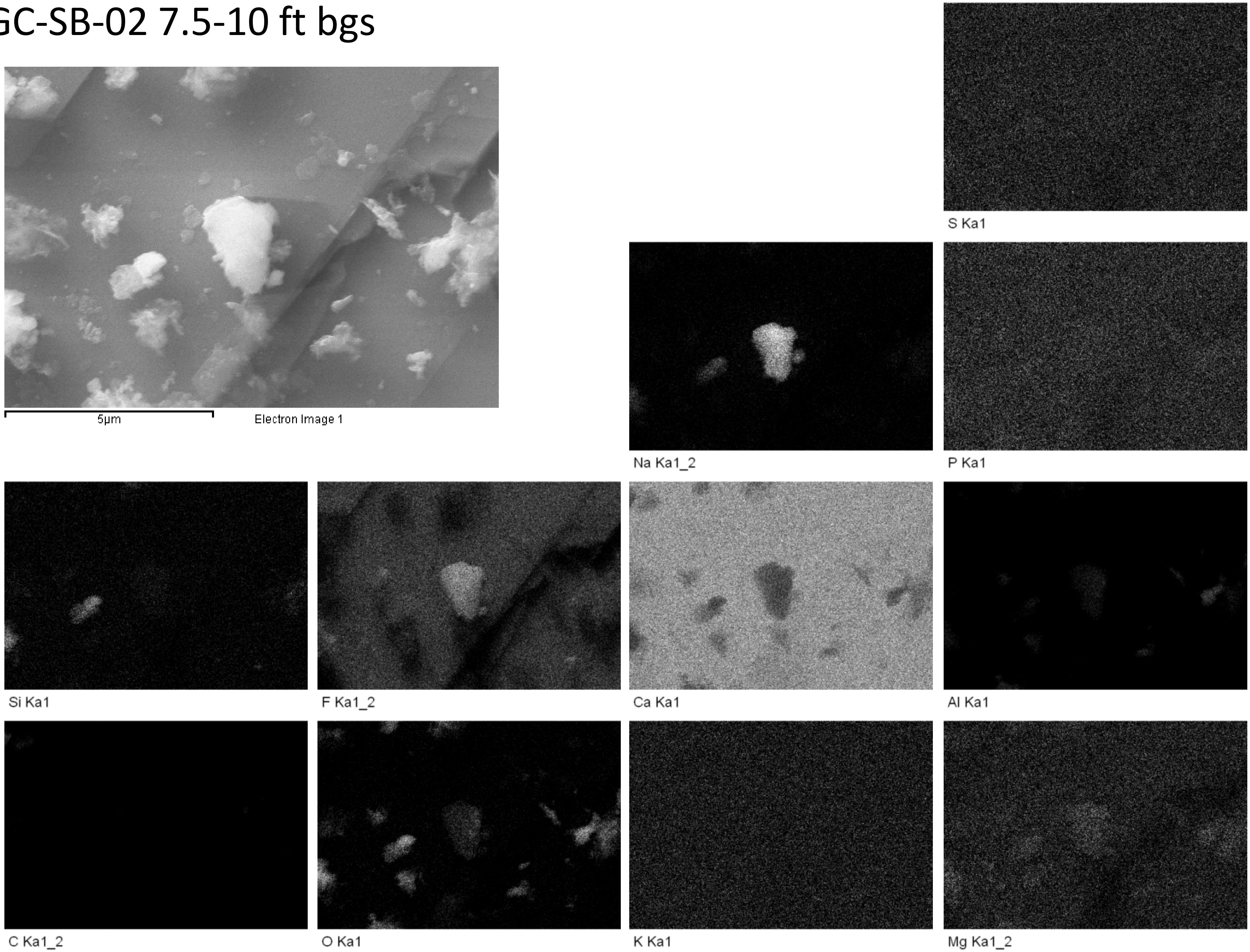

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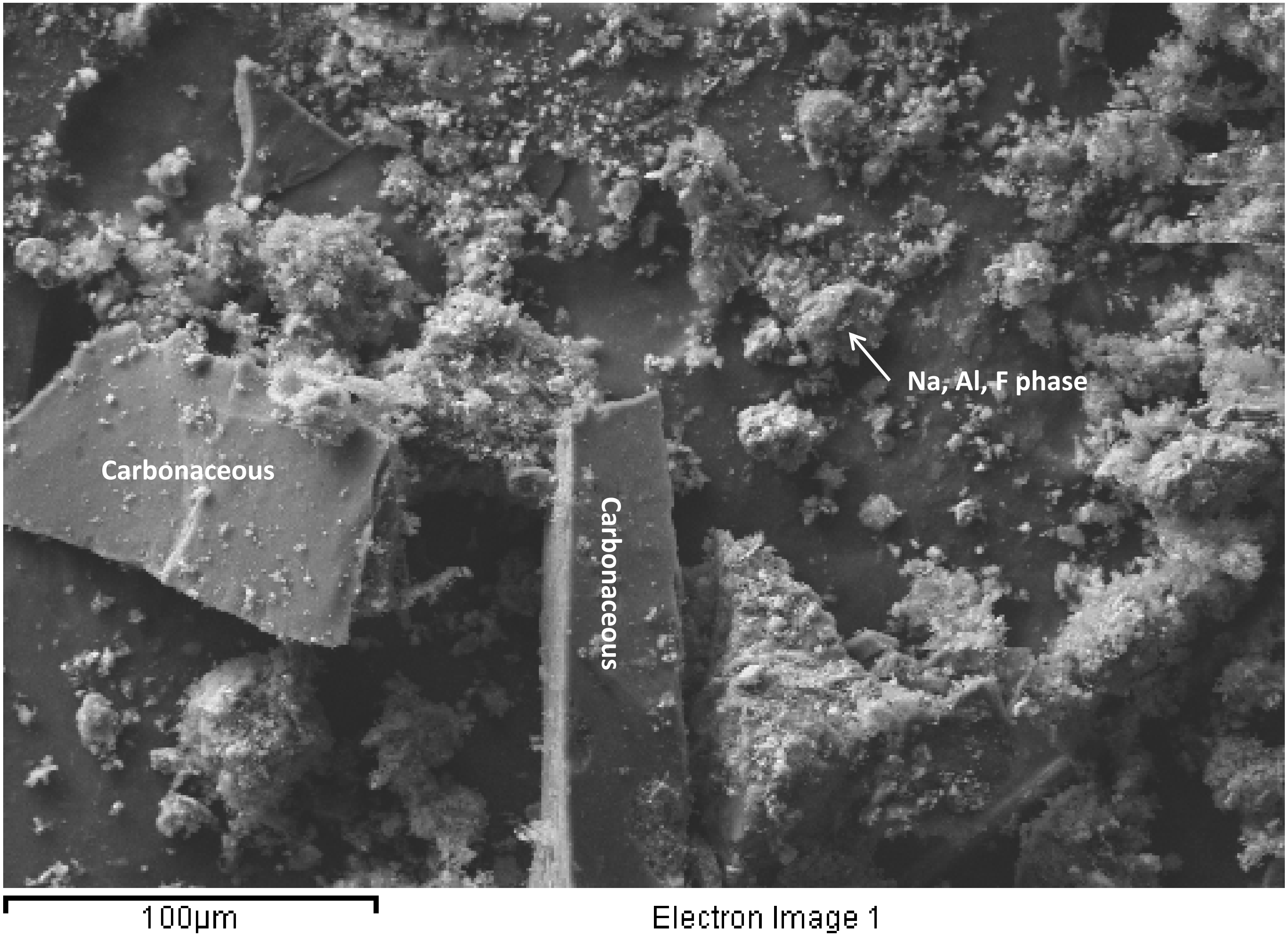

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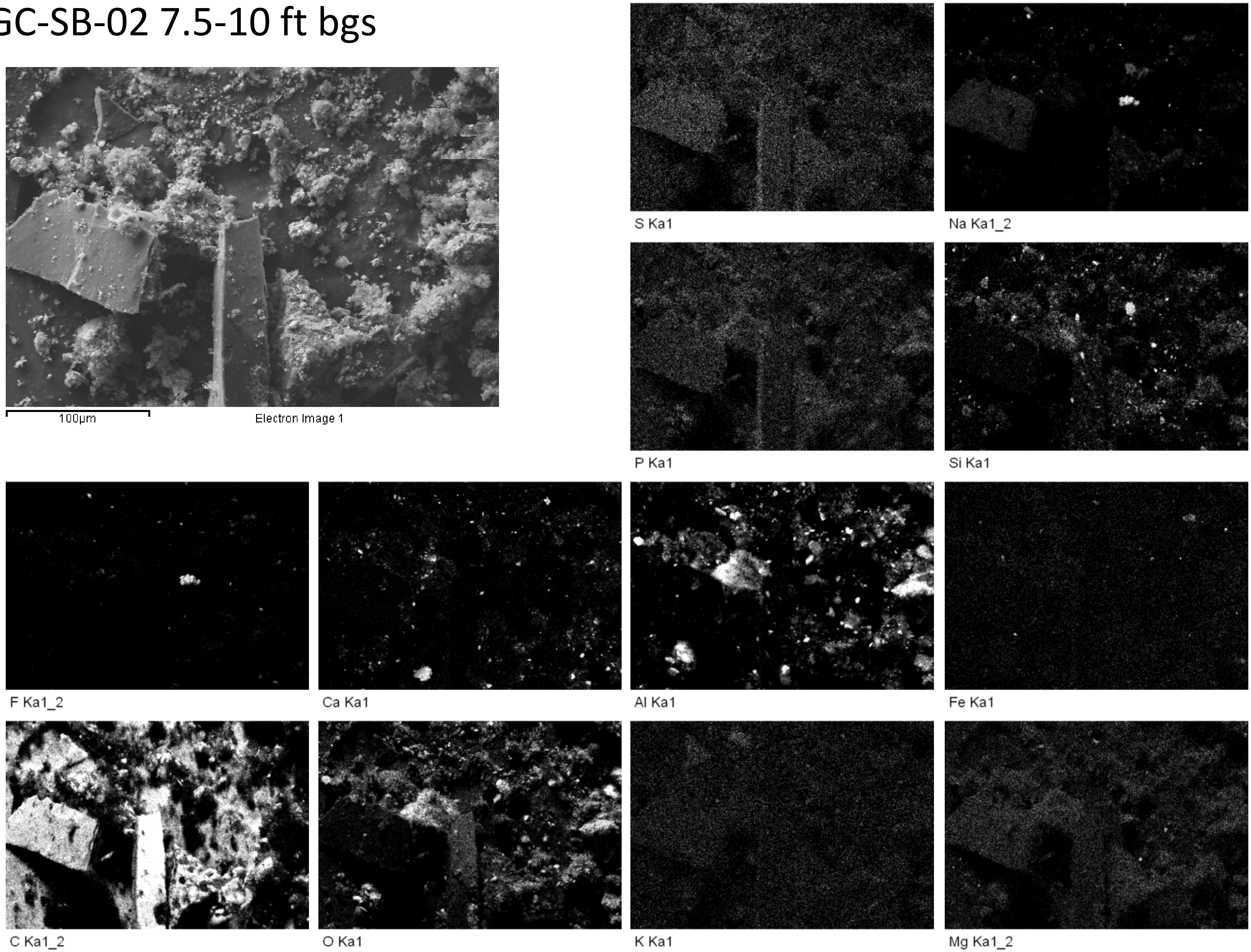

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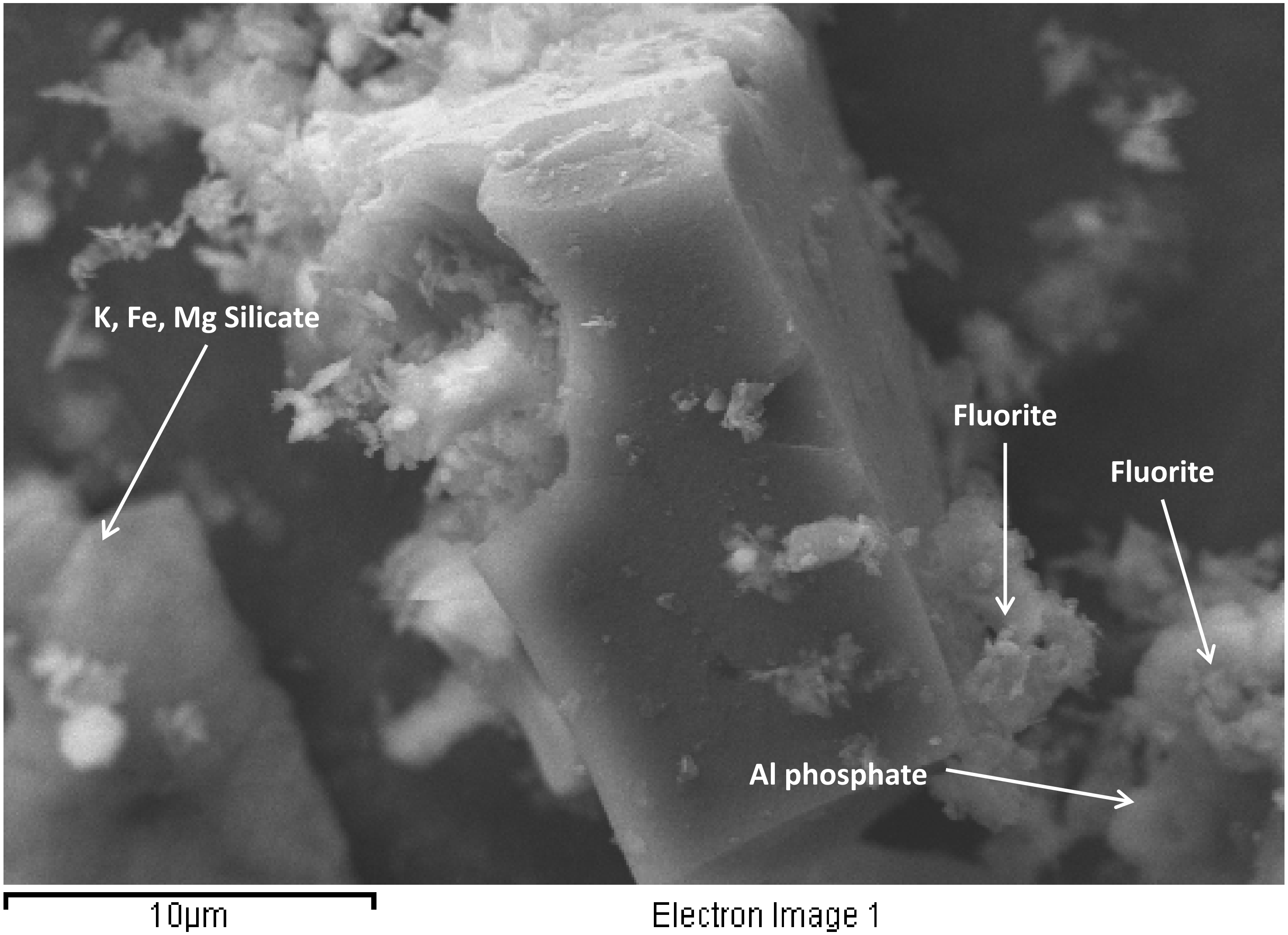

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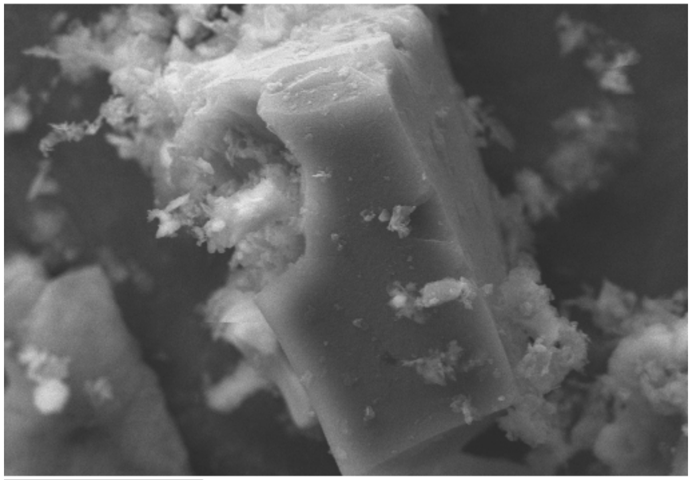
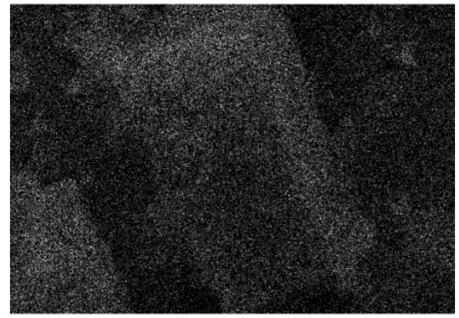
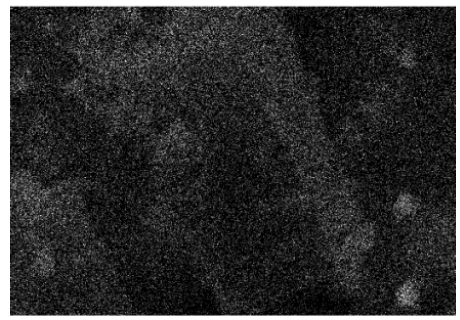


10µm Electron Image 1



S Ka1

Na Ka1_2



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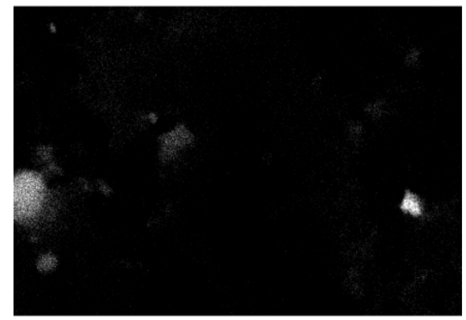

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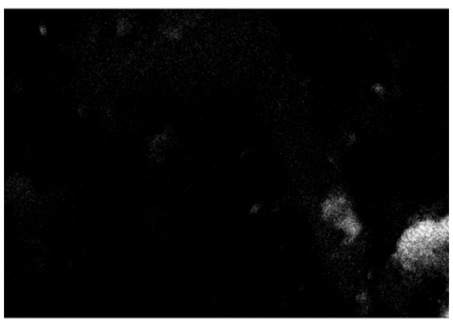

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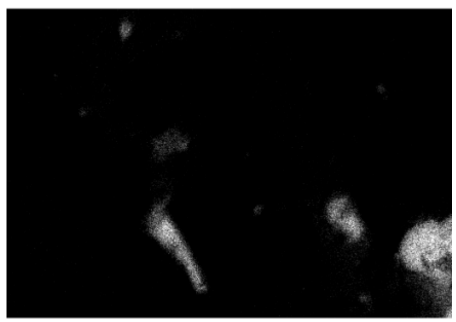
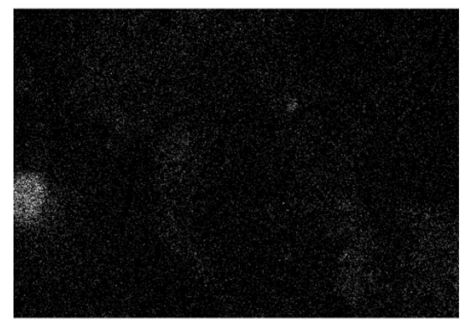


Ca Ka1

Al Ka1



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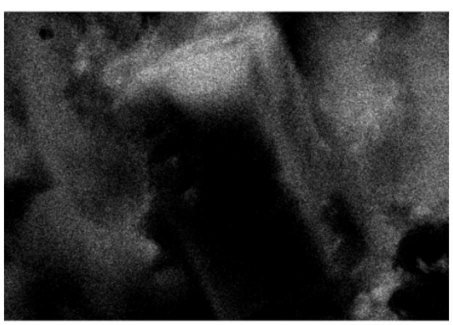

C Ka1_2

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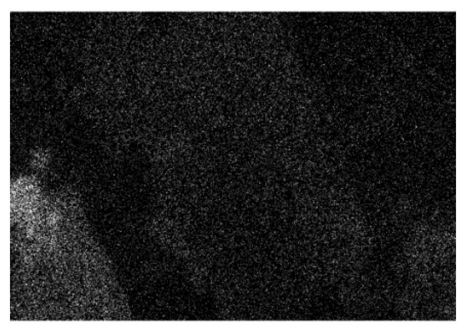

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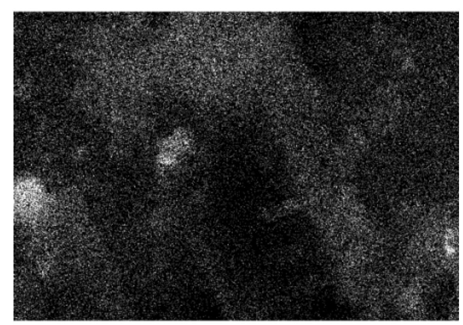
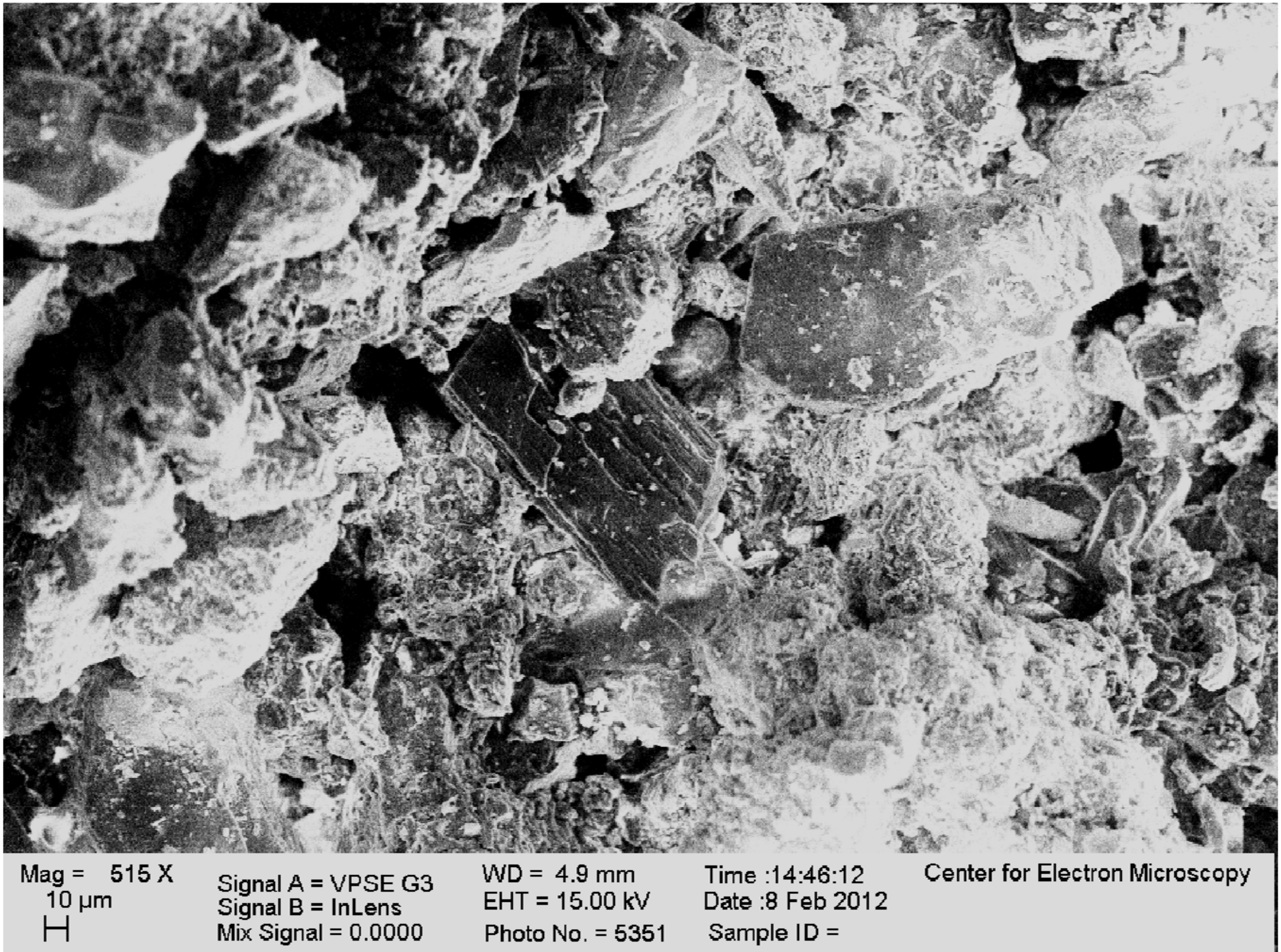
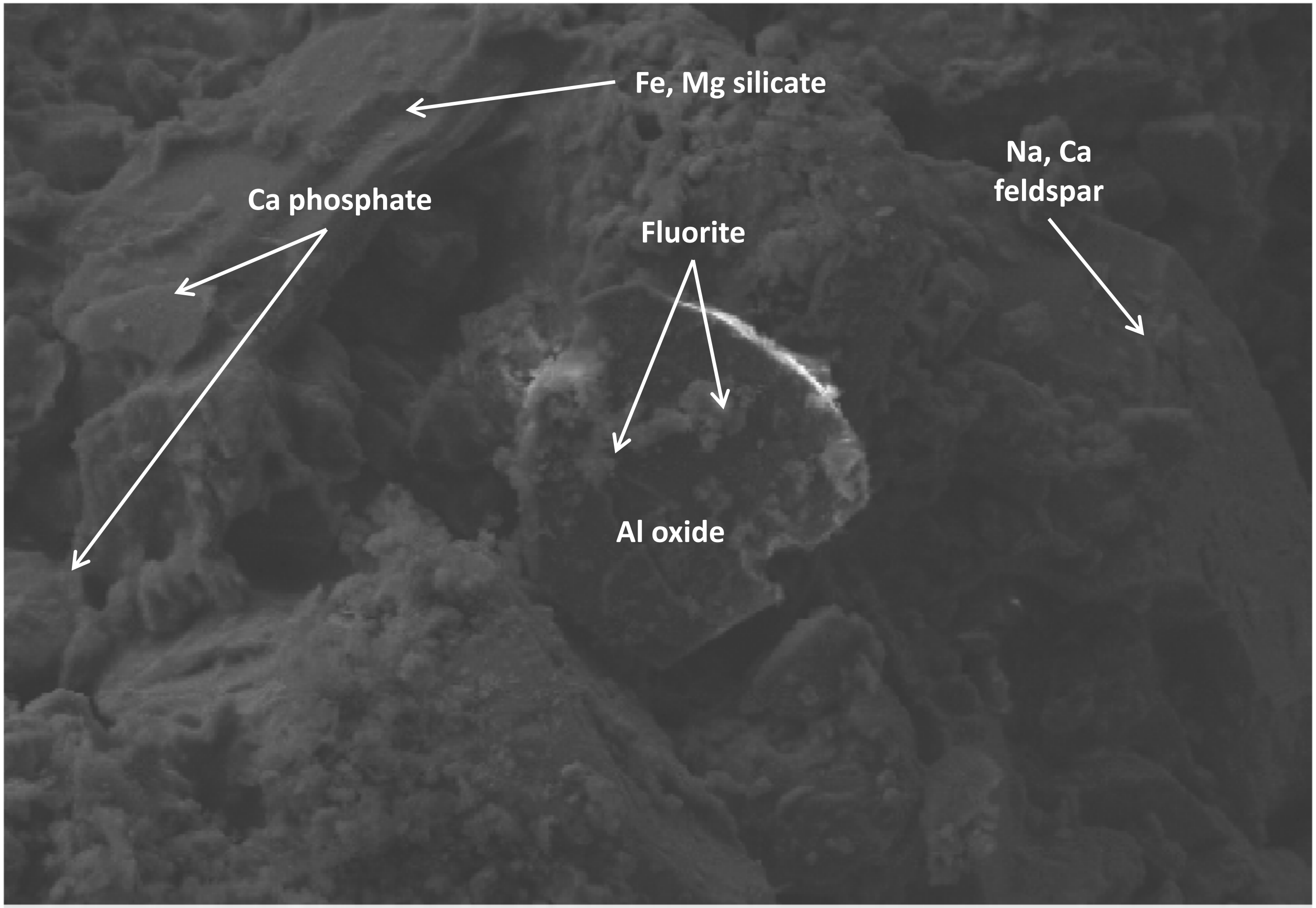


Mg Ka1_2

GC-SB-02 12.5-15 ft bgs

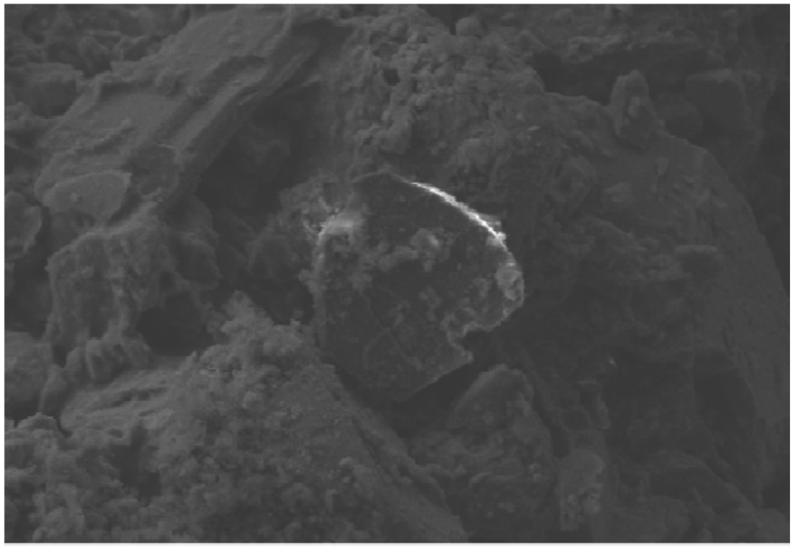


GC-SB-02 12.5-15 ft bgs

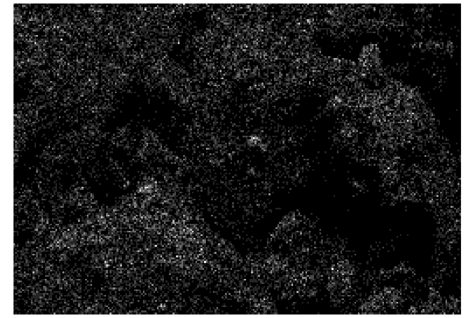


Electron Image 1

GC-SB-02 12.5-15 ft bgs

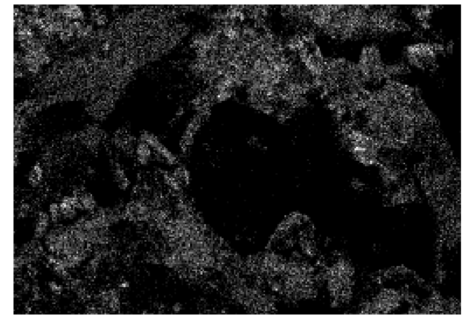


Electron Image 1



Na Ka1_2

P Ka1



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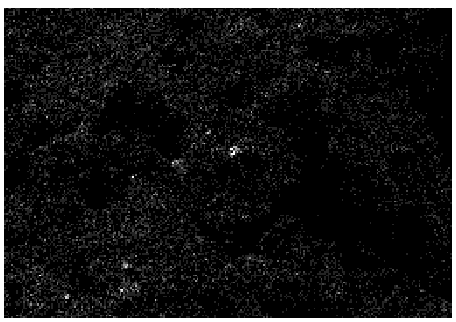
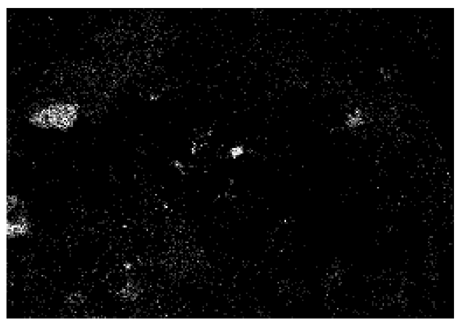


F Ka1_2



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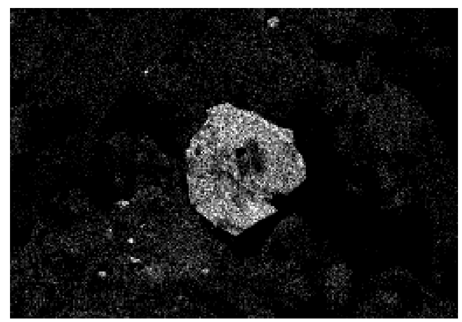

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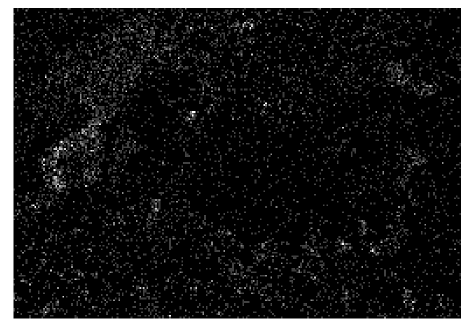

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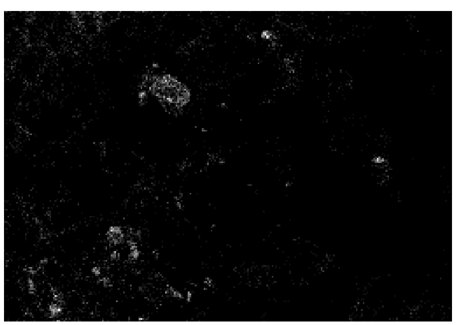

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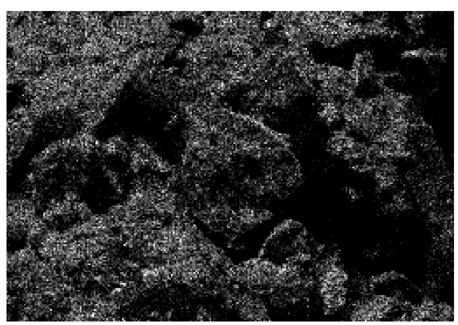

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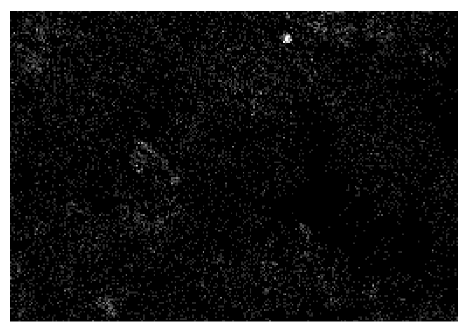

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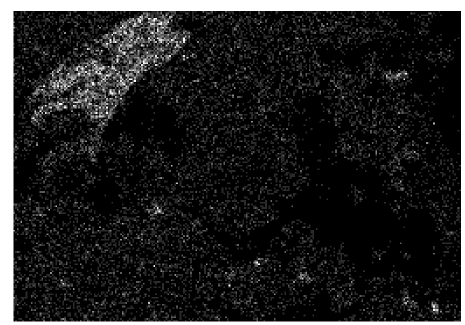

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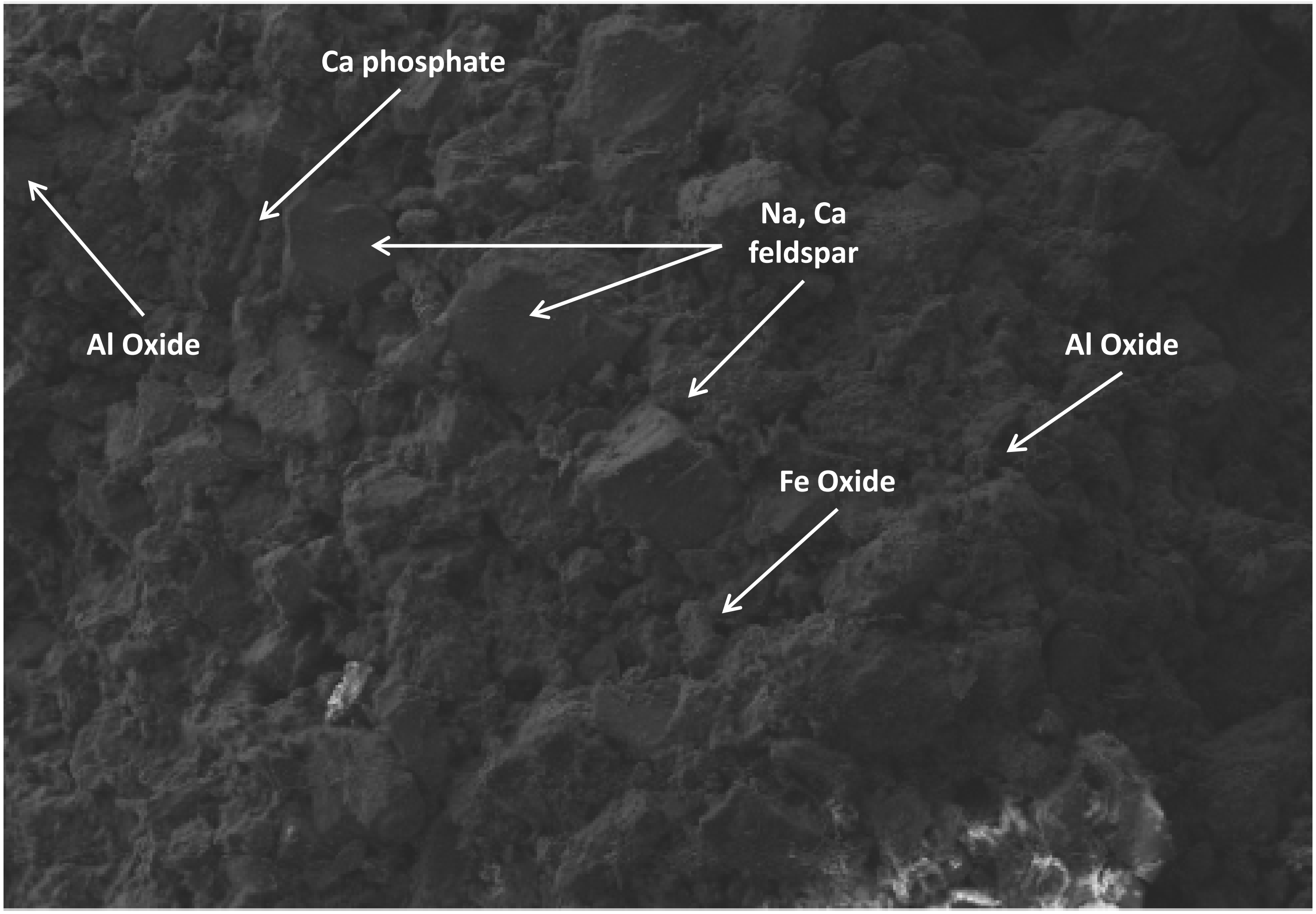
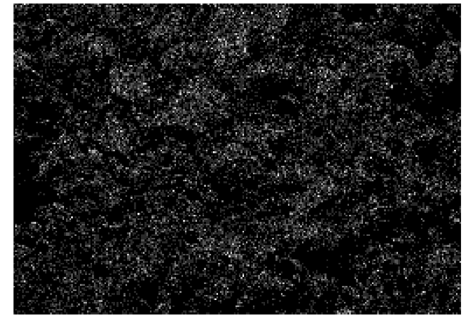
GC-SB-02 12.5-15 ft bgs



Electron Image 1

GC-SB-02 12.5-15 ft bgs

Electron Image 1



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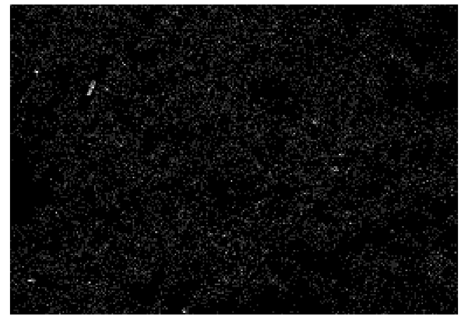

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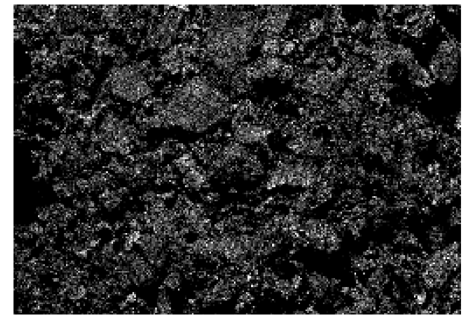

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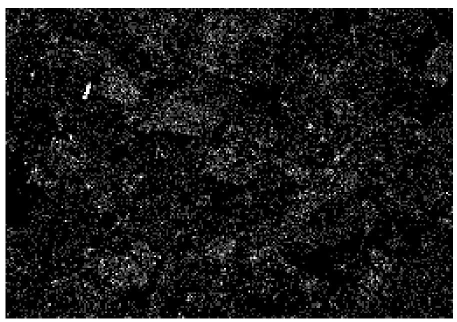
F Ka1_2



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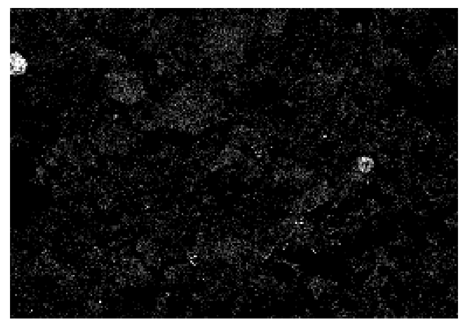

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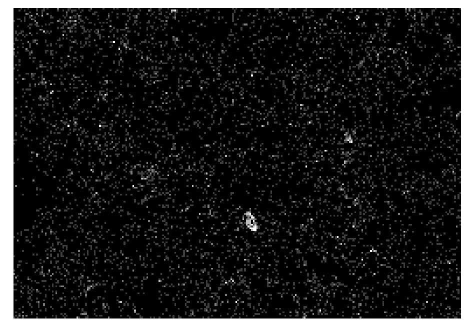

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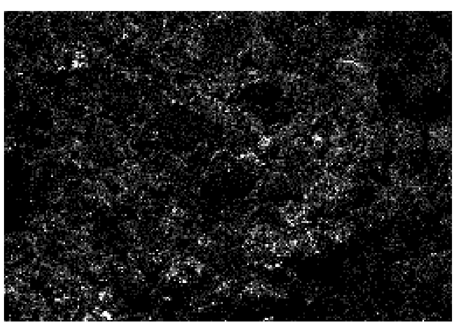

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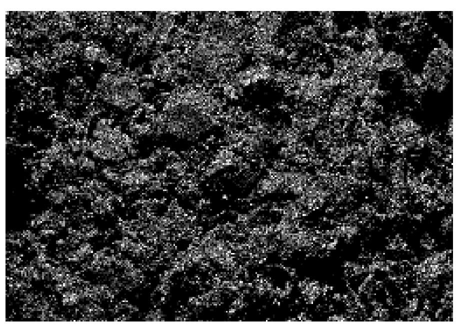

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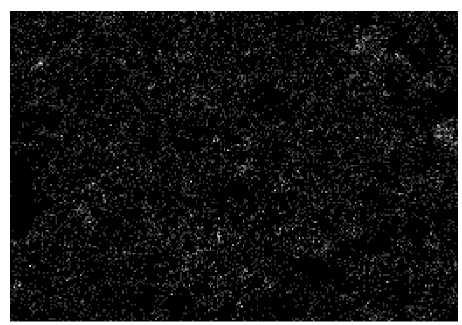

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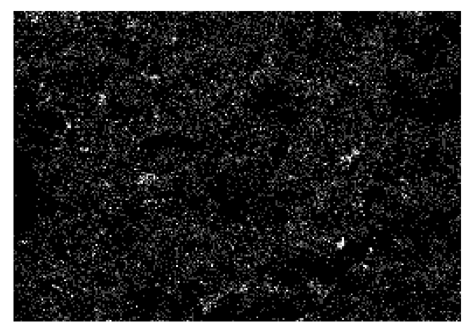

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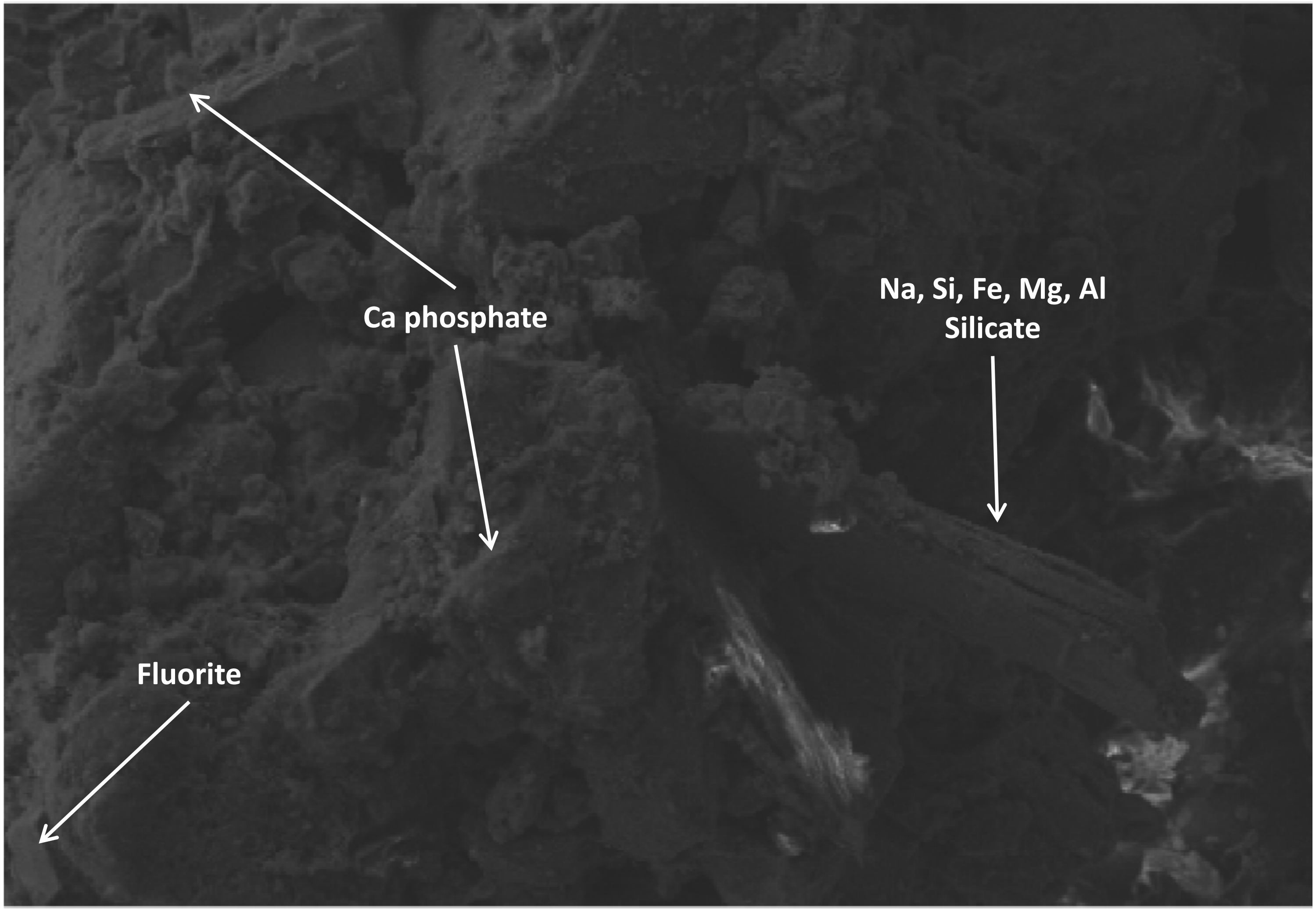

Electron Image 1

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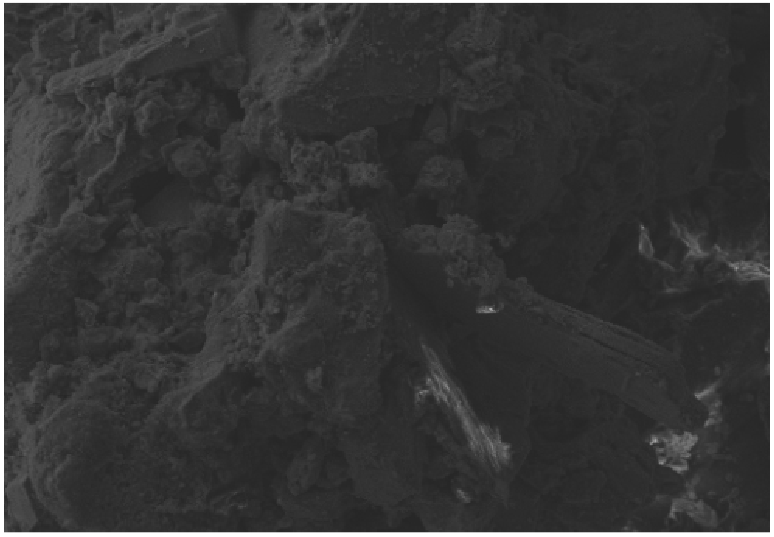

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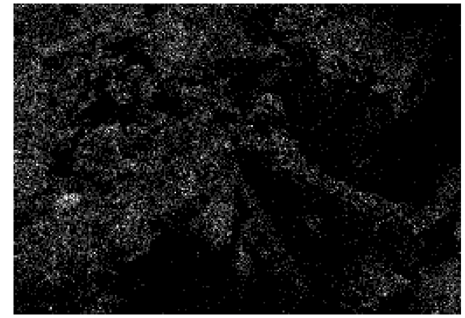

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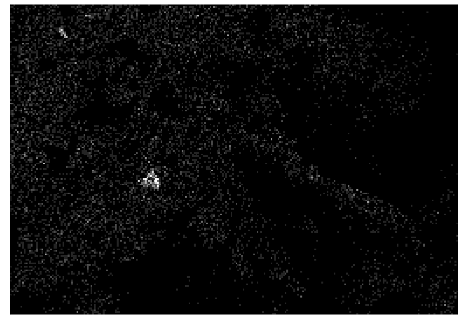

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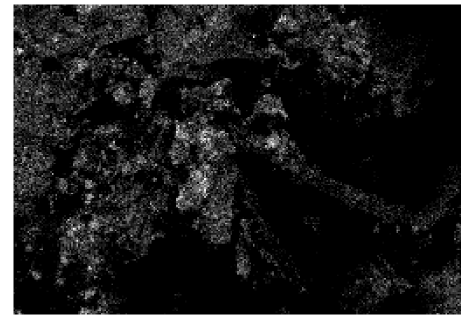

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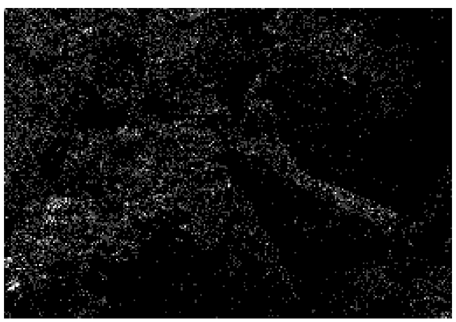

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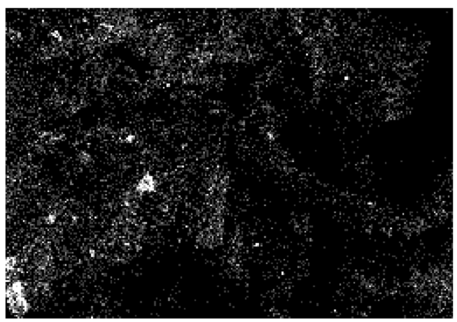

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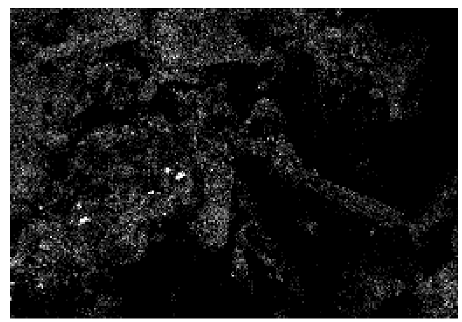

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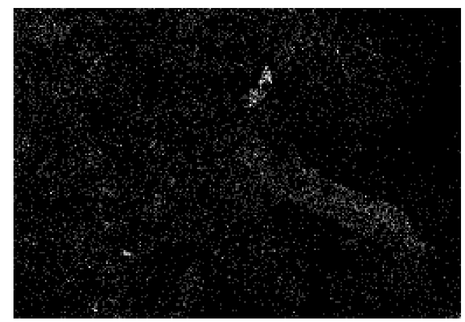

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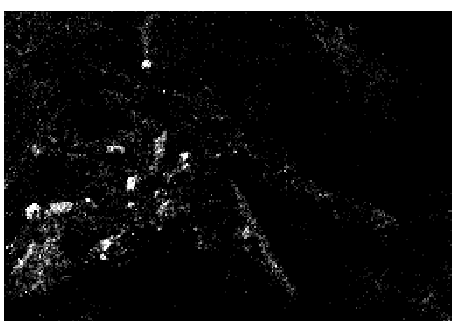

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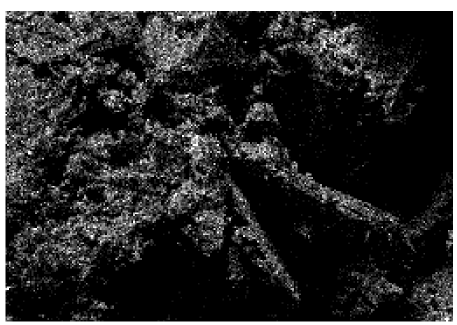

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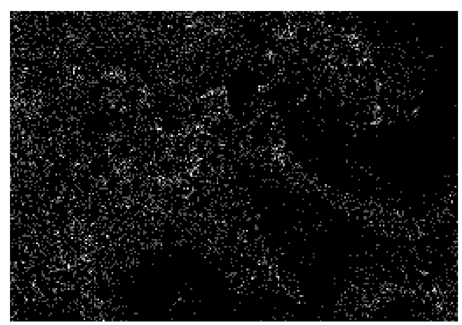

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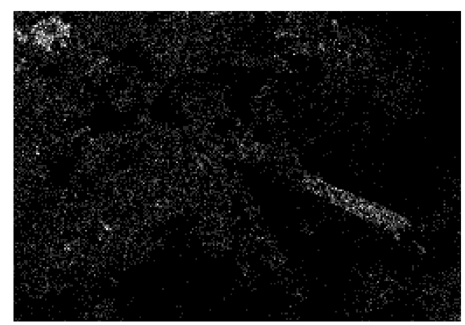
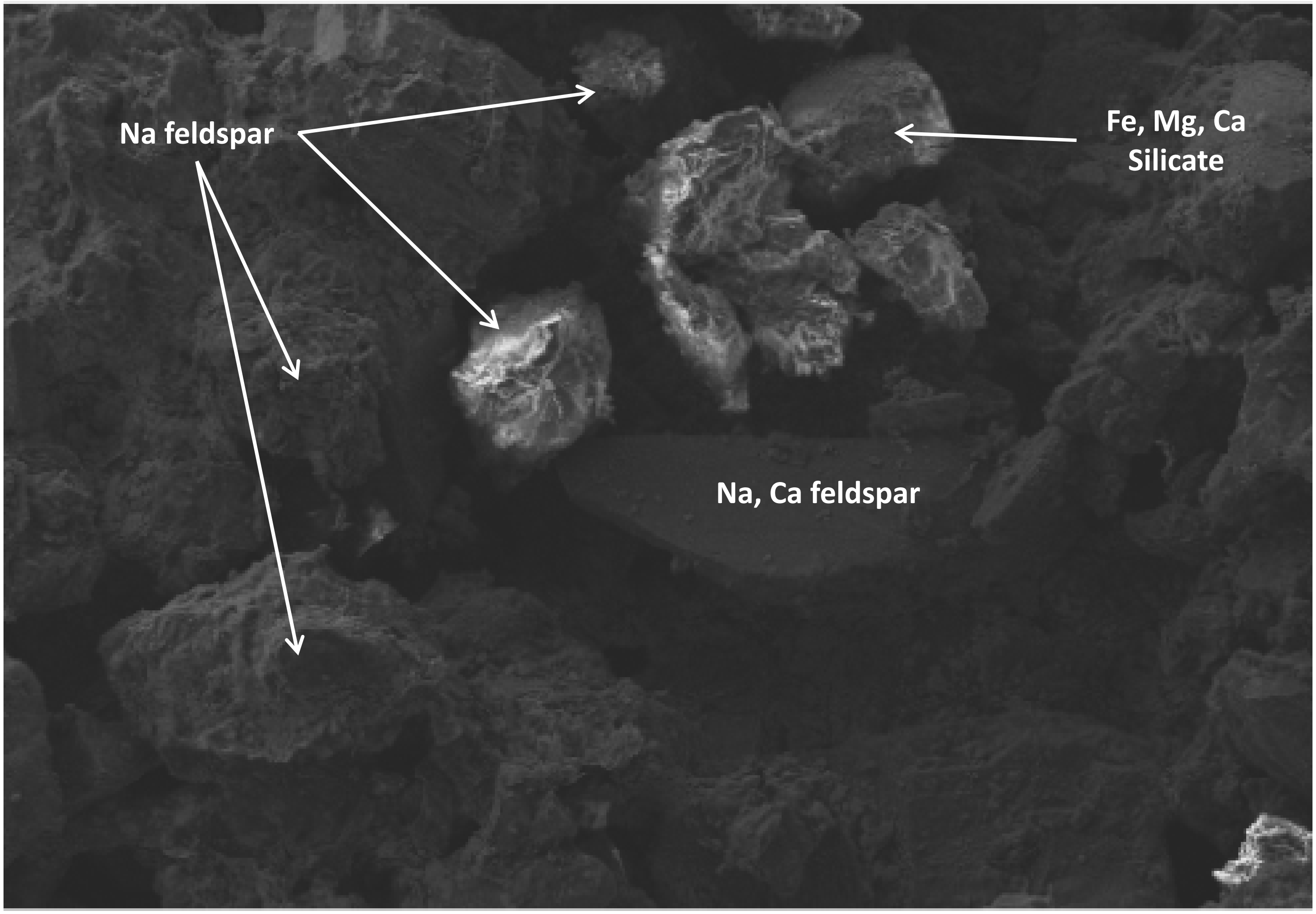


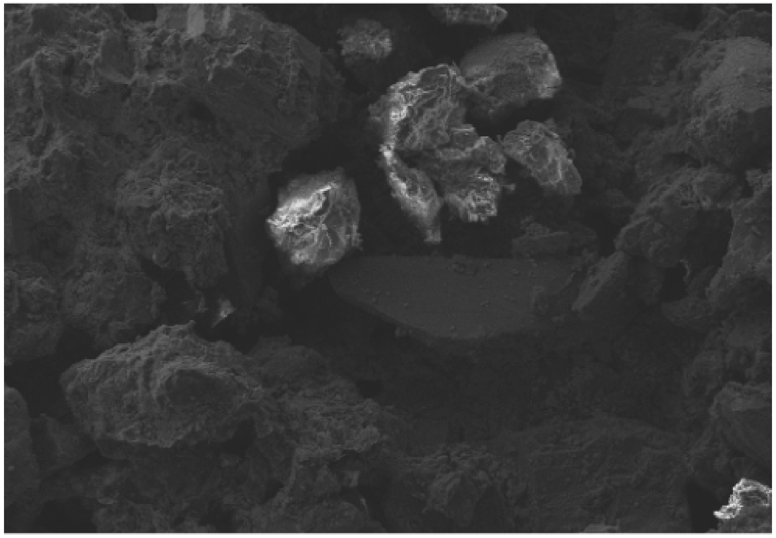
Mg Ka1_2

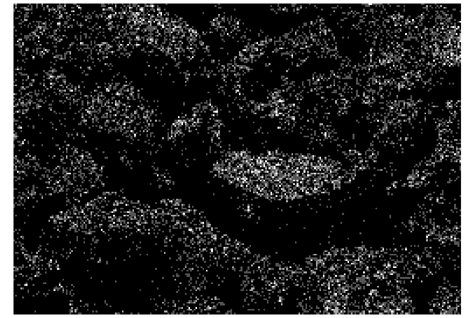
GC-SB-02 12.5-15 ft bgs



Electron Image 1

GC-SB-02 12.5-15 ft bgs


Electron Image 1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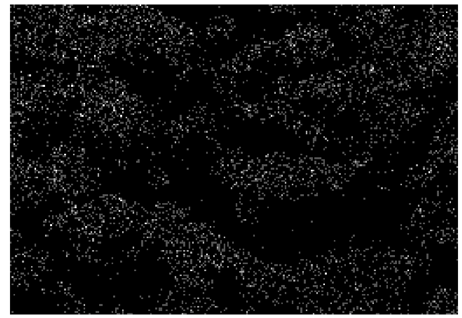
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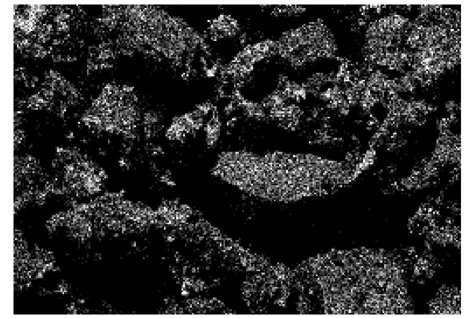
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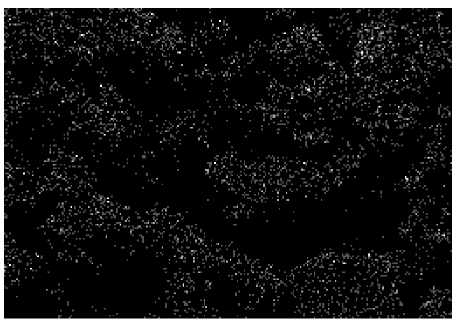
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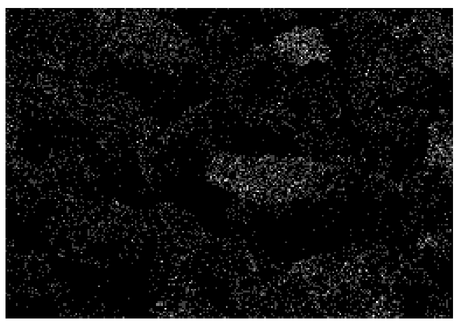
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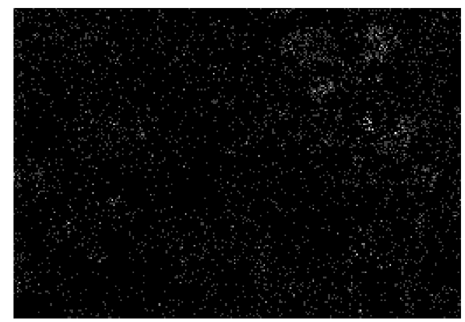
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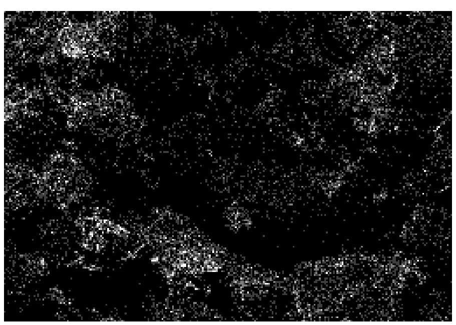
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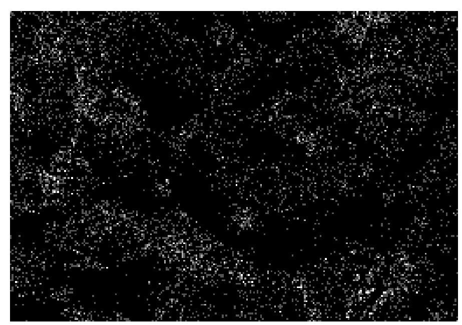
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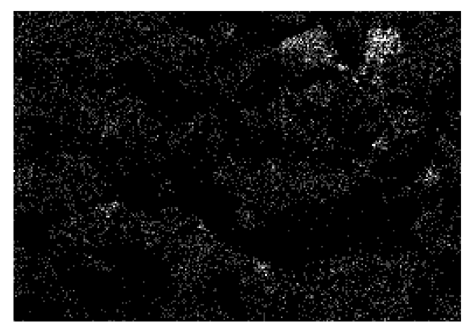
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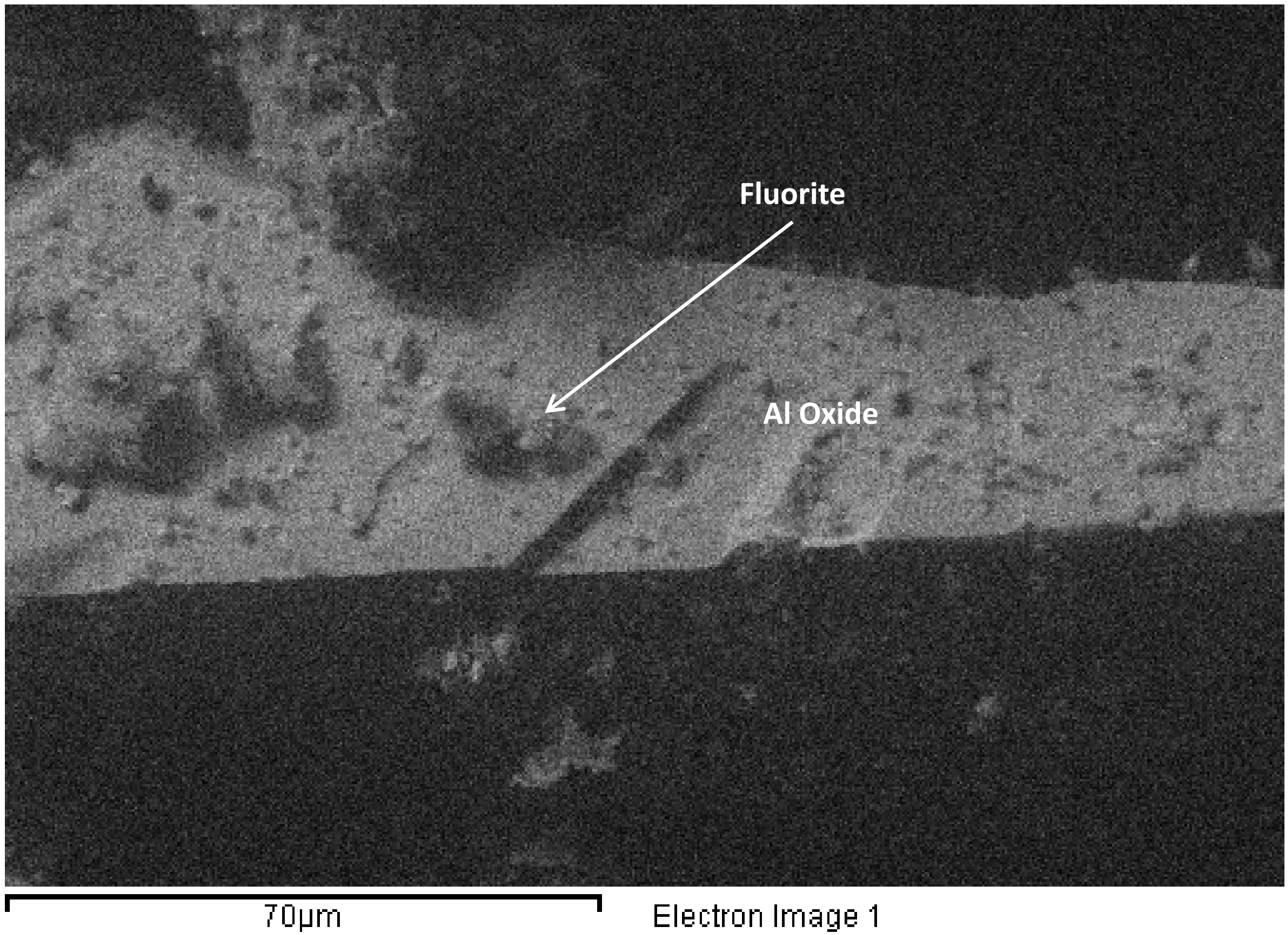

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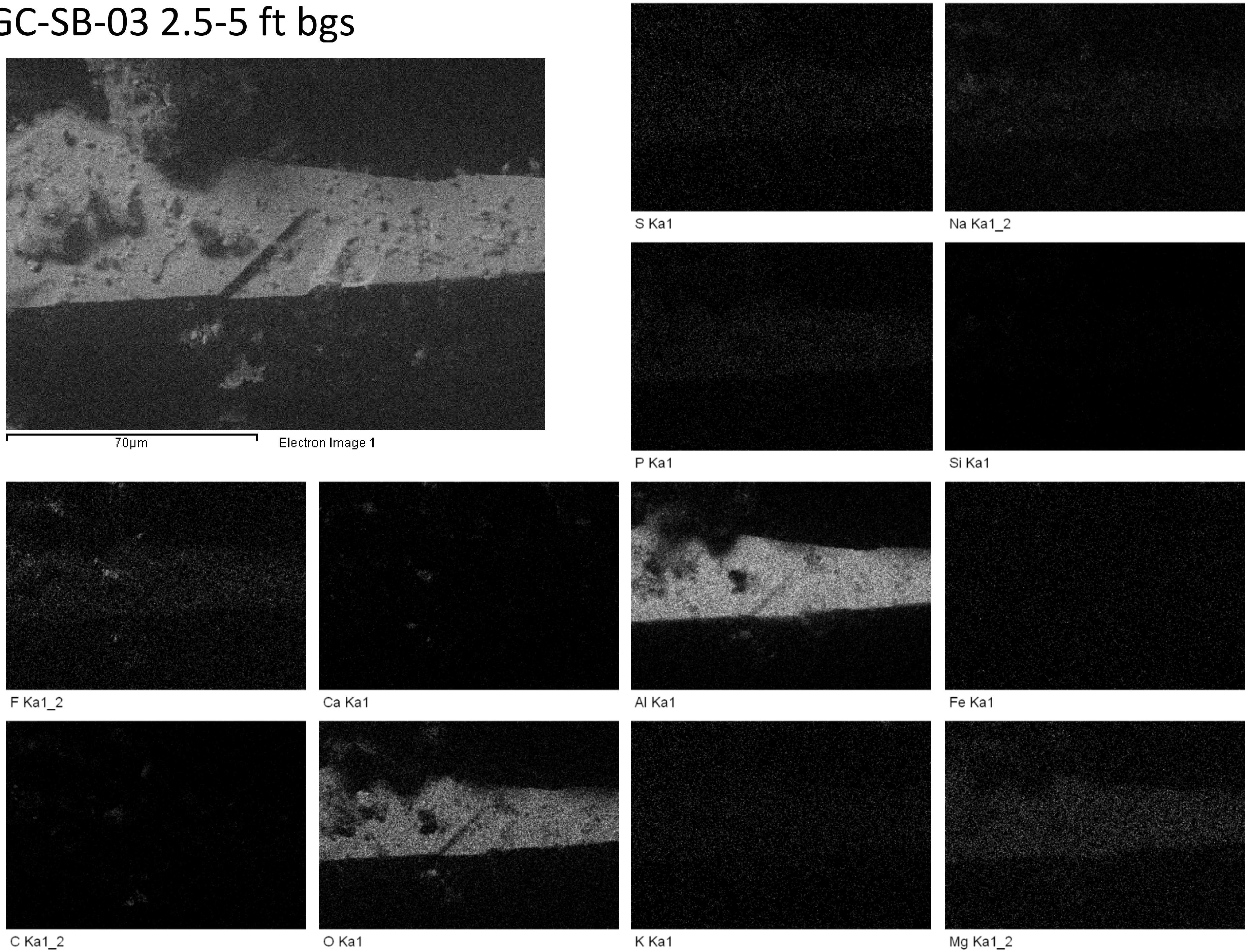

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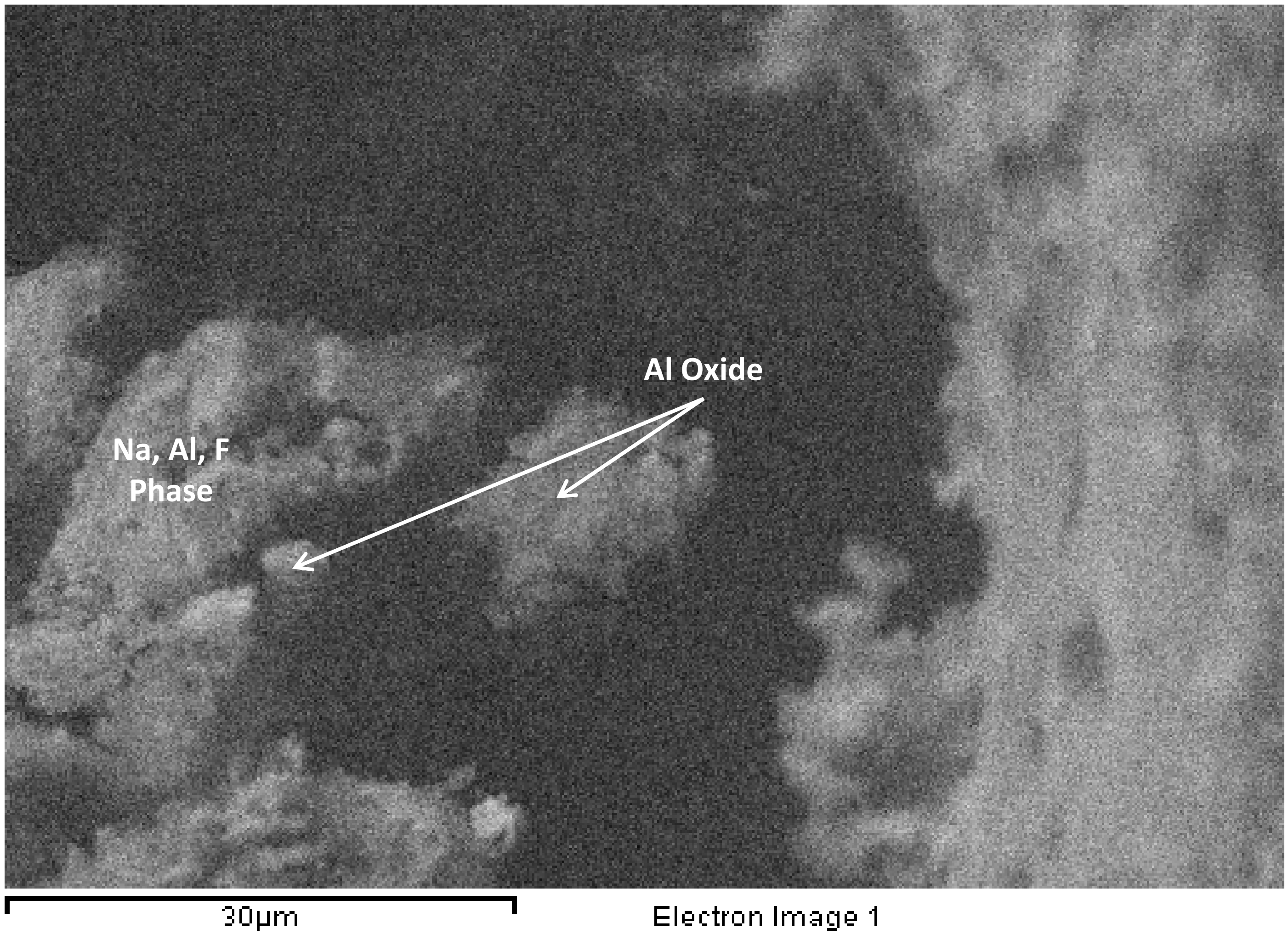

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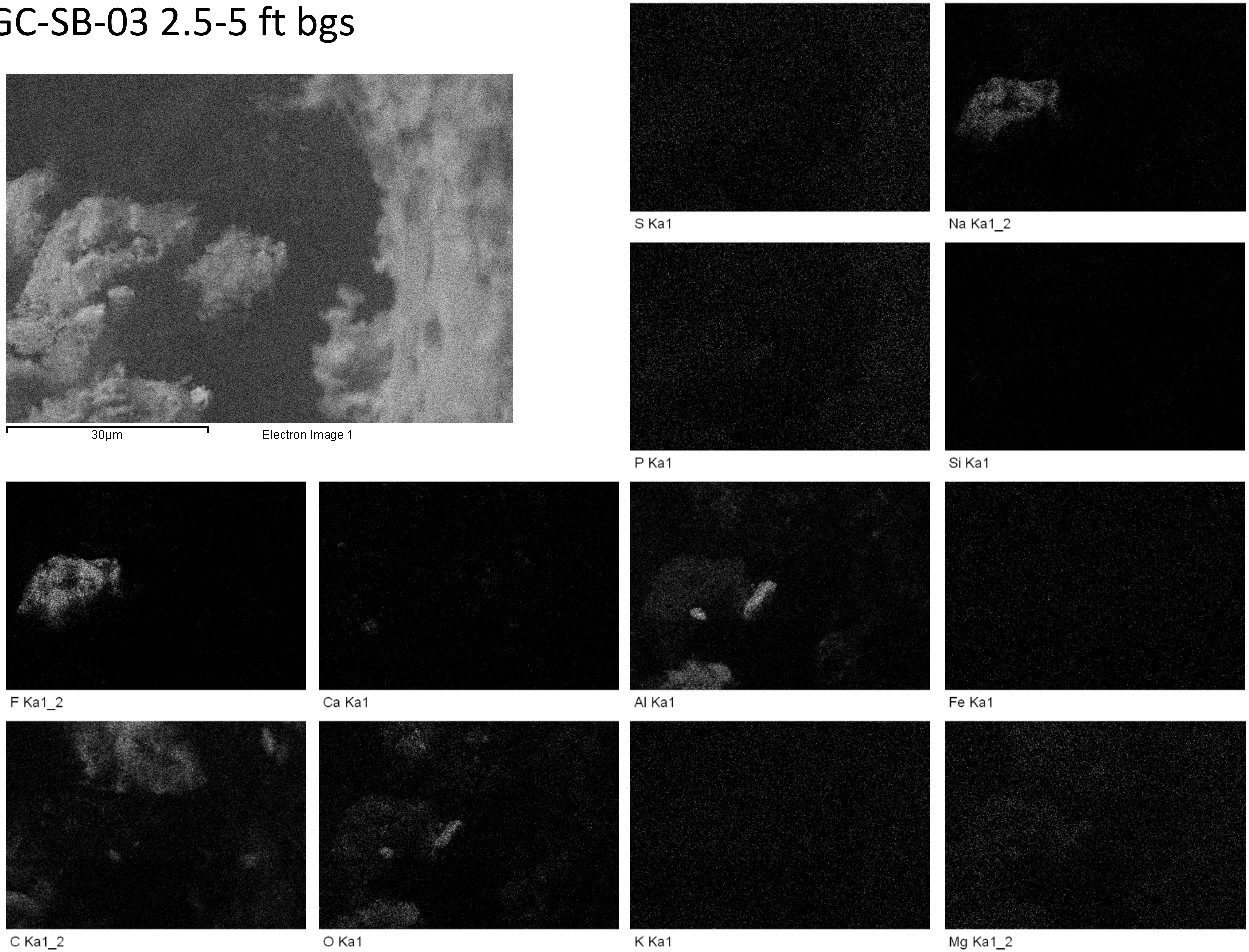

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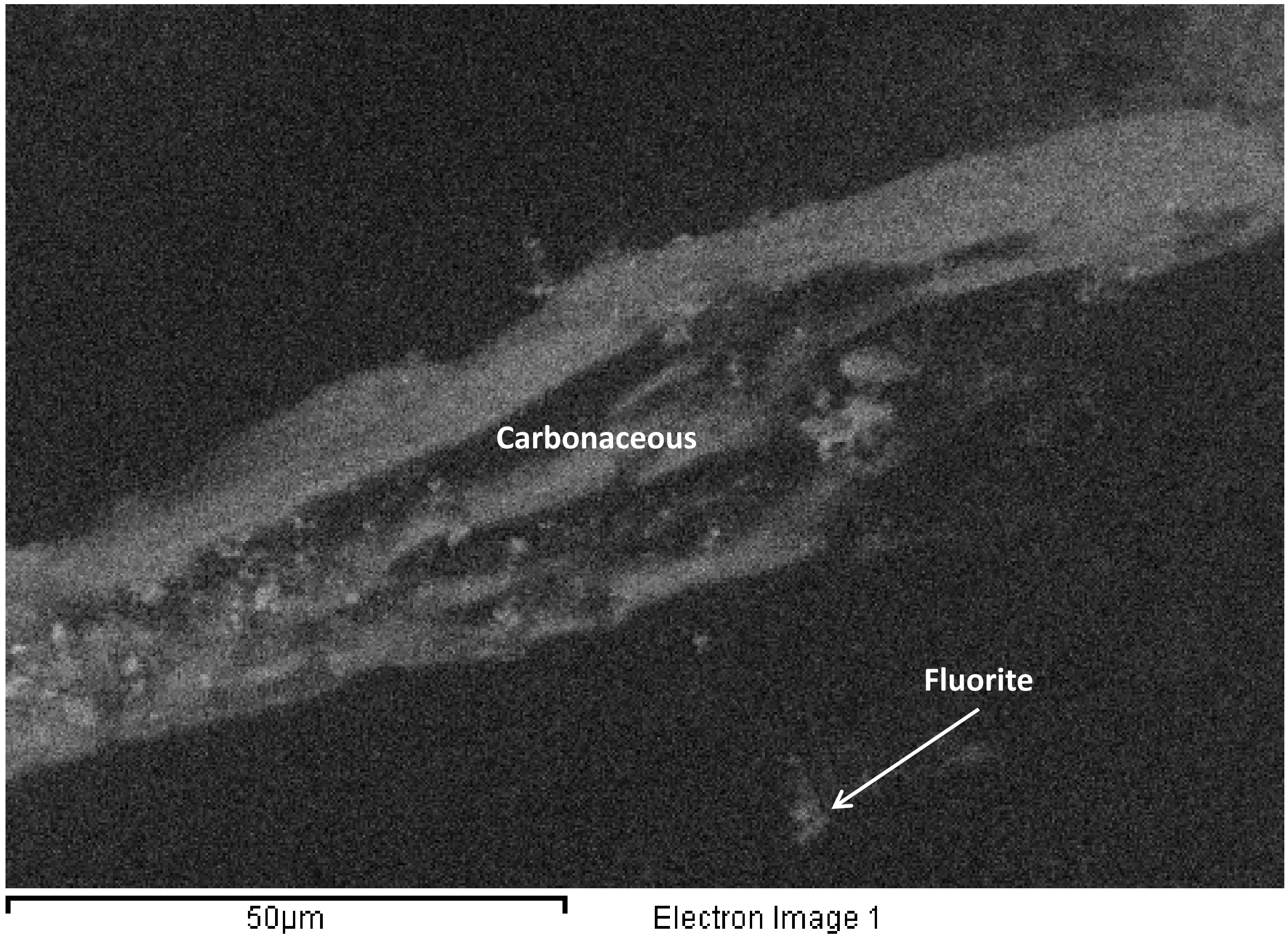

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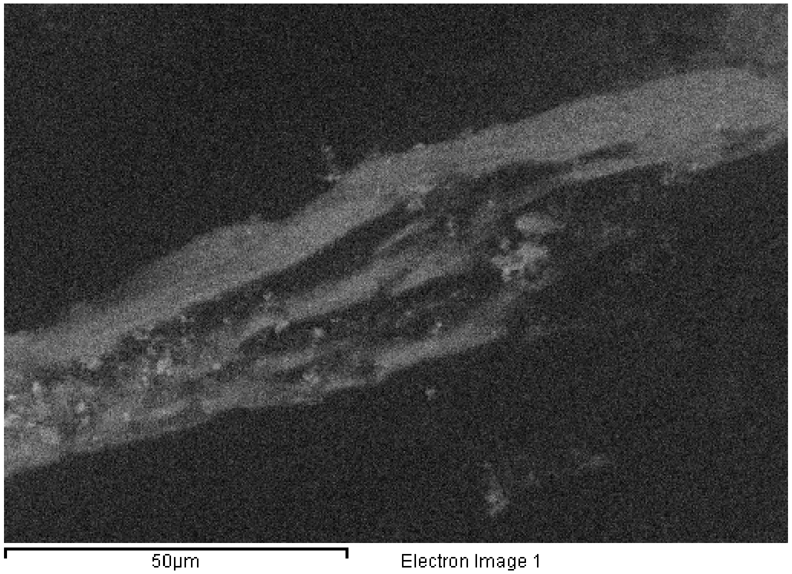

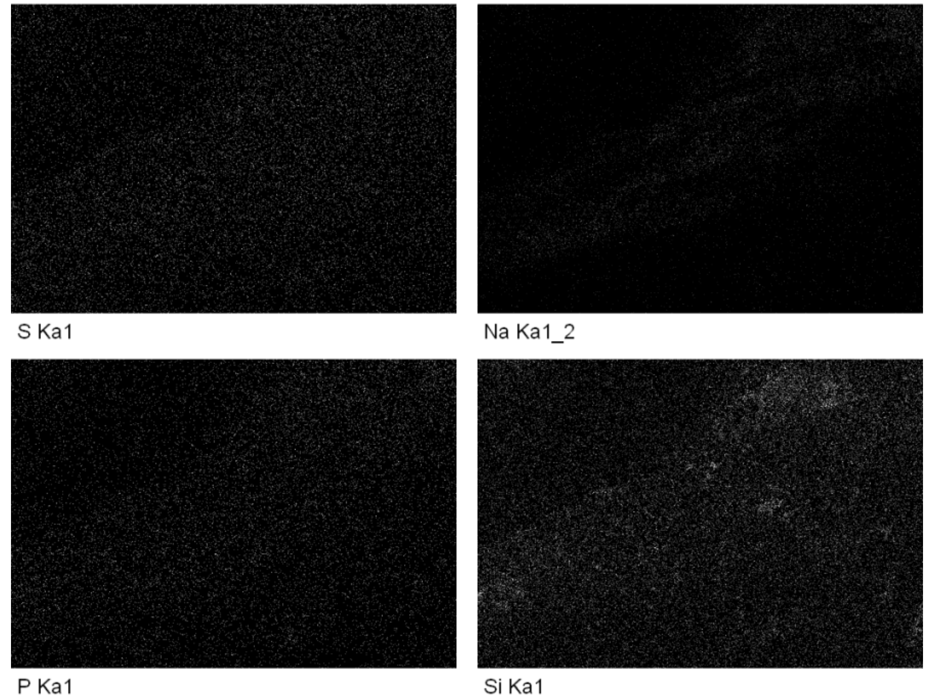

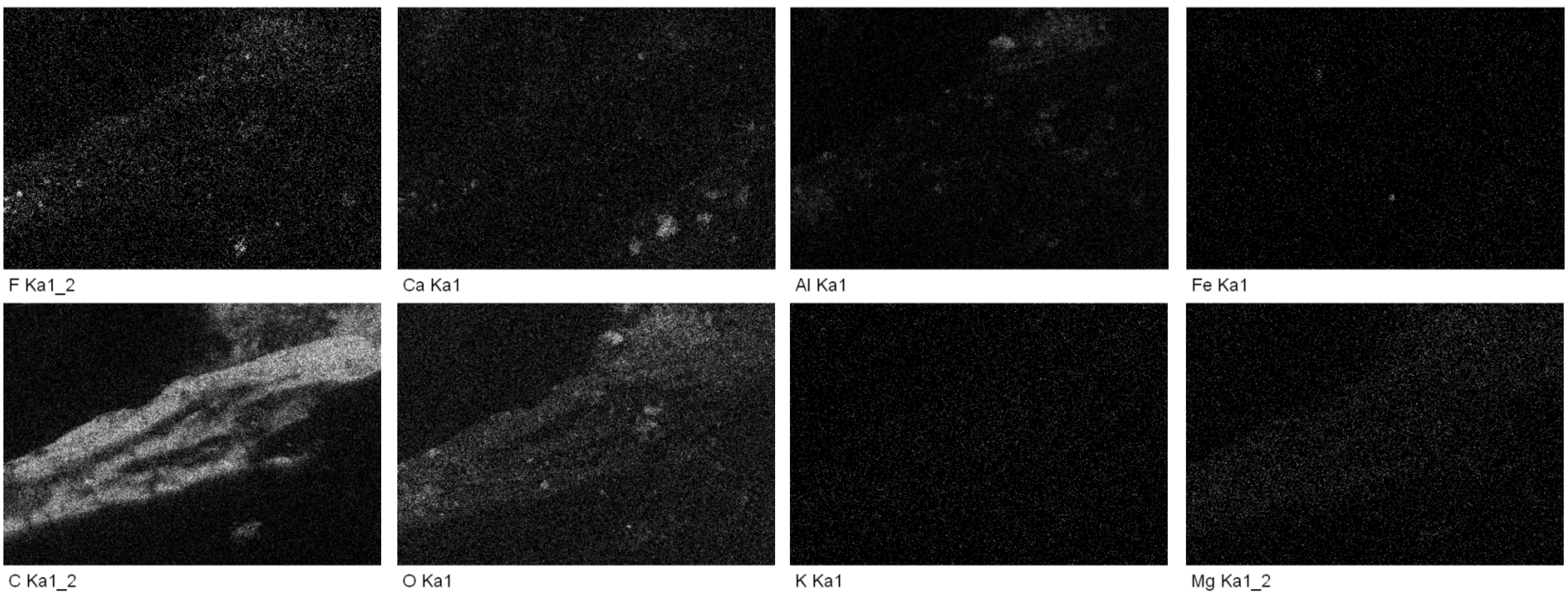

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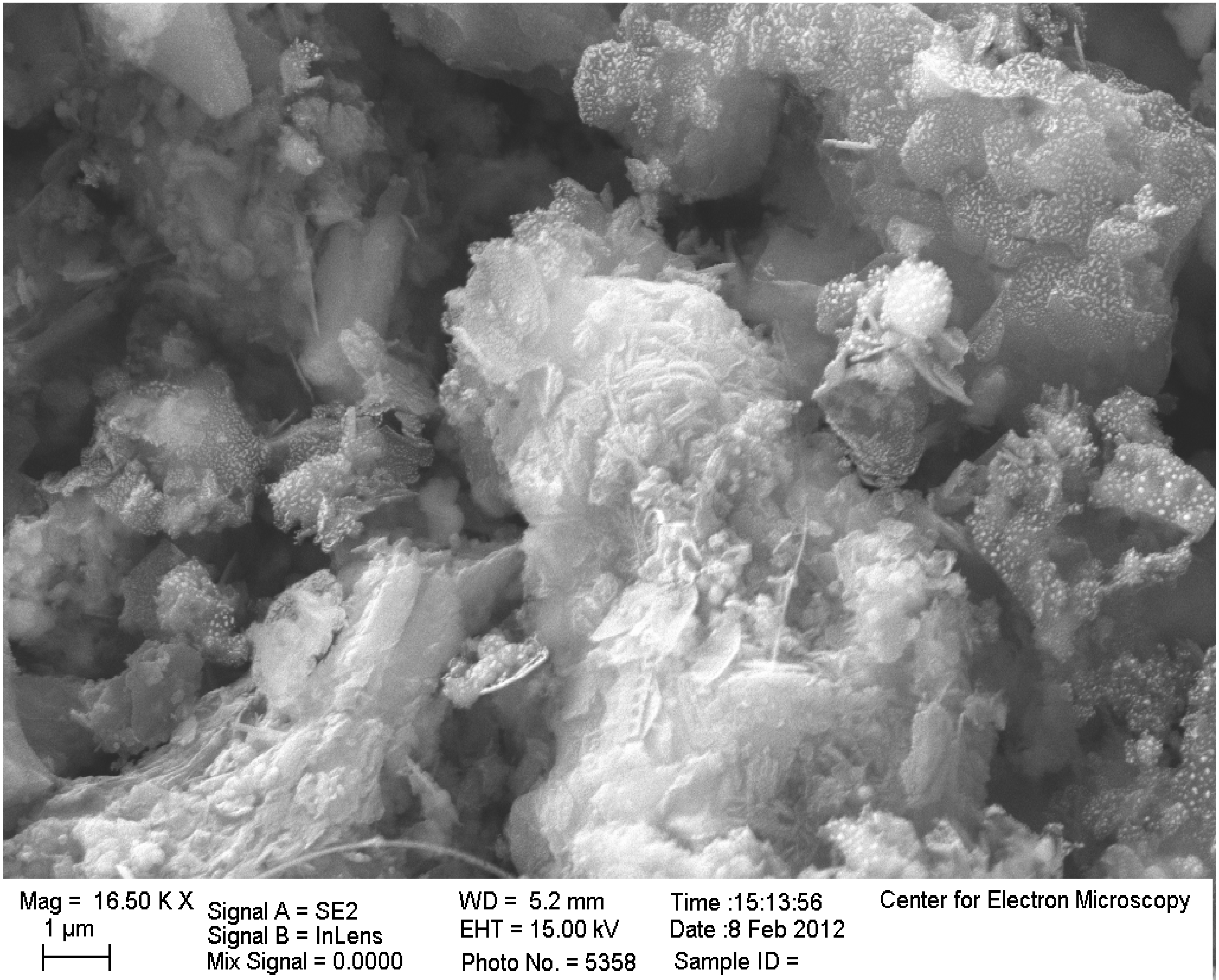

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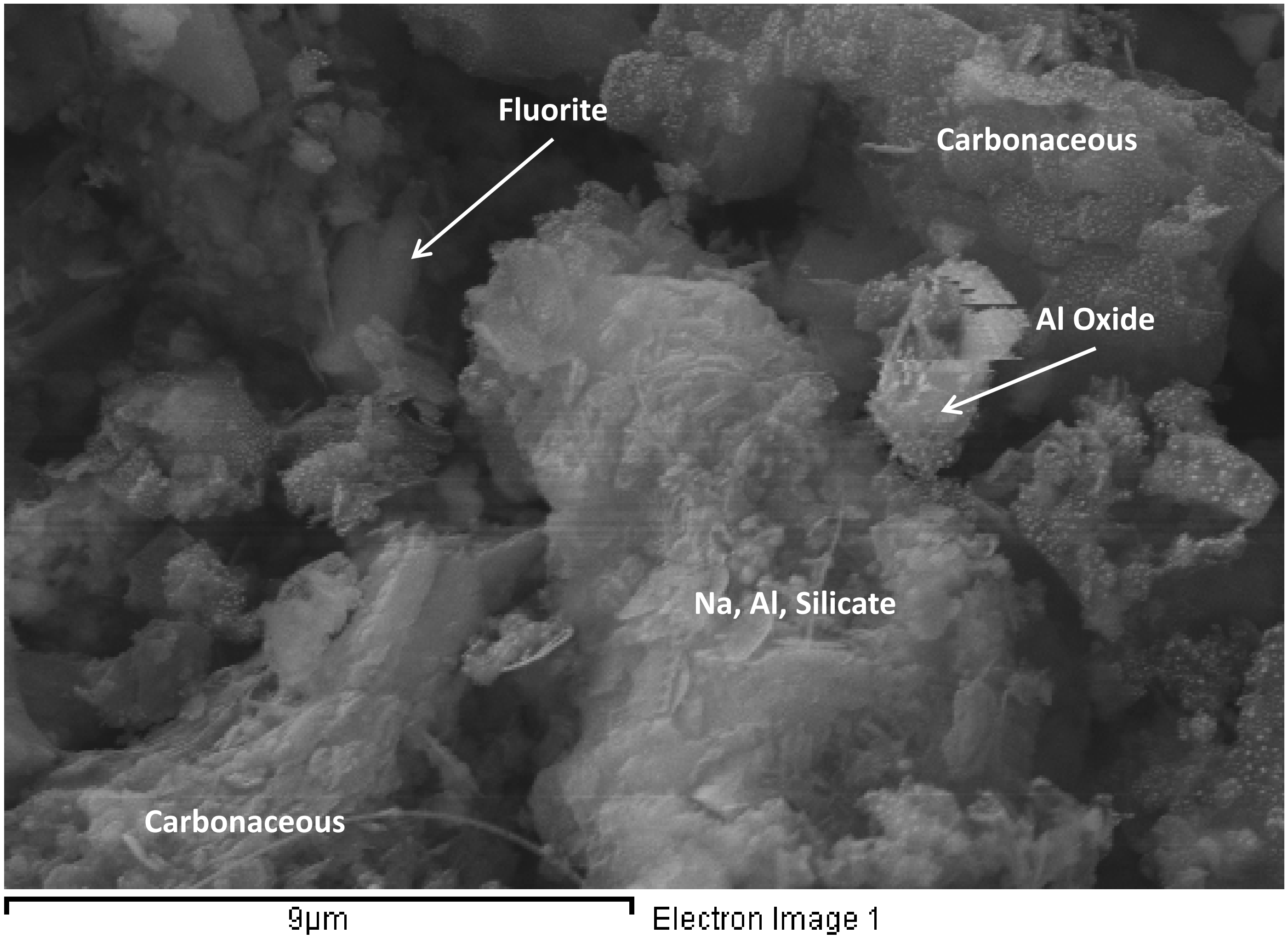

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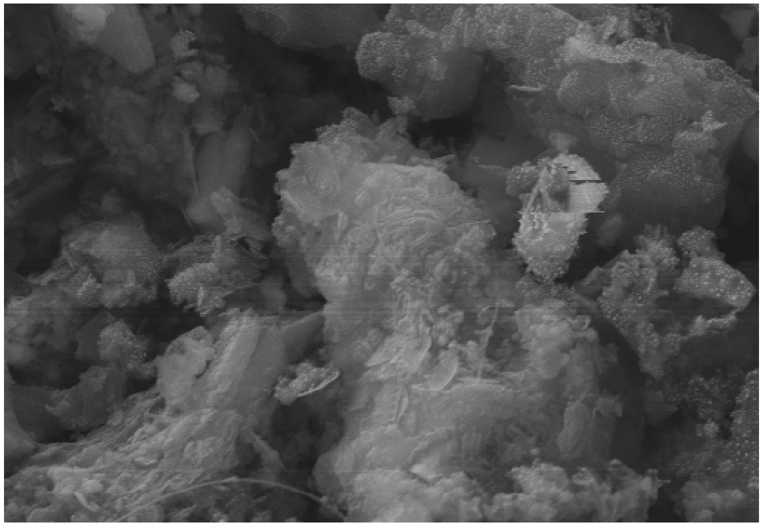

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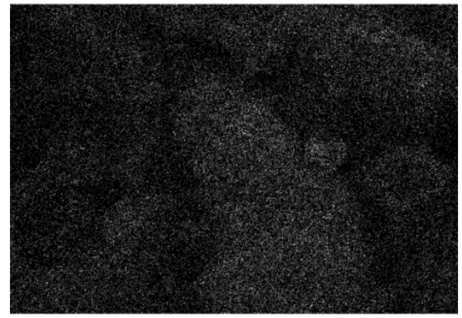

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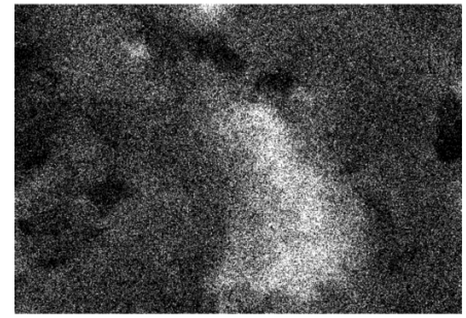

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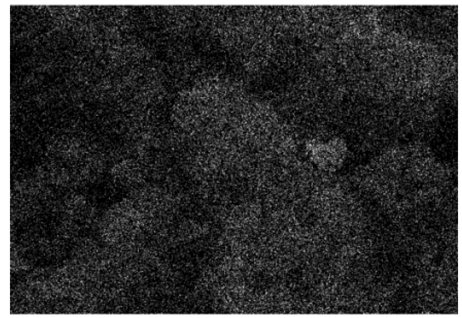

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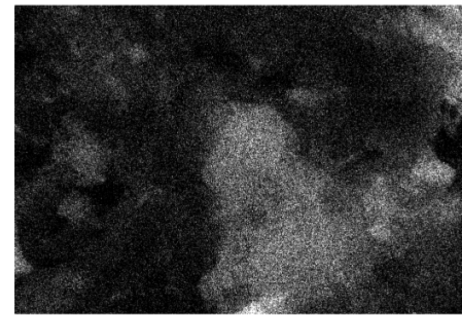

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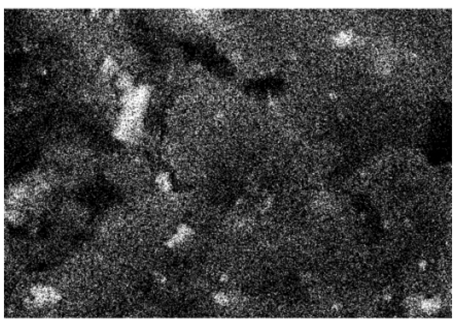

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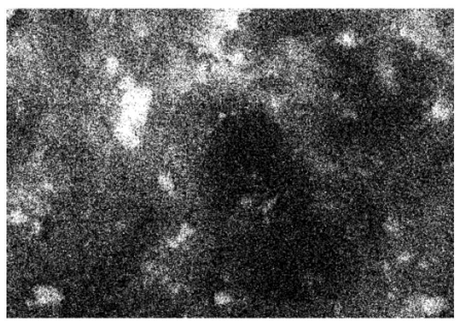

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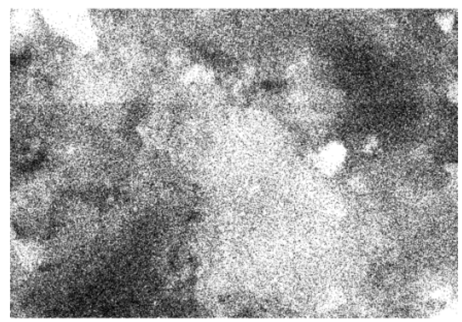

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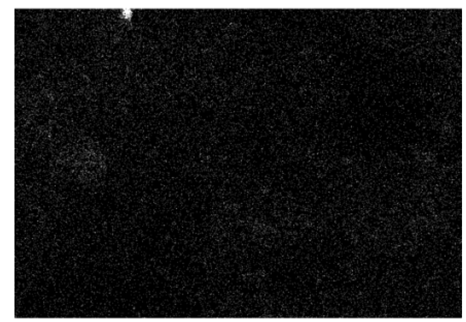

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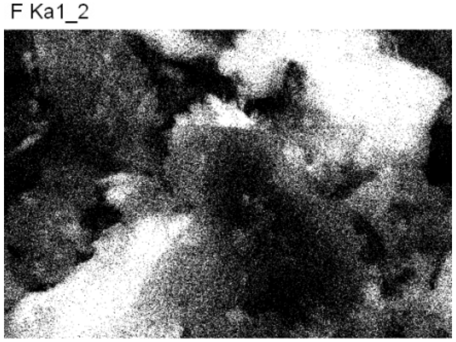

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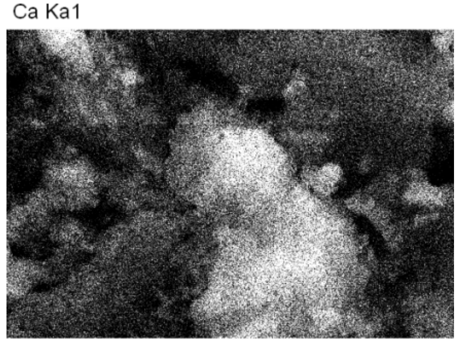

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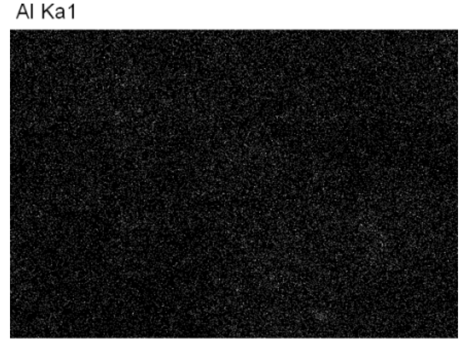

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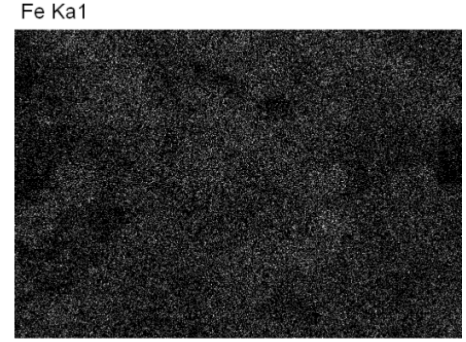
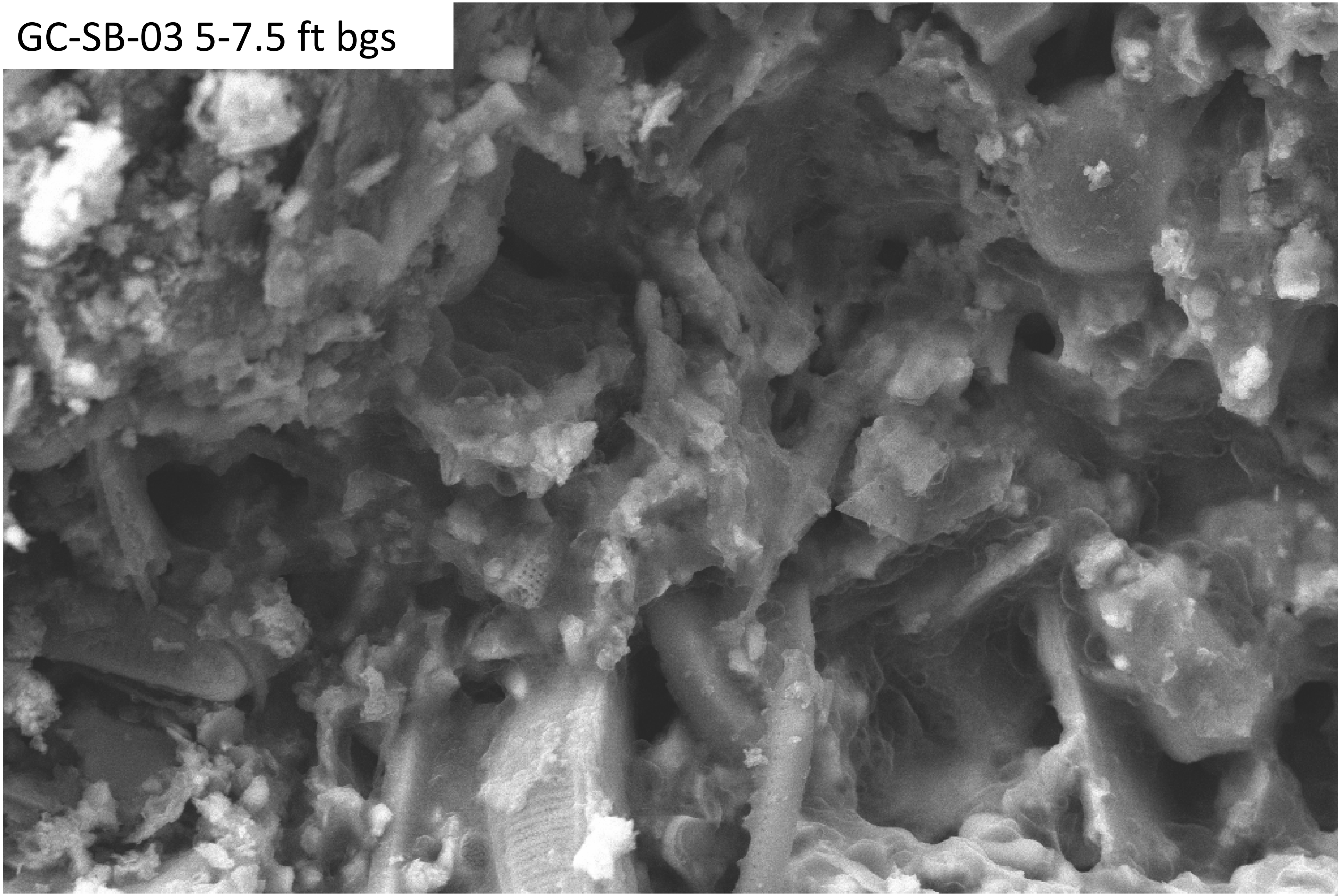


Mg Ka1_2

GC-SB-03 5-7.5 ft bgs



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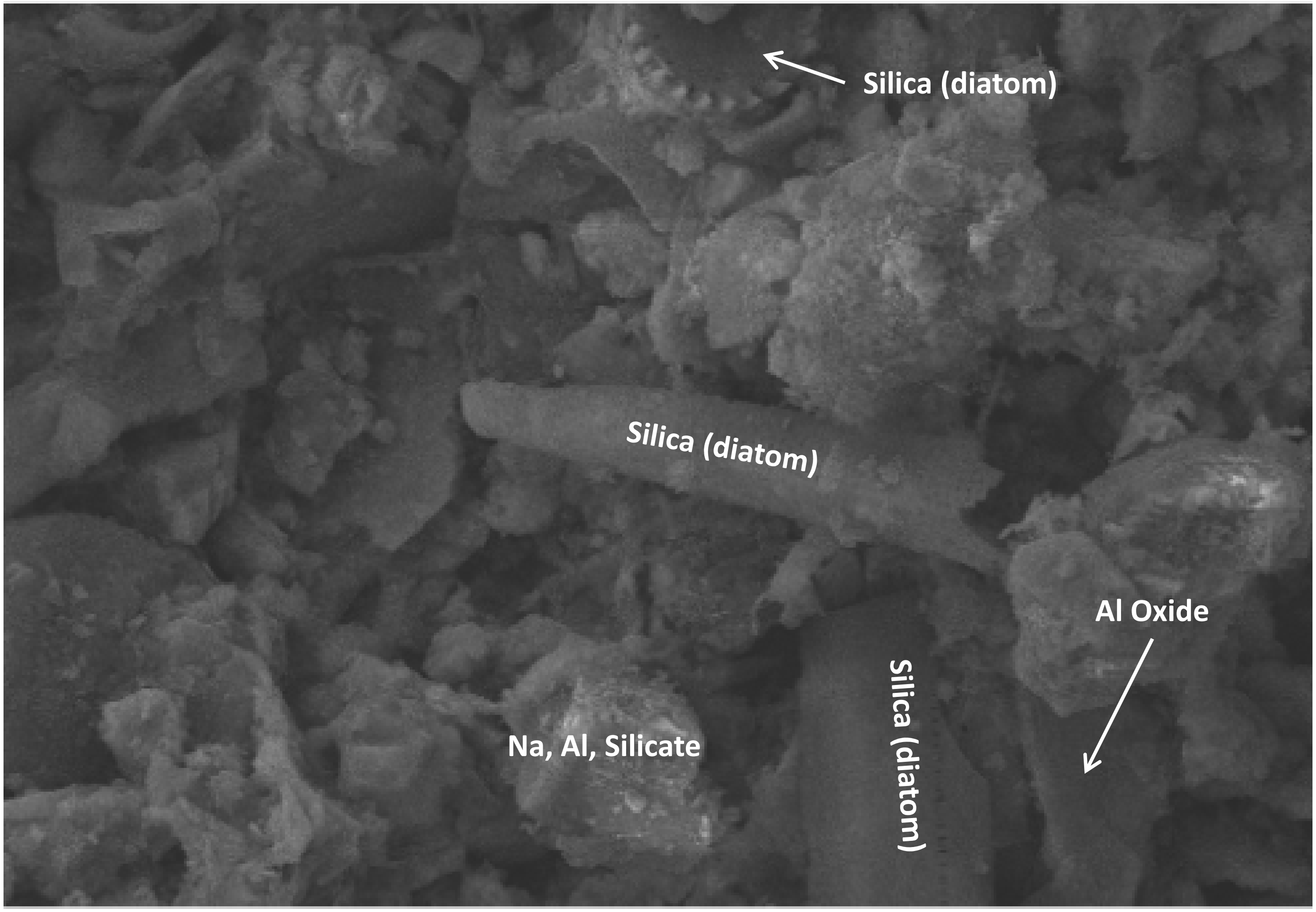
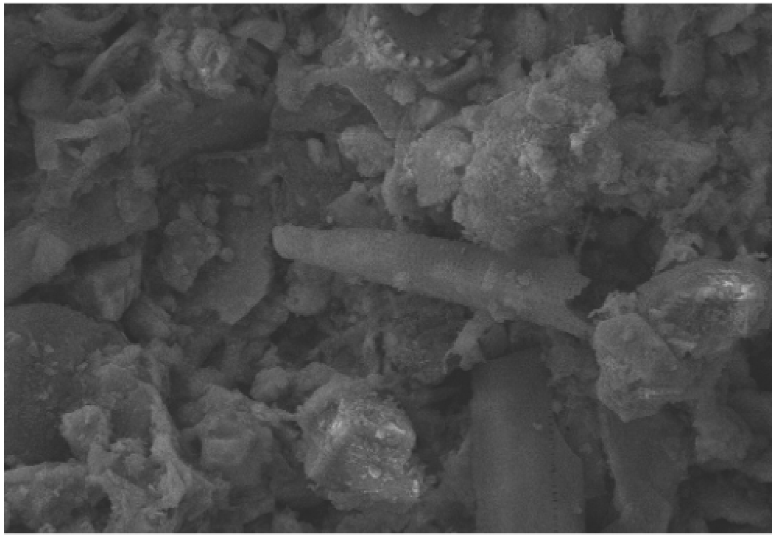
Center for Electron Microscopy

GC-SB-03 5-7.5 ft bgs

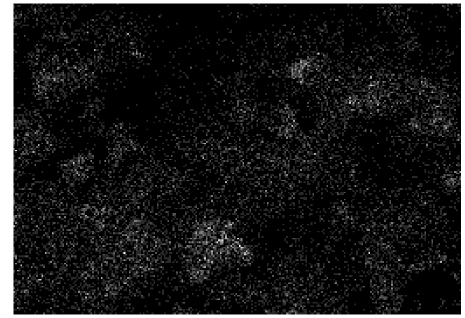


Electron Image 1

GC-SB-03 5-7.5 ft bgs



Electron Image 1



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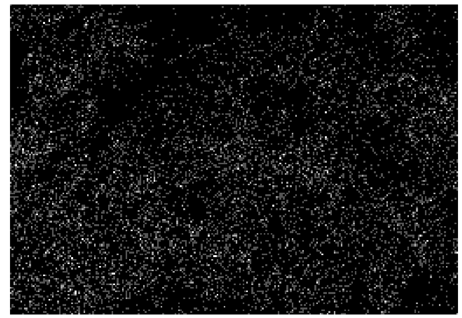

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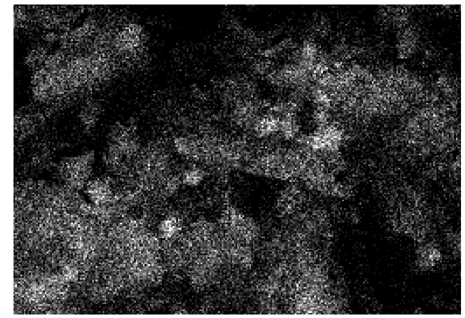

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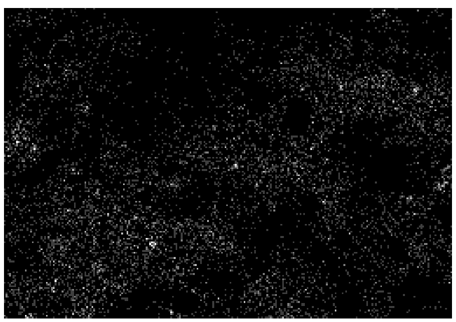
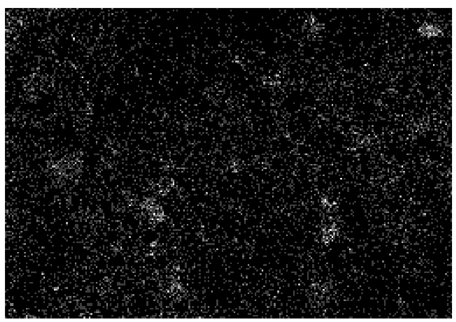


F Ka1_2



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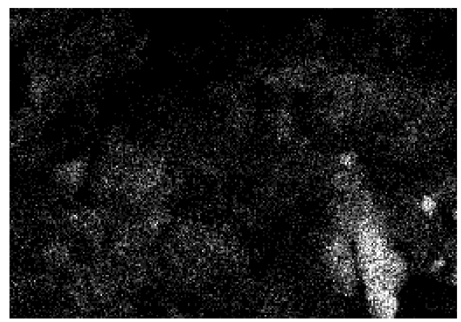

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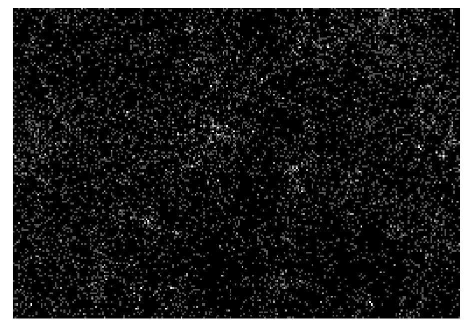

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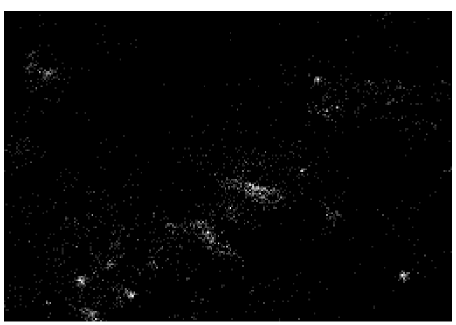

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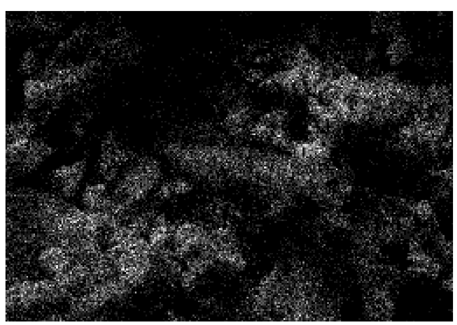

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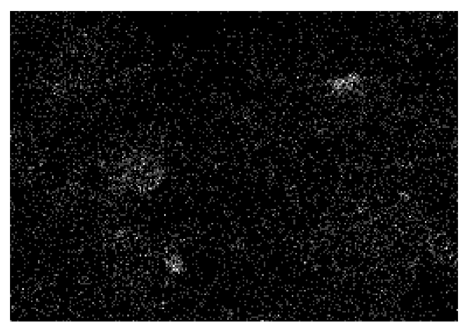

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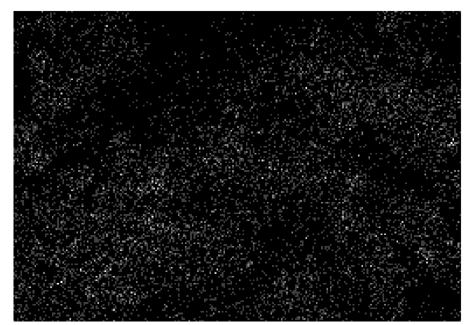

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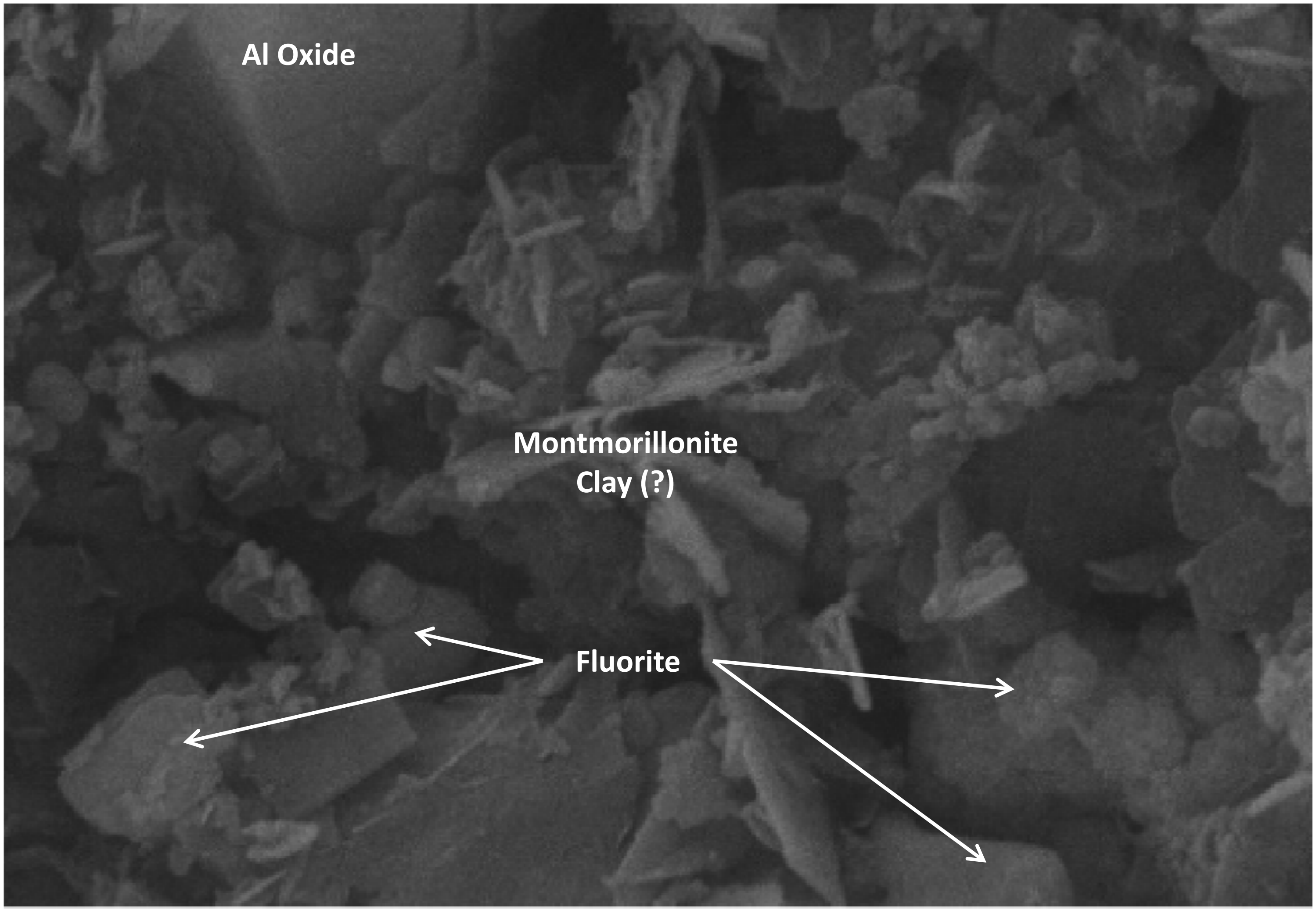
GC-SB-03 5-7.5 ft bgs



Electron Image 1

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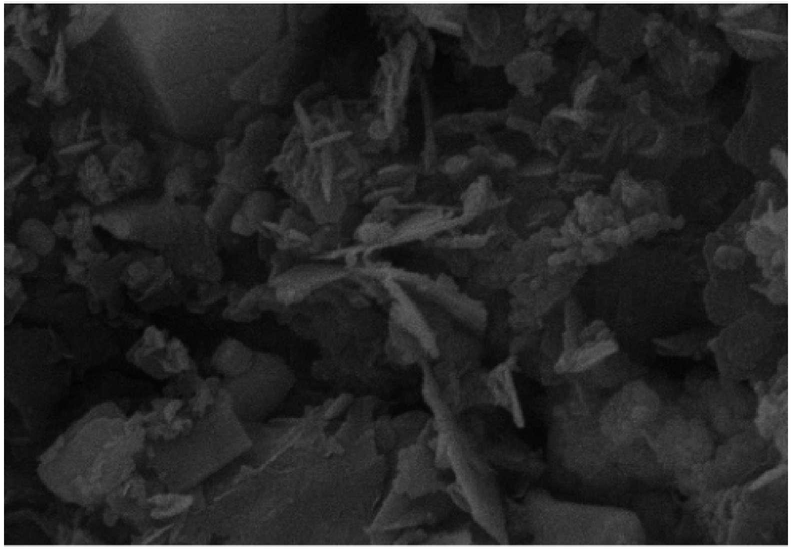

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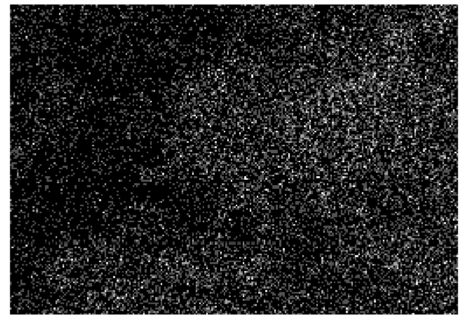

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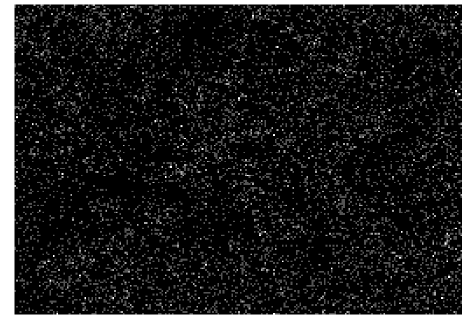

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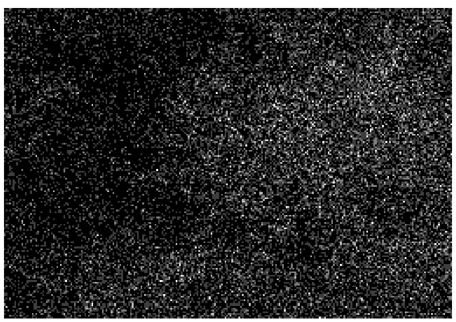

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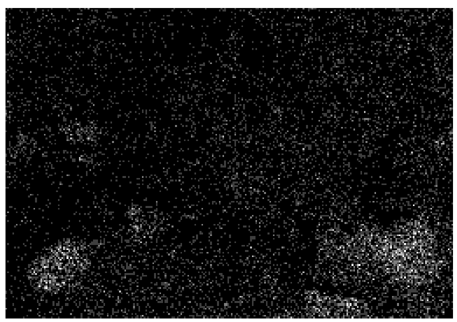

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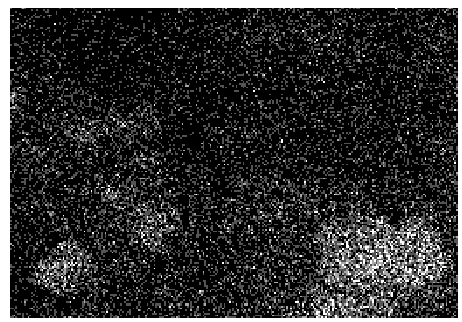

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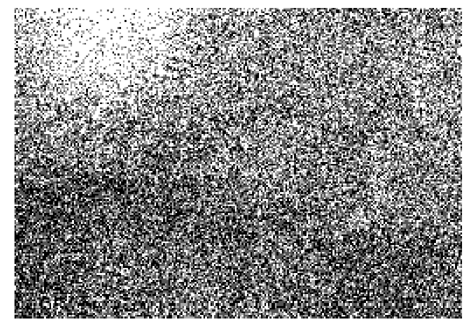

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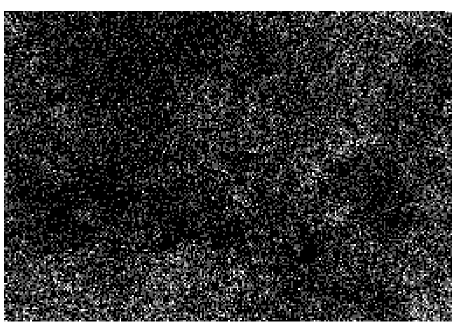
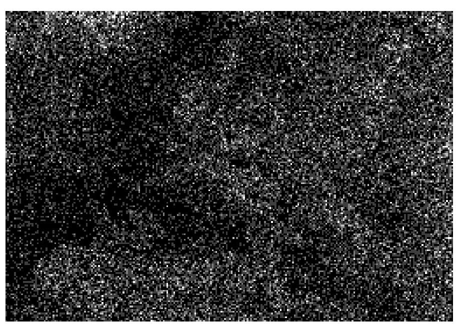


C Ka1_2



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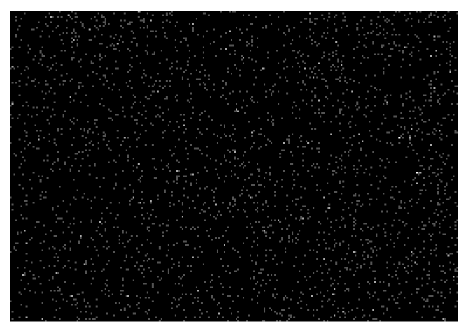

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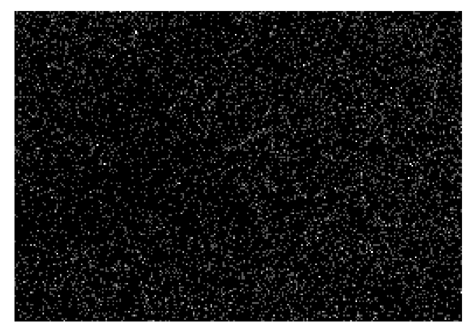

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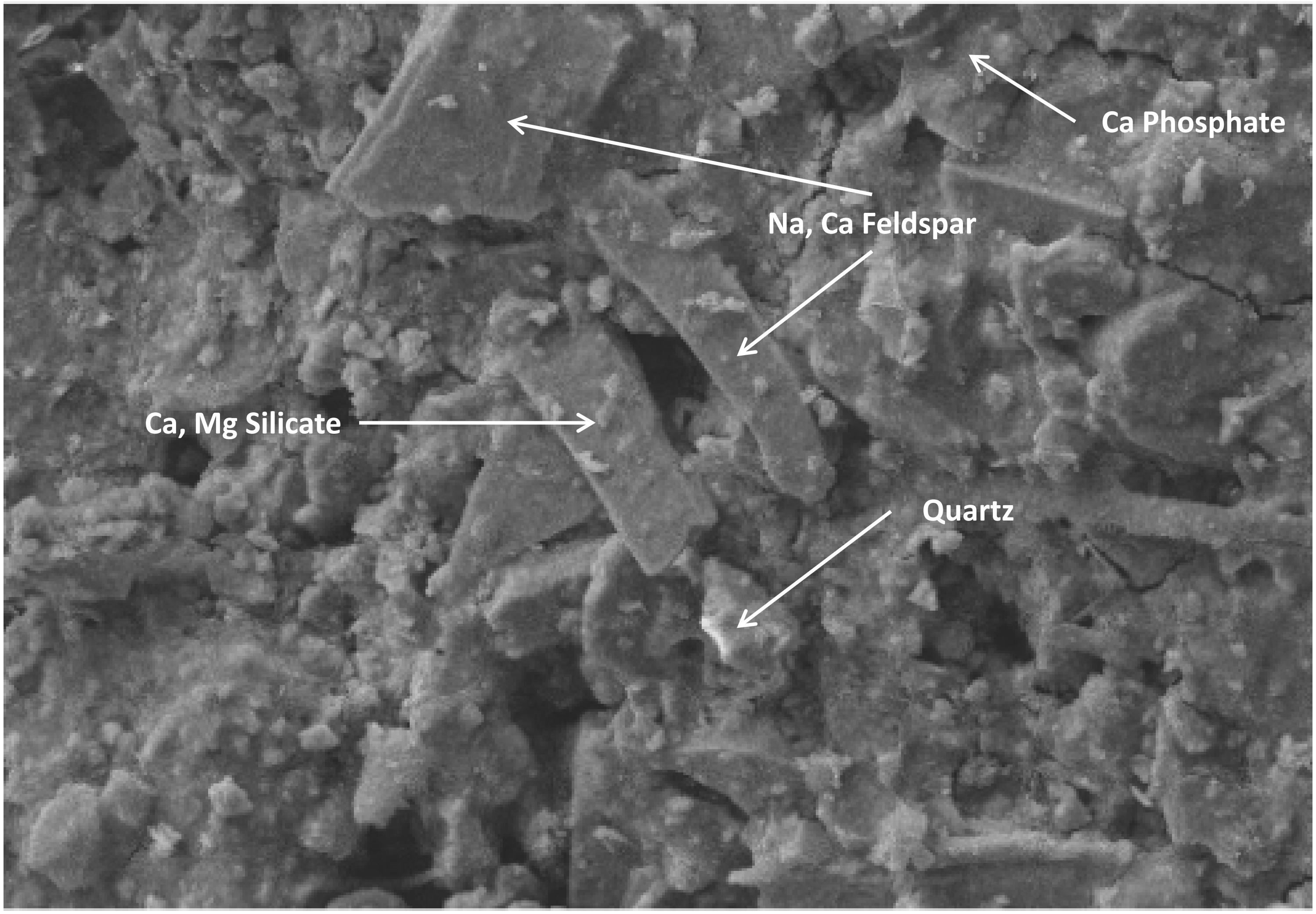

Electron Image 1

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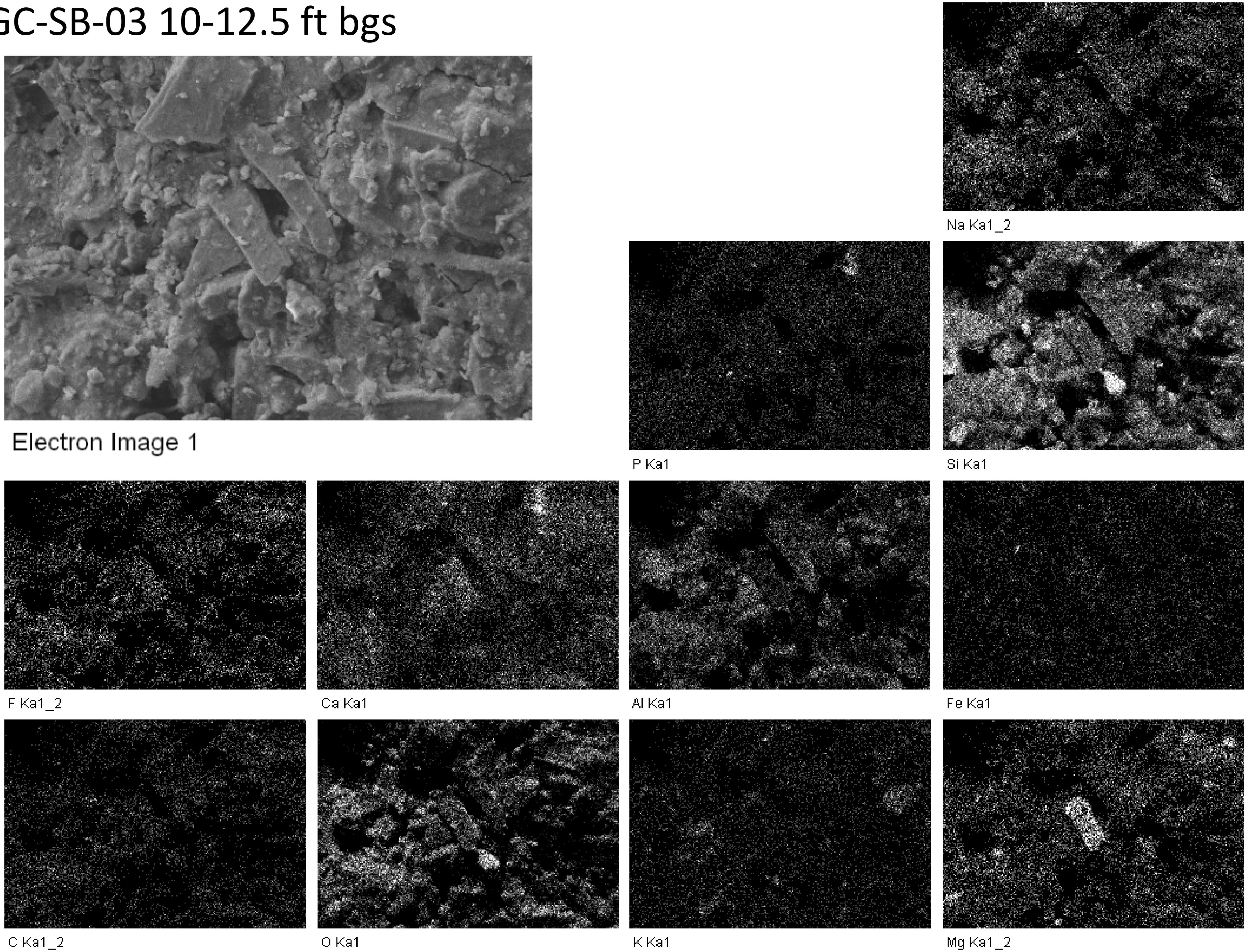

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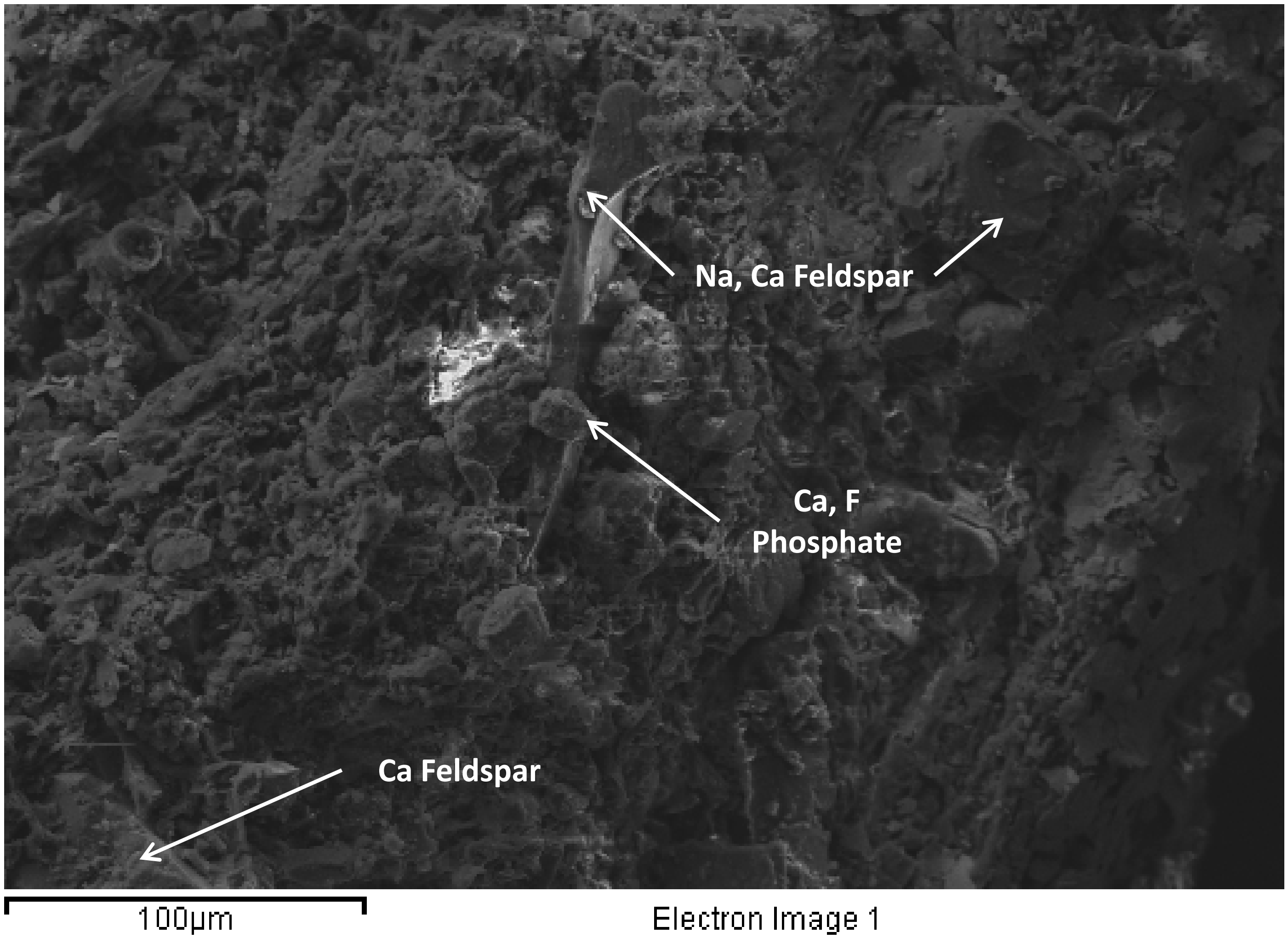

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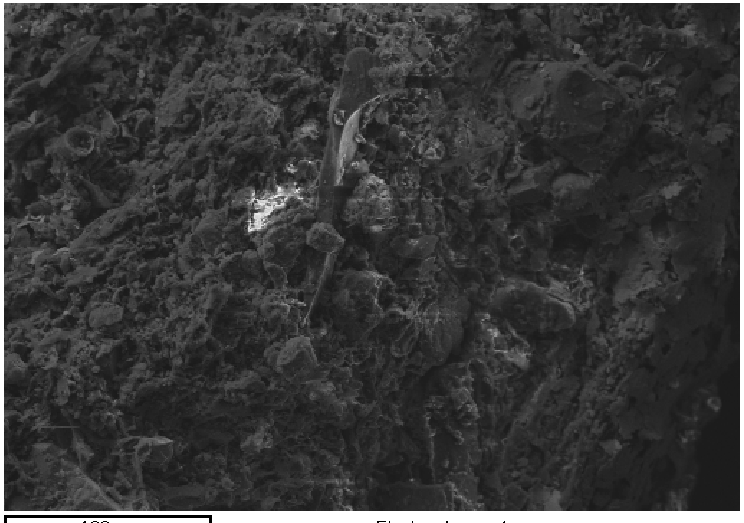


Electron Image 1

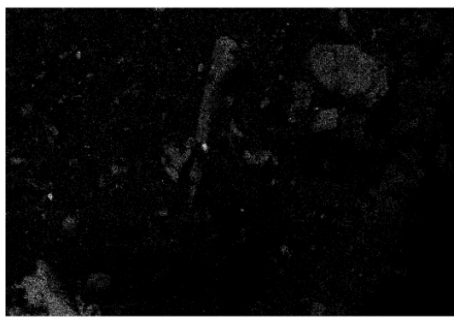

S Ka1


Na Ka1_2


P Ka1


Si Ka1


F Ka1_2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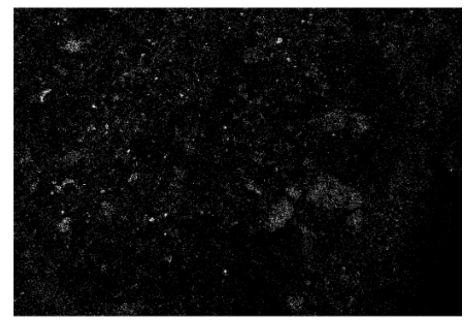
Al Ka1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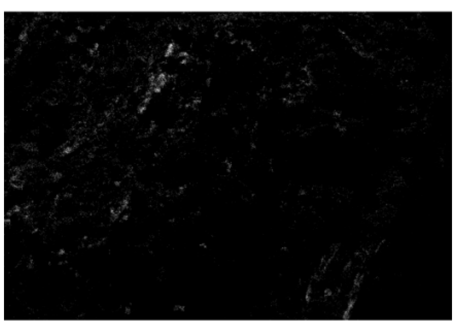
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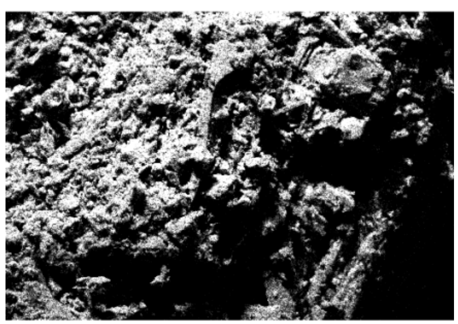
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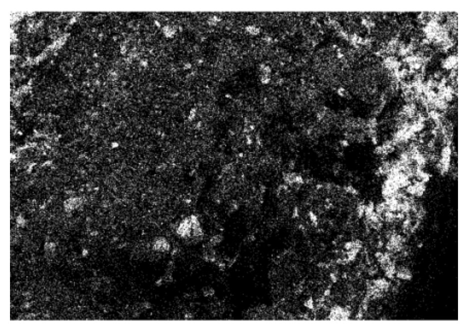
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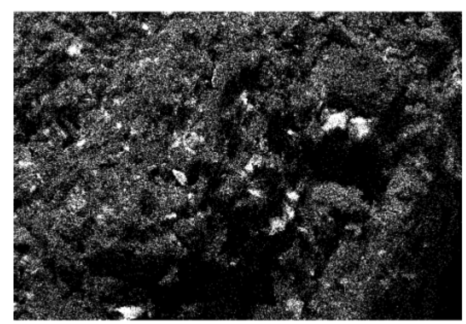
Mg Ka1_2

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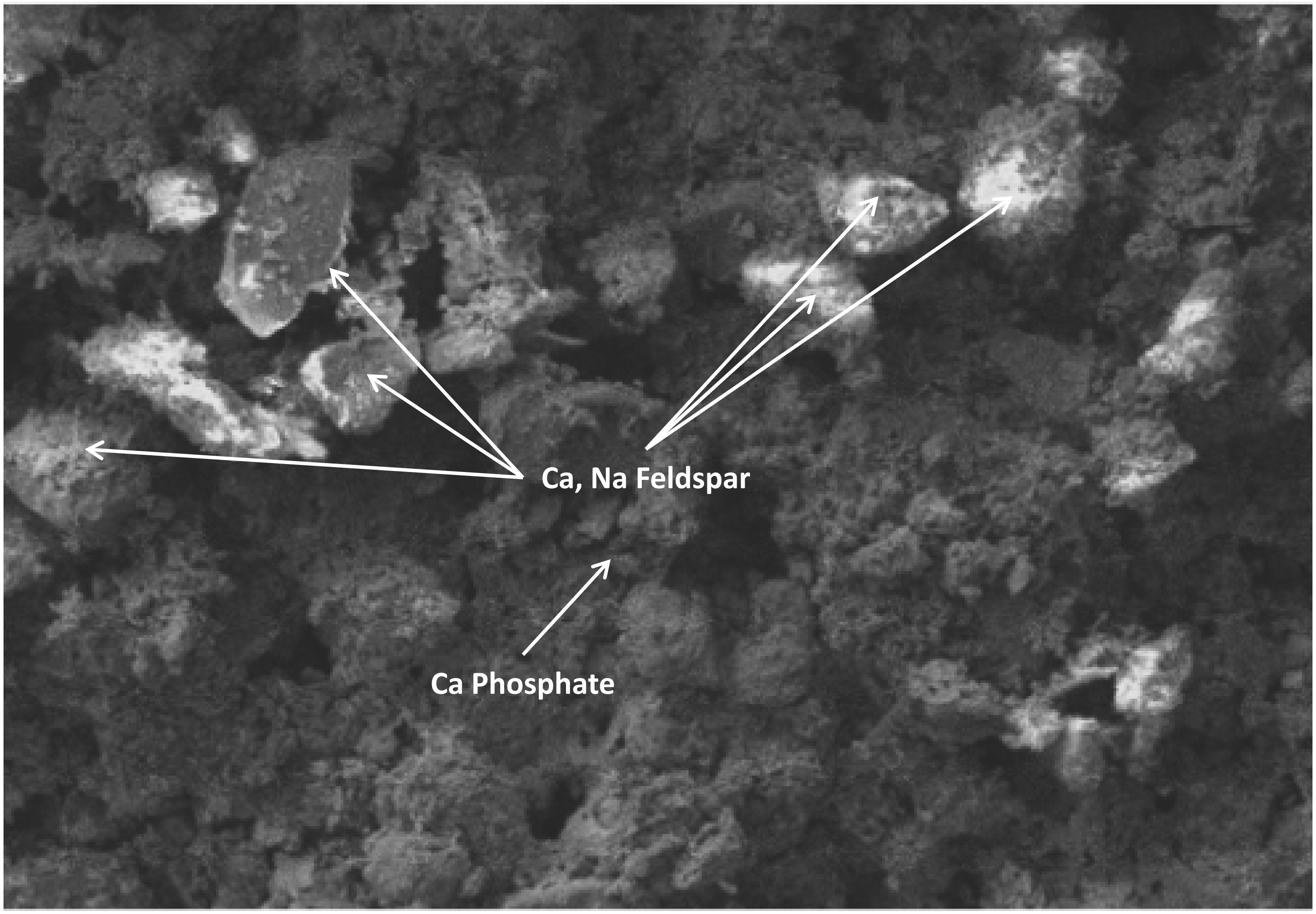

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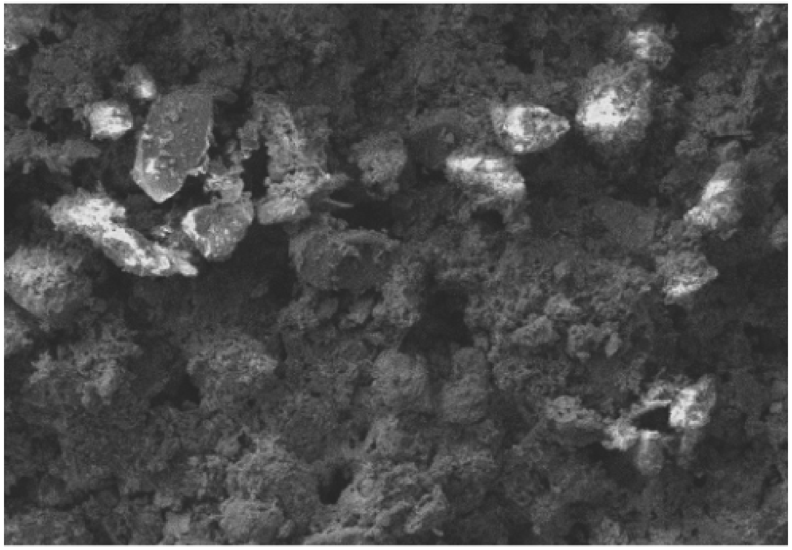

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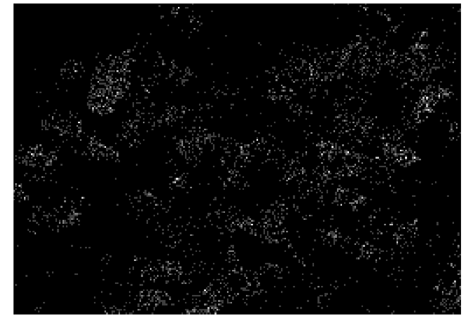

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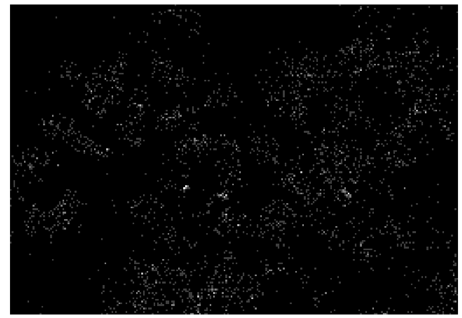

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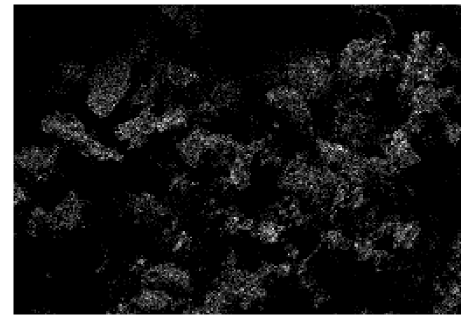

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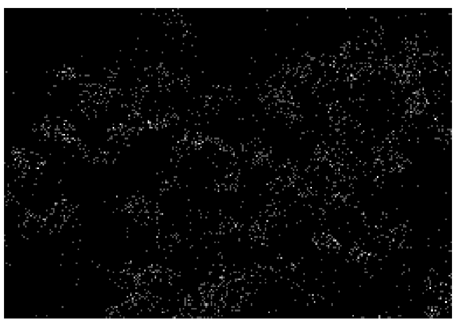

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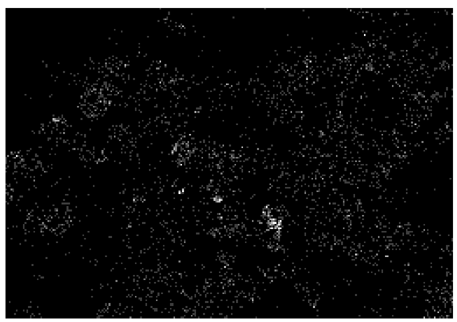
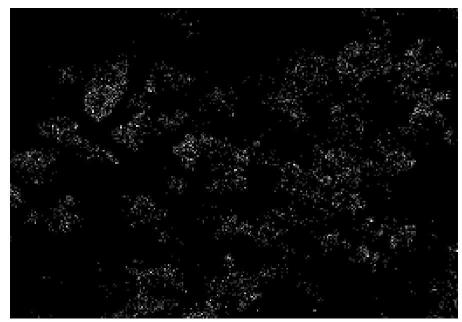


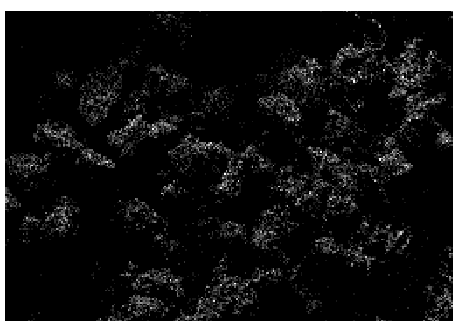
Ca Ka1



Al Ka1

Fe Ka1

C Ka1_2



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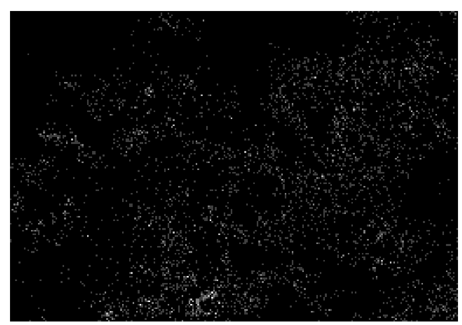

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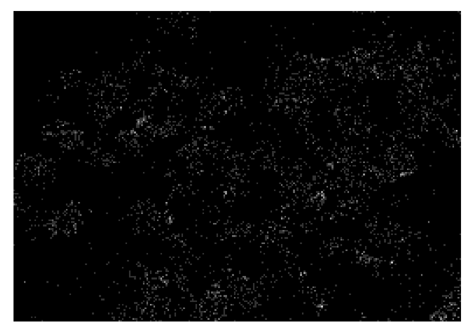

Mg Ka1_2

APPENDIX I-1
SITE-SPECIFIC TERRESTRIAL ECOLOGICAL EVALUATION

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degree Celsius
BAF	bioaccumulation factor
$CaCl_2$	calcium chloride
CaF_2	calcium fluoride
COEC	chemical of ecological concern
COPEC	chemical of potential ecological concern
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
LC50	lethal concentration 50
k_{ow}	octanol-water partition coefficients
LOAEL	lowest observable adverse effect level
mg/kg	milligram per kilogram
MTCA	Model Toxics Control Act
NaF	sodium fluoride
NOAEL	no observable adverse effect level
PAH	polycyclic aromatic hydrocarbon
PBET	physiologically based extraction test
PCB	polychlorinated biphenyl
Reynolds Facility	former Reynolds Metals Reduction Plant
RGAF	relative gut absorption factor
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SU	site unit
TEE	Terrestrial Ecological Evaluation
TPH-D	diesel range hydrocarbons
TRV	toxicity reference value
UCL	upper confidence limit
WAC	Washington Administrative Code
WAD	weak acid dissociable

1 INTRODUCTION

As part of a Model Toxics Control Act (MTCA; Washington Administrative Code [WAC] 173-340) site Remedial Investigation/Feasibility Study (RI/FS), the Washington State Department of Ecology (Ecology) requires a Terrestrial Ecological Evaluation (TEE) to determine whether a release of hazardous substances to soil may pose a threat to the terrestrial environment. The TEE follows Ecology guidance (WAC 173-340-7490) and procedures provided on the internet via the TEE Interactive Users Guide[1]. The following sections present the problem formulation and site-specific TEE for the former Reynolds Metals Reduction Plant (Reynolds Facility) in Longview, Washington. The problem formulation evaluates the site sources and history, identifies chemicals of potential ecological concern (COPECs), and develops a conceptual site model as the basis for evaluating COPEC exposure to receptors of concern. The site-specific TEE describes the evaluation methods, details of the literature survey, the risk characterization, and the uncertainty evaluation.

[1] http://www.ecy.wa.gov/programs/tcp/policies/terrestrial/TEEHome.htm

2 PROBLEM FORMULATION

The TEE problem formulation step includes screening the data to identify COPECs, determining exposure pathways, identifying terrestrial ecological receptors of concern, and conducting a toxicological assessment that summarizes toxicological properties for the identified COPECs. The following sections detail these problem formulation components.

2.1.1 Site Background

The Reynolds Facility is a former aluminum reduction plant. The majority of the area is covered by industrial buildings, supporting infrastructure, and on-site landfills. The site history and data from previous investigations describing contaminant distributions and fate and transport are detailed in this RI/FS (Anchor QEA 2013). Proposed remediation, restoration, and redevelopment activities will preclude soil exposure to terrestrial flora and fauna across a large area of the site (see Figure I-1-1). Low to intermediate quality habitat for terrestrial wildlife is present at several locations adjacent to industrial areas. The site contains at least 10 acres of mixed native and invasive vegetation within 500 feet of areas where contamination is located. Therefore, a site-specific evaluation must be conducted.

2.1.2 Screening for Chemicals of Potential Ecological Concern

For the purpose of conservatively identifying COPECs, all soil data from samples collected within the 0- to 6-foot interval[2], regardless of location and proximity to habitat, were included in the screening. The distribution of COPECs in samples from areas that contain or are adjacent to terrestrial habitat are identified and discussed further in the risk characterization step.

Historical and current RI/FS samples taken from within the top 6 feet of soil provide a dataset for 147 locations across the site (see RI/FS Section 5.2). These samples are from different sampling events and were analyzed for different selected parameters, including conventional parameters, cyanide, fluoride, metals, volatile organic compounds, semivolatile organic compounds, polycyclic aromatic hydrocarbons (PAHs), total petroleum

[2] Because the site is zoned for industrial use and will have institutional controls to prevent excavation of deeper soil, a conditional point of compliance to a depth of 6 feet was applied for COPEC screening and risk characterization.

hydrocarbons, pesticides, and polychlorinated biphenyl (PCB) Aroclors. The screening level assessment of site soil data compared the maximum detected concentrations or reporting limits to the ecological indicator soil concentrations (TEE Table 749-3). Because the site is zoned for industrial uses, only the wildlife values need to be considered (WAC 173-340-7493). When no wildlife or avian indicator soil concentration was available, the lowest of either the plant or soil biota value was applied for screening purposes. Cyanide has been detected in site soils, but there was not a TEE ecological indicator soil concentration. The U.S. Environmental Protection Agency (EPA; 2003) Region 5 ecological soil screening level for cyanide was used in the COPEC screening. For arsenic, the MTCA soil background concentration of 20 milligrams per kilogram (mg/kg) was applied.

Detected chemicals that exceeded the ecological indicator soil concentrations included total cyanide, fluoride[3], diesel range hydrocarbons (TPH-D), total PCB Aroclors, and benzo(a)pyrene (see Table I-1-1).

[3] Fluorine is a naturally occurring, widely distributed element and a member of the halogen family, which includes chlorine, bromine, and iodine. However, the elemental form of fluorine, a pale, yellow-green, irritating gas with a sharp odor, is so chemically reactive that it rarely occurs naturally in the elemental state. Fluorine occurs in ionic forms, or combined with other chemicals in minerals like fluorspar, fluorapatite, cryolite, and other compounds (ATSDR 2003). The terms "fluorine" and "fluoride" are often used interchangeably in the literature as generic terms. In this document, we will use "fluoride" as a general term to refer to all combined forms of fluorine.

Table I-1-1
Summary of Soil COPEC Screening

Chemical	Screening Value	Screening Value Basis	Maximum Concentration	Exceedance Factor	Detection Frequency	Number of Samples
Inorganic chemicals (mg/kg)						
Antimony	5	Plant	6	1.2	1.7%	58
Arsenic	20	Background	6	0.3	79.3%	58
Beryllium	10	Plant	1.95	0.2	10.3%	58
Cadmium	14	Wildlife	1.95	0.1	0.0%	58
Chromium	67	Wildlife	39.7	0.6	100.0%	58
Copper	217	Wildlife	120	0.6	100.0%	58
Fluoride	200	Plant	65,900	**330**	100.0%	114
Lead	118	Wildlife	18.9	0.2	100.0%	58
Mercury	5.5	Wildlife	0.137	0.0	7.9%	63
Nickel	980	Wildlife	55	0.1	100.0%	58
Selenium	0.30	Wildlife	6	20.0	0.0%	58
Silver	2.00	Plant	1.95	1.0	0.0%	58
Thallium	1.00	Plant	6	6.0	0.0%	58
Zinc	360	Wildlife	171	0.5	100.0%	58
Organic chemicals (mg/kg)						
Cyanide, total	1.33	Region 5 RCRA	524	**394**	82.2%	101
Cyanide, weak acid dissociable (WAD)			397	**298**	70.4%	27
Diesel range hydrocarbons	6,000	Wildlife	312	0.1	63.6%	66
Diesel range hydrocarbons (silica gel treated)	6,000	Wildlife	6,580	**1.1**	71.4%	21

Chemical	Screening Value	Screening Value Basis	Maximum Concentration	Exceedance Factor	Detection Frequency	Number of Samples
Gasoline range hydrocarbons	5,000	Wildlife	17.4	0.0	0.0%	1
Organic Chemicals (µg/kg)						
1,2,3-Trichlorobenzene	20,000	Soil Biota	446	0.0	0.0%	7
1,2,4-Trichlorobenzene	20,000	Soil Biota	517	0.0	0.0%	12
1,2-Dichloropropane	700,000	Soil Biota	44.6	0.0	0.0%	7
1,4-Dichlorobenzene	20,000	Soil Biota	517	0.0	0.0%	12
2,4,6-Trichlorophenol	10,000	Soil Biota	1,030	0.1	0.0%	7
2,4-Dinitrophenol	20,000	Plant	5,170	0.3	0.0%	7
4,4'-DDD (p,p'-DDD)	750	Wildlife	3.3	0.0	0.0%	2
4,4'-DDE (p,p'-DDE)	750	Wildlife	3.3	0.0	0.0%	2
4,4'-DDT (p,p'-DDT)	750	Wildlife	3.3	0.0	0.0%	2
4-Nitrophenol	7,000	Soil Biota	2,070	0.3	0.0%	7
Acenaphthene	20,000	Plant	5,000	0.3	46.1%	141
Aldrin	100	Wildlife	1.6	0.0	0.0%	2
Benzo(a)pyrene	12,000	Wildlife	62,000	**5.2**	87.9%	141
Chlordane, alpha- (cis-Chlordane)	2,700	Wildlife	1.6	0.0	0.0%	2
Chlordane, gamma-	2,700	Wildlife	1.6	0.0	0.0%	2
Chlorobenzene	40,000	Soil Biota	44.6	0.0	0.0%	7
Dieldrin	70	Wildlife	3.3	0.0	0.0%	2
Diethyl phthalate	100,000	Plant	1,030	0.0	0.0%	7
Dimethyl phthalate	200,000	Soil Biota	1,030	0.0	0.0%	7
Di-n-butyl phthalate	200,000	Plant	1,030	0.0	0.0%	7
Endrin	200	Wildlife	3.3	0.0	0.0%	2
Fluorene	30,000	Soil Biota	12,000	0.4	39.7%	141
Heptachlor	400	Wildlife	1.6	0.0	0.0%	2

Chemical	Screening Value	Screening Value Basis	Maximum Concentration	Exceedance Factor	Detection Frequency	Number of Samples
Heptachlor epoxide	400	Wildlife	1.6	0.0	0.0%	2
Hexachlorobenzene	17,000	Wildlife	207	0.0	0.0%	7
Hexachlorocyclopentadiene	10,000	Plant	1,030	0.1	0.0%	7
Nitrobenzene	40,000	Soil Biota	2,070	0.1	0.0%	7
N-Nitrosodiphenylamine	20,000	Soil Biota	517	0.0	0.0%	7
Pentachlorophenol	4,500	Wildlife	4,140	0.9	0.0%	7
Phenol	30,000	Plant	414	0.0	0.0%	7
Styrene	300,000	Plant	89.1	0.0	0.0%	7
Toluene	200,000	Plant	315	0.0	14.3%	7
Total PCB Aroclors (U = 1/2)	650	Wildlife	2,209	**3.4**	68.0%	25

Note:
Detected chemical exceedances of screening benchmarks are bold.

Of the 58 antimony detection limits, two were above the screening level. Antimony was only detected in 1 of the 58 samples, and the concentration (1.05 mg/kg) was below the screening value (5 mg/kg, based on plants). Therefore, antimony was not included as a COPEC.

All 58 thallium detection limits (range 1.12 to 6 mg/kg; mean 1.6 mg/kg) were above their respective conservative screening value (1 mg/kg), which was based on plants. No soil samples had detectable concentrations of thallium. All 58 selenium detection limits (range 2.25 to 6 mg/kg; mean 3.0 mg/kg) were above their respective conservative wildlife screening value (0.3 mg/kg). No soil samples had detectable concentrations of selenium. Because thallium and selenium were not detected in any of the 58 samples analyzed, these elements were not included as COPECs.

For TPH-D, only one sample (AQ-SSA6-01-2011) exceeded the wildlife screening value. This station is located in SU9. No single sample concentration was greater than two times the soil screening level, and less than 10 percent of the sample concentrations exceeded the soil screening level. Therefore, TPH-D was not included as a COPEC.

Fluoride and cyanide were detected at concentrations that exceeded conservative ecological indicator soil concentrations at a higher frequency and greater magnitude than the other chemicals (see Table I-1-1). Therefore, fluoride and cyanide were retained as COPECs.

Benzo(a)pyrene and total PCB Aroclor were detected in samples within industrial areas of the site. Although less than 10 percent of the samples exceed the benzo(a)pyrene screening level, three samples had concentrations of more than twice the screening level, and therefore, benzo(a)pyrene was retained as a COPEC. Although less than 10 percent of the samples exceed the total PCB Aroclor screening level, one sample had concentrations of more than twice the screening level, and therefore, total PCB Aroclor was retained as a COPEC.

The TEE (Table 749-3) screening value for fluoride was based on plants, and a literature screening benchmark was applied for cyanide. Fluoride and cyanide had the greatest magnitude and frequency of exceedance of the available soil screening levels, but there is also substantial uncertainty regarding the potential for risk to wildlife at the site. Because of the importance of a more accurate accounting of the potential risk posed by these chemicals, a site-specific TEE was conducted to determine protective concentrations of fluoride and cyanide.

Because the benzo(a)pyrene and total PCB Aroclors screening levels were based on TEE wildlife ecological indicator soil concentrations and had a relatively low magnitude and frequency of exceedance of the soil screening levels, there is less uncertainty regarding the ability to characterize potential risk to wildlife at the site. As such, the TEE ecological indicator soil concentrations for benzo(a)pyrene and total PCB Aroclors (WAC 173-340-7439; TEE Table 749-3) were retained as the protective benchmarks, instead of developing site-specific values.

2.1.3 Exposure Pathways

The majority of the site has incomplete exposure pathways due to man-made physical barriers (e.g., buildings, pavement, and landfill covers), although habitat exists in patchy areas across the site (see Figure I-1-1). The largest contiguous habitat feature consists of an approximately 22-acre field and an adjacent wooded area of approximately 4 acres to the east of the Closed BMP Facility. Limited riparian habitat exists along the shoreline due to the presence of the levee, although near the Dredge Disposal Pond, there are approximately 4 acres of intermediate quality habitat. Exposure pathways to terrestrial mammals and birds include soil ingestion and consumption of prey or forage plants. Although drinking water is a complete pathway, it is unlikely to be a significant source of contaminant uptake and is not addressed herein. The use of soil ingestion and prey exposure pathways is consistent with the TEE exposure models (TEE Table 749-5) applied herein.

2.1.4 Terrestrial Ecological Receptors of Concern

Avian and mammalian receptors may be exposed to site contaminants via consumption of plants and invertebrate prey, as well as incidental soil ingestion while foraging at the site. For the purposes of this assessment, it was assumed that the default TEE receptors for mammalian herbivore, mammalian predator, and avian predator (vole, shrew, and robin, respectively) are present and representative of the other similar species that may utilize the site.

2.1.5 Toxicological Assessment

The following section provides a toxicological summary of the COPECs, benzo(a)pyrene, cyanide, fluoride, and total PCB Aroclors, including the general mode of action and assessment of bioaccessibility.

2.1.5.1 Benzo(a)pyrene

Eisler (1987) provides a comprehensive review of the environmental effects of PAHs, like benzo(a)pyrene, as summarized in this section. PAHs consist of hydrogen and carbon arranged in the form of two or more fused benzene rings. There are thousands of PAH compounds, each differing in the number and position of aromatic rings and in the position of substituents on the basic ring system. Benzo(a)pyrene is a 5-ring PAH that has shown demonstrably to be carcinogenic, mutagenic, or teratogenic to a wide variety of organisms, including fish and other aquatic life, amphibians, birds, and mammals. In general, PAHs show little tendency to biomagnify in food chains despite their high lipid solubility, probably because most PAHs are rapidly metabolized. Inter- and intraspecies response to individual PAHs are quite variable and are significantly modified by many inorganic and organic compounds, including other PAHs.

PAHs are ubiquitous in nature—as evidenced by their detection in sediments, soils, air, surface waters, and plant and animal tissues—primarily as a result of natural processes, such as forest fires, microbial synthesis, and volcanic activities. Anthropogenic activities associated with significant production of PAHs—leading, in some cases, to localized areas of high contamination—include high-temperature (> 700 °C) pyrolysis of organic materials typical of some processes used in the iron and steel industry, heating and power generation, and petroleum refining.

2.1.5.2 Cyanide

Eisler (1991) provides a comprehensive review of the environmental effects of cyanide, as summarized in this section. Cyanides are readily absorbed through inhalation, ingestion, or skin contact, and are readily distributed throughout the body via blood. Cyanide is a potent and rapid-acting asphyxiant; it induces tissue anoxia through inactivation of cytochrome oxidase, causing cytotoxic hypoxia in the presence of normal hemoglobin oxygenation. Among the more consistent changes measured in acute cyanide poisoning are inhibition of brain cytochrome oxidase activity and changes in electrical activity in the heart and brain. At sublethal doses, cyanide reacts with thiosulfate in the presence of rhodanese to produce the comparatively nontoxic thiocyanate, most of which is excreted in the urine. Rapid detoxification enables animals to ingest high sublethal doses of cyanide over extended periods without harm.

There are no reports of cyanide biomagnification or cycling in living organisms, probably owing to its rapid detoxification. Cyanide seldom persists in surface waters and soils owing to complexation or sedimentation, microbial metabolism, and loss from volatilization.

2.1.5.3 Fluoride

Drury et al. (1980) provide a comprehensive review of the environmental effects of fluoride, as summarized in this section. The biochemistry of fluoride is complex. The manner in which excess fluoride interferes with biochemical processes at the molecular level includes preventing oxidative metabolism by inhibiting the action of enzymes that depend on polyvalent cations such as magnesium, calcium, iron, and manganese. In addition, other body functions that require complexable polyvalent metal ions (e.g., membrane transport, nerve conduction, muscle contraction, and blood clotting) are disrupted. It is apparent that the fluoride ion is responsible for the toxic effects. Accordingly, soluble inorganic fluoride salts are more toxic than insoluble salts, and most compounds that do not yield free fluoride ions in body fluids have little or no toxicity.

Fluoride does accumulate in plant and animal tissue. In animals, fluoride accumulates particularly in the skeleton and teeth. Accumulation of fluoride in earthworm tissue has also been observed (Vogel and Ottow 1991). Earthworms have neutral pH in the gut and excrete calcium carbonate (http://minmag.geoscienceworld.org/content/72/1/257.extract). Based on geochemical modeling, calcium fluoride will precipitate in the gut of earthworms (see Section 3.1.1.3). For the purposes of this TEE, an earthworm bioaccumulation factor (BAF) and plant uptake coefficient was developed from the literature (see Section 3.1).

2.1.5.4 Polychlorinated Biphenyl Aroclor

Eisler (1986) provides a comprehensive review of the environmental effects of PCBs, which are a group of 209 synthetic halogenated aromatic hydrocarbons and have been used extensively in the electricity generating industry as insulating or cooling agents in transformers and capacitors. Due to human activities and the chemical characteristics of the products, PCBs are now distributed worldwide. PCBs elicit a variety of biologic and toxic effects, including death, birth defects, reproductive failure, liver damage, tumors, and a wasting syndrome. They are known to bioaccumulate and to biomagnify within the food chain. As a result of legislation, virtually all uses of PCBs and their manufacture have been prohibited in the United States since 1979.

The toxicological properties of individual PCBs are influenced primarily by two factors—the partition coefficient based on solubility in N-octanol/water (K_{ow}) and steric factors resulting from different patterns of chlorine substitution. In general, PCB isomers with high K_{ow} values, and high numbers of substituted chlorines in adjacent positions, constitute the greatest environmental concern. Unfortunately, basic chemical information is lacking on many isomers. Also, biological responses to individual isomers or mixtures vary widely, even among closely related taxonomic species.

3 SITE-SPECIFIC TERRESTRIAL ECOLOGICAL EVALUATION

The following describes the site-specific TEE for fluoride and cyanide, the two COPECs identified in the screening as having the greatest uncertainty regarding potential risk to wildlife. The ecological indicator soil concentrations (TEE Table 749-3) were applied for evaluating potential risk from exposure to benzo(a)pyrene and total PCB Aroclor in site soils (see Section 2.1.2).

The TEE method applied is to establish that protective soil concentrations of fluoride and cyanide were based on the TEE exposure models described in TEE Table 749-5 (see TEE Attachment 1). A literature survey was conducted to accomplish the following:

- Identify screening benchmarks for chemicals not included in TEE Table 749-3.
- Identify toxicity reference values (TRVs) and BAF for chemicals, receptors, and prey items used in wildlife exposure models but not included in TEE Table 749-5.
- Parameterize the geochemical model that was also applied to evaluate the site-specific bioaccessibility of fluoride in soil.

3.1.1 Literature Survey

Initially, literature values were used to fill data gaps for Indicator Soil Concentrations in TEE Table 749-3. In this first case, there were limited sources to supplement the TEE Table 749-3 values, as described previously in Section 2.1.2. After COPECs were identified using a conservative screening step, the literature survey was used to identify toxicity and bioaccumulation data needed to calculate protective fluoride and cyanide soil concentration for wildlife based on the TEE wildlife exposure models presented in TEE Tables 749-4 and 749-5.

3.1.1.1 Fluoride

While TEE Table 749-3 includes a fluoride Indicator Soil Concentration for plants (200 mg/kg), this value is derived as a screening level (Efroymson et al. 1997) and is known to be uncertain[4]. TEE Table 749-3 does not include indicator values for soil biota or wildlife, nor are there default data for fluoride in the TEE wildlife exposure model (TEE Table 749-5). Therefore, a literature survey was conducted to locate applicable mammalian and avian toxicity data, invertebrate BAF values, and a plant uptake coefficient.

3.1.1.1.1 Fluoride Toxicity Reference Values

There are limited dietary studies for calculating avian and mammalian TRVs for fluoride. Available data were obtained from the primary literature and compiled from sources including WHO (2002), EPA (2007), ORNL (1980), and Sample et al. (1996). With the exception of limited rodent data, sodium fluoride was the compound used for dosing. The data reported in the Toxicological Benchmarks for Wildlife: 1996 Revision are used by Ecology as the basis of TEE Table 749-3 for compounds other than fluoride (Sample et al. 1996). Since there are only limited fluoride data suitable for use as wildlife TRVs and Ecology does not reference a default fluoride value, the available fluoride data from Sample et al. (1996) were considered suitable for use in the TEE.

Dietary studies with small mammals were limited to oral mortality tests (e.g., 96-hour LC50 tests) with mice or rats. Suitable chronic dietary studies with non-domesticated animals were limited to a single mink study, as reported by Sample et al. (1996). The lowest observable adverse effect level (LOAEL) TRVs for mink were allometrically scaled for the short-tailed shrew and meadow vole. The LOAELs for the shrew and vole are 150.7 and 115.2 mg/kg per day, respectively.

The fluoride TRV for the American robin that was developed by Sample et al. (1996) is based on a single reproductive study of the screech owl (Pattee et al. 1988). Screech owls feed almost exclusively on small mammals, whereas robins feed on approximately 50 percent invertebrates and 50 percent berries and seeds. Fleming et al. (1988) conducted a 16-day subacute dietary study on Japanese quail chicks, birds that feed primarily on vegetation. A quail TRV was based on a no-effect concentration of 1,000 mg/kg in food. The dose was calculated using the reported average feeding rates (9 grams per day) and final body weight

[4] The benchmark is based on a report of unspecified reductions in plant growth in a surface soil with the addition of 200 parts per million fluoride (Kabata-Pendias and Pendias 1984). Confidence in the benchmark for fluoride is low because it is based on this reference alone.

(62 grams; Fleming and Schuler 1988). The derived TRVs for the screech owl (32 mg/kg per day) and the quail (145 mg/kg per day) vary by a factor of five, indicating a difference in sensitivity that may overestimate the risk to the robin if only the screech owl TRV were used. To account for this low bias, an average of the screech owl and quail LOAEL values was applied as the TRV for the robin: 88.5 mg/kg per day.

3.1.1.1.2 Fluoride Earthworm Bioaccumulation and Plant Uptake Factors

Earthworm BAF for fluoride were not reported in TEE Table 749-5, nor were they readily available in the literature. However, Breimer et al. (1989) and Vogel and Ottow (1991) evaluated fluoride contamination of soils and earthworms near a site of long-term industrial emission in southern Germany. These two papers provide sufficient data to calculate a BAF. Soil concentrations were reported for total fluoride, hydrochloride-extractable fluoride, and water-extractable fluoride. Good correlation between total fluoride in earthworms and all three soil fluoride fractions was observed, and the authors conclude that fluoride is accumulated in earthworm tissue. Differences in earthworm fluoride fractions are attributed to soil chemistry.

A fluoride BAF was calculated using the literature-reported soil concentrations (Breimer et al. 1989) and earthworm tissue concentrations (Vogel et al. 1991). These two studies characterize study sample locations based on the range of acid soluble fluoride as non-polluted (less than 100 mg/kg), moderately polluted (100 to 200 mg/kg), or heavily polluted (greater than 200 mg/kg). These designations are used herein for the purpose of calculating the earthworm BAF. Soil concentration values were determined by measuring the bar heights of the Breimer et al. (1989) soil concentrations summary figure using Adobe Acrobat measuring tools (see Table I-1-2). Earthworm tissue (including gut content[5]) data were summarized by mean and range of concentration for several earthworm species collected from non-polluted and polluted collection areas. These data are transcribed directly into Table I-1-3.

[5] Earthworm tissue including gut content was used under the assumption that worms would be consumed whole by the wildlife receptors.

For the purpose of estimating a BAF, total fluoride soil data from moderately and heavily polluted areas were combined into a single "polluted" category, consistent with the presentation of the worm data. As a way to incorporate the variability of the soil and tissue data into the BAF computation, a Monte Carlo simulation was performed (see Table I-1-4). The mean and standard deviation was calculated for the non-polluted and polluted total fluoride soil and earthworm datasets. The mean BAFs for the non-polluted (0.288) and polluted (0.541) sites were calculated separately using 10,000 Monte Carlo iterations. The average of the non-polluted and polluted BAFs (0.401) was used as the final BAF for estimating earthworm tissue concentrations in the shrew and robin wildlife exposure models.

A plant uptake coefficient was not available in TEE Table 749-5; therefore, the literature was reviewed for applicable data. While plant uptake values were not reported directly in the literature reviewed, Weinstein and Davidson (2004) report that, "Plants growing in soils that contain up to about 600-800 mg/kg fluoride usually have from <2 to about 20 mg/kg." From this information, a conservative fluoride plant uptake coefficient (Kplant) of 0.033 was estimated by dividing 20 mg/kg plant tissue by 600 mg/kg soil. This Kplant value was applied in the meadow vole wildlife exposure model.

Table I-1-2
Summary of Total and Acid-soluble Fluoride Concentrations in Topsoil Samples

Estimated Total Fluoride[1]	Estimated Acid-soluble Fluoride[1]	Pollution Category
947.8	565.2	Heavy
1,026.1	460.9	Heavy
495.7	113.0	Moderate
626.1	130.4	Moderate
460.9	87.0	Non-polluted
643.5	69.6	Non-polluted
130.4	34.8	Non-polluted
452.2	52.2	Non-polluted
139.1	34.8	Non-polluted
330.4	52.2	Non-polluted

Notes:
1 = Units are milligram per kilogram Source: Breimer et al. (1989)

Table I-1-3
Summary of Topsoil and Earthworm Fluoride Concentrations
Used to Calculate Bioconcentration Factor

Soil Acid-soluble Fluoride Range[1]	Parameter[1]	Soluble Fluoride[1]	Total Fluoride[1]
Non-polluted Category (<100)	Mean	55.1	359.4
	SD	20.3	200.7
Moderate and Heavy Pollution Category (100 to >200)	Mean	317.4	773.9
	SD	230.0	253.7

Worm Species	Non-polluted			Polluted		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
Lr	64	15	221	323	145	563
Lc	82	26	217	280	157	525
Lt	90	44	177	254	43	521
Ac	175	--	--	322	76	515
Ar	--	--	--	518	--	--
Al	--	--	--	408	--	--
Ol	--	--	--	449	353	556
L spp.	86	15	331	303	93	724
A spp.	111	78	175	355	113	588
Mean	**101.3**	**--**	**--**	**356.9**	**--**	**--**
SD	**39.1**	**--**	**--**	**85.8**	**--**	**--**

Notes:
1 = Units are milligram per kilogram
Total fluoride soil data source: Breimer et al. (1989)
Total fluoride earthworm with gut content data source: Vogel and Ottow (1991)
A = *Aporrectodea*
Ac = *Aporrectodea caliginosa*
Al = *Aporrectodea longa*
Ar = *Aporrectodea rosea*
L = *Lumbricus*
Lc = *Lumbricus castaneus*
Lr = *Lumbricus rubellus*
Lt = *Lumbricus terrestris*
Ol = *Octolasion lacteum* and *Octolasion cyaneum*
SD = standard deviation
spp. = species (plural)

Table I-1-4
Summary of Monte Carlo Estimate of Bioaccumulation Factor

Pollution Category	Mean BAF[1,2,3]	Lower CL	Upper CL	Valid Iterations
Non-polluted	0.288	0.035	1.265	10,000
Moderate and Heavy Pollution	0.514	0.238	1.018	10,000
Average BAF	**0.401**	--	--	--

Notes:
1 = Mean BAF is calculated as the ratio of total fluoride in earthworm tissue to total fluoride in soil.
2 = Reported mean BAF is the result from 10,000 Monte Carlo iterations.
3 = Average of the polluted and non-polluted Monte Carlo-derived BAFs was used in the wildlife exposure model for robins and shrews.
BAF = bioaccumulation factor
CL = confidence limit

3.1.1.1.3 Fluoride Bioaccessibility Evaluation

As documented in Section 6 of this RI/FS, the major mineralogy of natural alluvial soils at the site consists of quartz, plagioclase (calcium-rich) feldspar, alkali (sodium or potassium) feldspar, and smectite clay (montmorillonite). Calcium and magnesium are the predominant exchangeable cations in native montmorillonite. Iron, aluminum, and manganese oxides are also ubiquitously present in varying amounts and likely form surface coatings on the other mineral particles. The spatial distribution of fluorite (calcium fluoride), albite, and plagioclase in the subsurface provides evidence for natural attenuation of dissolved fluoride concentrations, both vertically and laterally, as groundwater flows from the southern area near the cryolite ditches northward across the test area. The soil mass of calcium present in plagioclase feldspar and smectite is much larger than the mass of fluoride in the alkaline groundwater, providing a robust mechanism for fluorite precipitation to control downgradient dissolved fluoride concentrations. In other words, the chemical nature of the site soils limits dissolved fluoride, and fluoride is predominantly present in mineral forms that are unlikely to be bioaccessible or toxic to terrestrial biota.

Animal test data demonstrate significant differences between the toxicity of sodium fluoride (NaF) and calcium fluoride (CaF_2). Rat data from Toxnet (2013; http://toxnet.nlm.nih.gov/) show a difference of two orders of magnitude in acute gavage lethal concentration 50 (LC50) values for NaF (32 mg/kg) and CaF2 (4250 mg/kg). Because all of the available literature toxicity data for wildlife were from exposures to sodium fluoride, the chemical properties of

NaF and CaF_2[6] were compared. To this end, the bioaccessibility of fluoride compounds was evaluated using the REACT application of the Geochemist's Workbench geochemical modeling platform (Bethke 2006) to calculate fluoride solubility under simulated gut fluid conditions as represented in physiologically based extraction tests (PBETs)[7]. The physical (temperature and liquid-to-solid ratio) and geochemical (pH and fluid chemistry) conditions for the gastric and intestinal phases of the PBET were defined based on protocols described by Moriarty et al. (2012) for the shrew and Kaufmann et al. (2007) for the shrew and robin. Because the low pH gastric and neutral intestinal conditions are similar for the shrew and robin, the geochemical modeling results were applied to both species.

The geochemical modeling results are provided in TEE Attachment 2. The model computes the soluble concentration of fluoride in the stomach and intestine fluids as a function of increasing soil fluoride concentrations. For the purpose of determining the relative bioaccessibility of CaF_2, the estimated percent dissolved fluoride fraction computed by the model was applied. Modeled gastric phase and intestinal phase conditions are summarized in Table I-1-5.

Table I-1-5
Summary of Geochemical Modeling Input Conditions

Gut Parameter	Gastric Phase	Intestinal Phase
Liquid/Solid Ratio	40	40
Temperature	37 ˚C	37 ˚C
Fluid Composition	pH = 1.8 (hydrochloride)	pH = 7 (sodium carbonate)
	0.4 M glycine	0.4 M glycine

Notes:
°C = degree Celsius
M = moles

[6] (http://en.wikipedia.org/wiki/Sodium_fluoride) and (http://en.wikipedia.org/wiki/Calcium_fluoride)
[7] PBET tests provide a laboratory bench-scale test of bioaccessibility by simulating the chemical uptake via the stomach and intestines. The properties of the stomach acid and intestinal digestive fluids are mimicked using flasks containing acids, glycine, sodium chloride, and other chemicals found in these organs. The synthetic digestive fluids are spiked with soil and agitated. The resulting dissolved fraction is measured to estimate the bioaccessible concentration.

At low CaF_2 concentrations in the gastric phase, essentially all of the fluoride is dissolved. Dissolved fluoride concentrations increase with increasing CaF_2 concentrations until a saturation threshold is reached above which fluoride concentrations are controlled by the solubility of CaF_2. The saturation threshold depends on fluid chemistry, particularly pH and calcium concentration. Because of the low pH in the gastric fluid, this concentration is relatively high at approximately 5,460 mg/kg. By comparison, in the intestinal phase, the saturation threshold occurs at approximately 655 mg/kg. In addition, the geochemical model was applied to evaluate fluoride solubility in a simulated earthworm gut. In this case, the parameters were as follows: ratio of liquid to solid = 100; 0.01 moles of calcium chloride ($CaCl_2$); pH = 7; temperature = 25°Celsius. In the case of the simulated earthworm gut, the saturation threshold was approximately 250 mg/kg. The percent reduction in predicted CaF_2 bioaccessibility becomes a linear function of soil concentration after the solubility threshold is reached.

The model results were applied as a modification to the relative gut absorption factor (RGAF) in the TEE equations (TEE Table 749-5). The ratio assumed that the modeled dissolved fraction was 100 percent bioaccessible and that the intestinal retention time was twice that of the stomach. The predicted model bioaccessibility ratios were applied to the concentration of fluoride calculated to be protective of the robin under the default assumption of 100 percent gut absorption (e.g., 100 percent bioaccessibility). The TEE protective soil concentration calculated assuming a RGAF of 1 is approximately 1,400 mg/kg for the robin. At this concentration, the modeled CaF_2 bioaccessibility would be approximately 65 percent to 100 percent in the stomach and 48 percent in the intestine. Therefore, an RGAF of 0.65 was applied for the robin. A slightly lower RGAF of 0.62 was calculated for the shrew using this method.

Additionally, the default TEE equation (TEE Table 749-5) was modified to apply the RGAF to both incidental soil ingestion and earthworm content. This is consistent with the use of total earthworm fluoride (e.g., gut soil content and tissue) in the calculation of the BAF. It is also consistent with the fact that CaF_2 is relatively insoluble (28 percent) at the TEE protective soil concentration for the robin, calculated assuming an RGAF of 1 (1,400 mg/kg).

3.1.1.2 Cyanide

The default TEE wildlife exposure model (TEE Tables 749-4 and 749-5) does not include data for cyanide. Therefore, a literature review was conducted to identify TRVs, BAF, and plant uptake factors. Mammalian toxicity data for cyanide were adopted from Sample et al. (1996), and the TRVs for the short-tailed shrew and meadow vole were applied. The toxicity data for these wildlife receptors consisted of one "no observable adverse effect level" (NOAEL) for rat. The NOAEL was converted to a LOAEL by multiplying by an uncertainty factor of 10, consistent with the methods applied by Sample et al. (1996).

Avian toxicity data were not identified by Sample et al. (1996), but Eisler (1991) presents the results of an 8-week dietary study of the domestic chicken. Chickens fed a cassava diet containing up to 103 mg total cyanide per kg ration showed no significant effects on survival, growth, histology, hemoglobin, hematocrit, or lymphocyte number. Eisler (1991) does not provide a dose for these data, so the scaling assumptions applied for the chicken by Sample et al. (1996) were applied to estimate the NOAEL dose in units of mg/kg-body weight per day. There is some indication that domestic chickens may be more resistant to cyanide than some other birds, particularly those that feed predominately on flesh, such as vultures, kestrels, or owls. In order to ensure that a conservative dose was obtained, the body weight and feeding rate for 5-week-old chicks, 0.534 kg and 0.044 kg per day, respectively, were applied to the model.

Eisler summarizes the effects of cyanide on mammals and notes that cyanide has low persistence in the environment and is not observed to be accumulated or stored in any mammal studies and that cyanide biomagnification in food webs has not been reported (1991). BAF or plant uptake coefficients were not found in the literature. For the purposes of this TEE, it was conservatively assumed that the BAF and Kplant were 1.

3.1.2 Risk Characterization

Benzo(a)pyrene, cyanide, fluoride and total PCB Aroclor were identified as COPECs. For benzo(a)pyrene and total PCB Aroclor, default ecological indicator soil concentrations (TEE Table 749-3) were applied to characterize potential risk. For cyanide and fluoride, a site-specific TEE was conducted using the standard wildlife exposure models for the robin, shrew, and vole (TEE Table 749-4). As detailed in Section 3.1.1, data from the literature were used to identify TRVs, worm BAF, and plant uptake coefficients that were not included in TEE Table 749-5. For fluoride, the RGAF was modified based on geochemical modeling taking into account the finite solubility of calcium fluoride. The proportions of contaminated food, food and soil ingestion rates, and home ranges were applied as presented in TEE Table 749-4. The fluoride and cyanide indicator soil concentrations calculated for the robin, shrew, and vole are summarized in Table I-1-6. The lowest value for fluoride was based on the avian predator (American robin) at 2,110 mg/kg. The lowest value for cyanide was based on the robin, at 65.7 mg/kg.

Table I-1-6
Summary of Soil Concentrations for Protection of Wildlife

Chemical	Mammalian Predator (Shrew)[1]	Avian Predator (Robin)[1]	Mammalian Herbivore (Vole)[1]
Fluoride	2,570	2,110[2]	6,300
Cyanide	6,180	65.7[2]	3,360

Notes:
1 = Units are milligram per kilogram.
2 = Protective soil concentration.

The maximum concentration of total cyanide in site soils was observed at station AS-SSA7-05 at 24.4 mg/kg. This value is well below the protective concentration, so no risk to terrestrial biota is indicated for cyanide. Additionally, this station is located within SU10, which will be remediated.

Mean station fluoride concentrations (i.e., average of samples within the 0 to 6 interval at a given station) ranged from 65 mg/kg at station PZ3 to 65,900 mg/kg at station GC-LY-01. The majority of stations with average fluoride concentrations above the fluoride protective soil concentration were located within established SUs, particularly SU3, SU4, SU5, SU6, and SU7 in the East Groundwater Area, and SU10 adjacent to the Columbia River. Adjacent to SU3, SU4, SU5, SU6, and SU7, in small patches of potential habitat, average fluoride concentrations at three stations—LYS1 (523 mg/kg), SPLP3 (732 mg/kg), and GC-SB-04 (614 mg/kg)—were below the fluoride protective soil concentration, indicating that elevated fluoride soil concentrations are confined to the SUs. Adjacent to SU10, in an area where habitat could support use by terrestrial receptors, average fluoride concentrations at four stations—SSA7 01 (363 mg/kg), SSA7-02 (253 mg/kg), SSA7-09 (303 mg/kg), and SSA7-10 (629 mg/kg)—were below the fluoride protective soil concentration.

Of the 56 U-Ditch confirmation samples, two exceeded the fluoride protective soil concentration at stations S03W (2,450 mg/kg) and B02 (2,180 mg/kg). All other U-ditch confirmation samples were below the fluoride protective soil concentration, and the 95% upper confidence limit (UCL) on the mean was 829 mg/kg (TEE Attachment 3).

Six samples exceeded the benzo(a)pyrene wildlife screening level: DP1, DP10, PZ4, B21, DP14, and AQ-SSA4-05-2011. DP1 is within SU8. DP10, PZ4, B21, and DP14 are all within SU3. AQ-SSA4-05-2011 is within SU11. The overall exposure concentration to wildlife foraging the site was determined by calculating a 95% UCL using available soil data (see Attachment 3). The recommended ProUCL 95% UCL statistic on the benzo(a)pyrene dataset is the 97.5% KM (Chebyshev) UCL, with a value of 8.3 mg/kg. The benzo(a)pyrene 95% UCL is below the ecological indicator soil concentration of 12 mg/kg (TEE Table 749-3). Overall, current risk to wildlife from exposure to benzo(a)pyrene is likely to be very low and will be alleviated as areas SU3, SU8, and SU11 are remediated.

Two samples exceeded the total PCB wildlife screening level (total PCB Aroclor): AQ-SSA7-03-2011 and AQ-SSA7-05-2011, located within SU10. The overall exposure concentration to wildlife foraging the site was determined by calculating a 95% UCL using available soil data (see Attachment 3). The recommended ProUCL 95% UCL statistic on the total PCB Aroclor dataset is the 95% Adjusted Gamma KM-UCL, with a value of 0.54 mg/kg. The total PCB Aroclor 95% UCL is below the ecological indicator soil concentration of 0.65 mg/kg (TEE Table 749-3). Overall, current risk to wildlife from exposure PCB Aroclors is likely to be very low and will be alleviated as area SU10 is remediated.

3.1.3 Uncertainty Analysis

The primary sources of uncertainty in this site-specific TEE include limited toxicity reference data, limited bioaccumulation and plant uptake data, and differences in conditions between the site and toxicity study test conditions.

3.1.3.1 Toxicity Reference Data

Toxicity data from tests with dietary exposure were limited. The mammalian fluoride toxicity data used for the wildlife exposure model was based on mink dietary exposure to sodium fluoride. The avian toxicity value was based on quail and owl dietary exposures to sodium fluoride. Sodium fluoride is a salt that would result in a high fraction of bioaccessible fluoride ions in the exposure diet. As discussed in Section 3.1.3.2, the speciation of fluoride in site soils is expected to be in a form that limits bioaccessibility. Based on these differences, the literature toxicity data for fluoride are likely to overestimate toxicity from fluoride in site soil.

The mammalian toxicity data for cyanide were based on a rat study that used a dietary exposure to potassium cyanide. As noted in Section 3.1.1.1.3, cyanide rapidly forms chemical complexes in soil and is metabolized by microbes. As a result, cyanide has a low persistence in soil. Relative to the rat exposure, the bioaccessibility of cyanide at the site is expected to be low.

The avian toxicity data for cyanide was based on a domestic chicken study with dietary exposure to cyanide via the cassava plant, a cyanogenic plant species. This exposure method is likely to result in a higher dose of cyanide than would be obtained from earthworms at the site because cyanide does not biomagnify or cycle in living organisms (Eisler 1991). Therefore, relative to a diet of cassava plant, the bioaccessibility of cyanide in bird diets at the site is expected to be low.

The avian toxicity data for cyanide was based on an 8-week dietary exposure study of the domestic chicken. Eisler (1991) notes that the domestic chicken may be less sensitive to cyanide than other bird species. To provide a safety factor in the calculation of the cyanide soil protective wildlife concentration for avian carnivores, the dose was estimated using data for 5-week-old chicks. While a less conservative dose could have been calculated using body weight and food ingestion rates for 8-week-old chicks, the use of data for 5-week-old chicks helps ensure that the dose is protective of potentially more sensitive species, like the American robin. Based on the conservative assumptions, it is assumed that the calculated protective cyanide soil concentration would overestimate risk to wildlife from site soil exposure.

3.1.3.2 Worm Bioaccumulation Factors and Plant Uptake Coefficients

For fluoride, the worm BAF was calculated using data for worms and soil reported for a site in southern Germany. Details on the calculation of the worm BAF value, which used a Monte Carlo approach to account for variability in the soil and worm datasets, are provided in Section 3.1.1.1.2. While the variability around the BAF values is relatively high, the use of mean values is assumed to be a reasonable estimate of the fluoride BAF. For the Kplant value, a conservative approach was applied to literature-derived soil and plant tissue values to calculate the maximum Kplant value that could be obtained from the data. Given the uncertainty around the fluoride Kplant value, this conservative approach is considered appropriate but may overestimate the actual plant uptake of fluoride from site soils.

For cyanide, no data were available on which to estimate the BAF or Kplant values. Therefore, a value of 1 was applied for both of these parameters. Given the labile nature of cyanide in soil, it is likely that a BAF of 1 overestimates the true bioaccumulation by worms. Although some plants may be cyanogenic, the Kplant value of 1 was considered conservative because cyanogenic properties are unrelated to soil conditions. As such, the Kplant value may overestimate actual plant uptake of cyanide from site soils.

3.1.3.3 Bioaccessibility Differences Between Toxicity Test and Site Conditions

The fluoride ion is responsible for toxicity, and the geochemistry of fluoride at the site is likely to result in lower exposure to toxic forms than the exposures to the sodium fluoride salt in the mink or owl experiments. Similarly, the bioaccessibility of fluoride to plants and earthworms is based on the site geochemistry and is expected to be low. Geochemical modeling calibrated with site data has been performed in support of groundwater fate and transport evaluations. The leaching of fluoride from source area soils is limited by the geochemical properties of the soils and groundwater, indicating that the proportion of fluoride ions in soils at the site available to terrestrial biota is low.

Site soils have a high capacity to bind fluoride ions into mineral forms that are unlikely to be bioaccessible or toxic to terrestrial biota. The uncertainty associated with differences between site conditions and fluoride toxicity data is that the available toxicity data may overestimate the potential risk from exposure to site soils.

The use of potassium cyanide in the dietary rat study may overestimate the toxicity of cyanide in site soils due to complexation, which would reduce bioaccessibility. Similarly, the use of cassava plants as the source of cyanide to the domestic chicken would not accurately represent exposure to birds from cyanide in site soils. The uncertainty associated with differences between site conditions and the available cyanide toxicity data is that the available toxicity data may overestimate the potential risk from exposure to site soils. Based on the conservative assumptions, it is assumed that the calculated protective fluoride soil concentration would overestimate risk to wildlife from site soil exposure.

4 CONCLUSIONS

The Reynolds Facility is a former aluminum reduction plant, and the majority of the site area is covered by industrial infrastructure and on-site landfills. The site contains at least 10 acres of mixed native and invasive vegetation within 500 feet of areas where contamination is located, so a site-specific TEE was conducted in accordance with WAC 173-340-7490. COPECs were identified using conservative screening benchmarks. Fluoride and cyanide were the only COPECs present in potential habitat areas and were, therefore, the focus of the TEE. Methods for conducting the site-specific TEE included a literature survey for toxicity and bioaccumulation data and site-specific geochemical modeling to address fluoride bioaccessibility.

Cyanide concentrations in all site soil samples were below the calculated protective concentration. Therefore, cyanide is unlikely to pose a risk to terrestrial wildlife at the site.

Fluoride concentrations in site soils exceeded the calculated protective concentration in areas of the site that have been designated as remediation SUs. Outside of the designated SUs, only two samples in the U-Ditch area exceeded the protective fluoride soil concentration. The U-Ditch area 95% UCL was less than the protective soil fluoride concentration. Therefore, fluoride is unlikely to pose a risk to terrestrial wildlife at the site.

Benzo(a)pyrene and total PCB Aroclor concentrations in site soils exceeded the ecological indicator soil concentrations in areas of the site that have been designated as remediation SUs. On a site-wide basis, the 95% UCLs for these chemicals are less than their respective protective concentrations. Therefore, benzo(a)pyrene and total PCB Aroclors are unlikely to pose a risk to terrestrial wildlife at the site.

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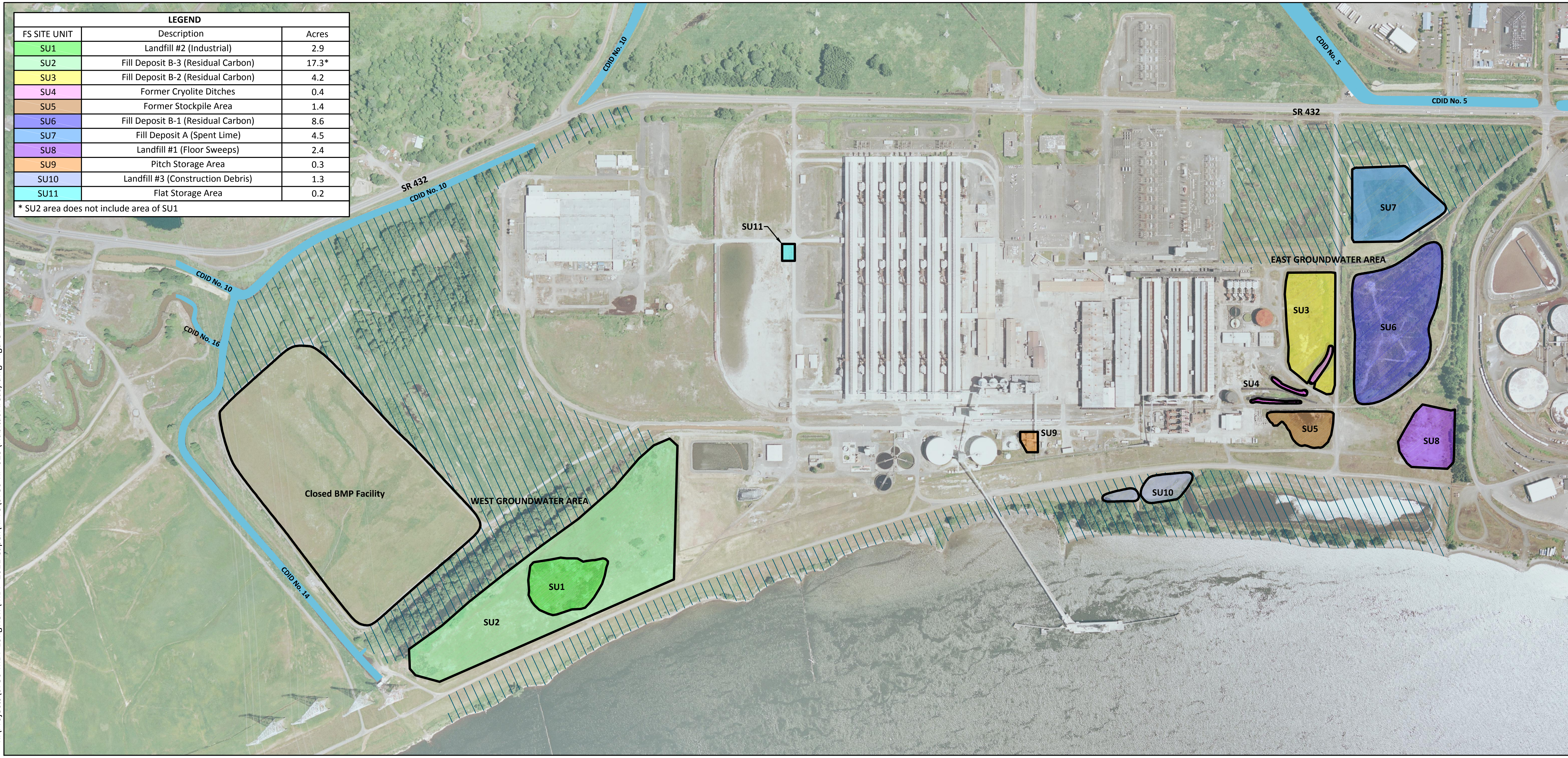
FIGURE

LEGEND		
FS SITE UNIT	Description	Acres
SU1	Landfill #2 (Industrial)	2.9
SU2	Fill Deposit B-3 (Residual Carbon)	17.3*
SU3	Fill Deposit B-2 (Residual Carbon)	4.2
SU4	Former Cryolite Ditches	0.4
SU5	Former Stockpile Area	1.4
SU6	Fill Deposit B-1 (Residual Carbon)	8.6
SU7	Fill Deposit A (Spent Lime)	4.5
SU8	Landfill #1 (Floor Sweeps)	2.4
SU9	Pitch Storage Area	0.3
SU10	Landfill #3 (Construction Debris)	1.3
SU11	Flat Storage Area	0.2

* SU2 area does not include area of SU1



K:\Projects\0730-MBT-Longview\MBT- 2011 Capex\RI-FS\0730-RP-023 (Habitat Areas).dwg Figure I-1-1

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SOURCE: Aerial image from Aerometric dated June 2013.

LEGEND:

Habitat Areas evaluated as part of the Terrestrial Ecological Evaluation (TEE)

0 600
Scale in Feet

ANCHOR QEA

Figure I-1-1
Habitat Areas and FS Site Units
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview

ATTACHMENT 1
FLUORIDE AND CYANIDE TEE CALCULATIONS

Attachment 1a
Fluoride TEE Calculations

Factors	Def	Value	Units	Description
T(shrew)	TRV shrew	150.7	mg/kg-day	short-tailed shrew LOAEL, based on mink chronic LOAEL
FIR(shrew)	food ingestion rate	0.45	kg dry weight/kg body weight day	default
PSb(shrew)	Portion of contaminated food (eartheworm in diet)	0.5	unitless	default
BAF(worm)	earthworm bioaccumlation	0.401	mg/kg / mg/kg (unitless)	Briemer (1989) and Vogel and Ottow (1991) to estimate BAF.
SIR(shrew)	soil ingestion rate	0.0045	kg dry soil/kg body weight - day	default
RGAF(soil, shrew)	gut absorption	1	unitless	default
T(robin)	TRV robin	88.5	mg/kg -day	American robin LOAEL, based on average of Japanese quail and screech owl data
FIR(robin)	food ingestion rate	0.207	kg dry food/kg body weight -day	default
PSb(robin)	proportion of contaminated food (soil biota) in Robin diet	0.52	unitless	default
SIR(robin)	soil ingestion rate	0.0215	kg dry soil/kg body weight -day	default
RGAF(soil, robin)	gut absorption	1	unitless	default
T(vole)	TRV vole	115.2	mg/kg-day	Meadow vole chronic LOAEL, based on chronic mink LOAEL (Sample et al., 1996)
FIR(vole)	food ingestion rate	0.315	kg dry food/kg body weight -day	default
P(plant, vole)	proportion of contaminated food (soil biota) in Robin diet	1	unitless	default
Kplant	plant uptake coefficient	0.033	mg/kg plant/ mg/kg soil	Based on Weinstein and Davidson 2004.
SIR(vole)	soil ingestion rate	0.0079	kg dry soil/kg body weight day	default
RGAF(soil, vole)	gut abosrbtion factor	1	unitless	default

Mammalian predator:	
1590.52	mg/kg
Avain predator:	
1368.38	mg/kg
Mammalian herbivore:	
6296.80	mg/kg

Formula below modified to apply RGAF to food and soil ingestion		RGAF	RGAF determined based on modeled solubility of CaF2 under stomach and intestinal pH environments
RGAF(soil+food, shrew)		0.62	applied to earthworm and soil ingestion
RGAF(soil+food, robin)		0.65	applied to earthworm and soil ingestion

Mammalian predator:	
2565.36	mg/kg
Avain predator:	
2105.20	mg/kg

Attachment 1b
Cyanide TEE Calculations

Factors	Definition	Value	Units	Description
T(shrew)	TRV shrew	1419	mg/kg-day	Short-tailed shrew LOAEL, based on rat chronic NOAEL. Sample et al. (1996). Consumption of 500 ppm CN significantly reduced offspring growth and food consumption, however values for treated individuals were only marginally less than controls (reductions were 7% or less). While the effects of 500 ppm Cn in the diet were statistically significant, they were not considered to be biologically significant. Because the study considered exposure throughout a critical lifestage (reproduction), this dose was considered to be a chronic NOAEL. Applied a 10x uncertainty factor per Sample et al. (1996)
FIR(shrew)	food ingestion rate	0.45	kg dry weight/kg body weight day	default
PSb(shrew)	Portion of contaminated food (earthworm in diet)	0.5	unitless	default
BAF(worm)	earthworm bioaccumulation	1.000	mg/kg / mg/kg (unitless)	Expect low bioaccumulation. Used 1 to be conservative. Likely much lower BAF.
SIR(shrew)	soil ingestion rate	0.0045	kg dry soil/kg body weight - day	default
RGAF(soil, shrew)	gut absorption	1	unitless	default
T(robin)	TRV robin	8.49	mg/kg -day	Chicken LOAEL. Domestic chicken from Eisler (1991). 103 mg/kg dietary concentration of CN during 8-week study. Used Sample et al. (1996) scaling assumptions to estimate dose . Assumed 5 week-old chicks. Body weight: 0.534 kg Food Consumption: 0.044 kg/d
FIR(robin)	food ingestion rate	0.207	kg dry food/kg body weight -day	default
PSb(robin)	proportion of contaminated food (soil biota) in Robin diet	0.52	unitless	default
SIR(robin)	soil ingestion rate	0.0215	kg dry soil/kg body weight -day	default
RGAF(soil, robin)	gut absorption	1	unitless	default
T(vole)	TRV vole	1084	mg/kg-day	Meadow vole chronic LOAEL, based on chronic rat NOAEL (Sample et al., 1996). Consumption of 500 ppm CN significantly reduced offspring growth and food consumption, however values for treated individuals were only marginally less than controls (reductions were 7% or less). While the effects of 500 ppm Cn in the diet were statistically significant, they were not considered to be biologically significant. Because the study considered exposure throughout a critical lifestage (reproduction), this dose was considered to be a chronic NOAEL. Applied a 10x uncertainty factor per Sample et al. (1996)
FIR(vole)	food ingestion rate	0.315	kg dry food/kg body weight -day	default
P(plant, vole)	proportion of contaminated food (soil biota) in Robin diet	1	unitless	default
Kplant	plant uptake coefficient	1	mg/kg plant/ mg/kg soil	Expect low soil uptake. Used 1 to be conservative. Likely much lower Kplant.
SIR(vole)	soil ingestion rate	0.0079	kg dry soil/kg body weight day	default
RGAF(soil, vole)	gut abosrbtion factor	1	unitless	default

Mammalian predator:	
6183.01	mg/kg
Avian predator:	
65.74	mg/kg
Mammalian herbivore:	
3357.08	mg/kg

ATTACHMENT 2
GEOCHEMICAL MODELING RESULTS: SOIL FLUORIDE BIOACCESSIBILITY

DEVELOPMENT OF SITE-SPECIFIC RELATIVE GUT ABSORPTION FACTOR VALUES FOR AVIAN AND MAMMALIAN PREDATORS

This attachment provides supplemental information regarding the site-specific terrestrial ecological evaluation (TEE) provided in Appendix I-1 of the Remedial Investigation (RI)/ Feasibility Study (FS) for the Former Reynolds Metals Reduction Plant (Former Reynolds Plant). The RI/FS and TEE provide details on the chemical composition of site soils. Attachment 2 provides estimates of how site-specific values for the relative gut absorption factor (RGAF) were developed for fluoride for use in the TEE.

Background

As discussed in the TEE, fluoride can be present in several different mineral forms. The fluoride present at the Former Reynolds Plant was associated with an on-site recycling process, which used calcium to separate and recover fluoride and aluminum from residual carbon. Fluoride remaining in the residual carbon and other plant fill materials is predominantly present as calcium fluoride (CaF_2), which is much less toxic and less bioavailable to terrestrial biota than sodium fluoride (NaF).

The modeling was performed specifically for the predatory shrew and robin because these two species were determined to be the most sensitive receptor species (default soil protective concentrations approximately five times lower [more stringent] than for the herbivorous vole).

Bioaccessibility Modeling

The physical (temperature and liquid-to-solid ratio) and chemical (pH and fluid chemistry) conditions for the gastric and intestinal phases of the bioaccessibility model were based on literature values and are detailed in TEE. These parameters are defined (Moriarty et al. 2012). The output of chemical equilibrium modeling used to calculate fluoride solubility under simulated gut fluid conditions for these receptors is attached as Attachment 2a (shrew and robin) and Attachment 2b (earthworm).

For the purpose of determining the relative bioaccessibility of CaF_2, the estimated percent dissolved fluoride fraction computed by the chemical equilibrium model for the stomach and intestinal phases was applied. Because of the low pH in the gastric fluid, essentially all of the fluoride in the stomach is dissolved at or below CaF_2 concentrations of 5,460 mg/kg. By comparison, in the neutral pH intestinal phase, the saturation threshold occurs at approximately 655 mg/kg. In the case of the simulated neutral pH earthworm gut, the saturation threshold was approximately 250 mg/kg. The percent reduction in predicted CaF_2 bioaccessibility becomes a linear function of soil concentration after the solubility threshold is reached.

RGAF Estimates

To calculate the modified RGAF for the robin and shrew, the following steps were performed:

- Determine the protective soil concentration for robin and shrew assuming an RGAF of 1. These concentrations are 1,370 mg/kg and 1,590 mg/kg, respectively.
- Determine the modeled percent solubility of CaF_2 in the gastric and intestinal phases at concentrations of 1,370 and 1,590 mg/kg.
  - In the gastric phase, CaF_2 is essentially 100% soluble at both concentrations.
  - In the intestinal phase, CaF_2 is approximately 48% soluble at a concentration of 1,370 mg/kg. CaF_2 is approximately 43% soluble at a concentration of 1,590 mg/kg.
- Assuming the intestinal retention time is twice that of the stomach, the modified RGAF was determined as follows:

$$Modified\ RGAF = \left(\%Gastric\ solubility\ \times\ {}^{1}/_{3}\right) + \left(\%Intestinal\ solubility\ \times\ {}^{2}/_{3}\right)$$

The resulting modified RGAFs for robin and shrew are 0.65 and 0.62, respectively.

Application of the Site-specific RGAF

The default wildlife exposure model equation for calculating the protective soil concentrations for mammalian and avian predators only applies the RGAF to the soil ingestion term (Ecology Table 749-4). For this site-specific TEE, the equation was adjusted to apply the modified RGAF to both soil ingestion and ingestion of soil biota (e.g., earthworms). This was done for two reasons. First, the earthworm bioaccumulation factor was based on total earthworm fluoride (e.g., gut soil content and tissue), and earthworms living in site soil will contain the same form of fluoride in their gut. Second, the earthworm gut has a neutral pH, and the solubility of CaF_2 in earthworm gut is low. Therefore, the predominant form of fluoride associated with earthworms was assumed to be the same as site soil and subject to the same bioaccessibility constraints that would apply to the digestion of soil. The resulting adjustment to the equation to calculate the soil protective concentration for mammalian and avian predators is as follows:

$$SCP = (TRV)/[(FIR \times PSB \times BAFworm \times RGAF) + (SIR \times RGAF)]$$

where:

SCP	=	Protective soil concentration for predators (avian and mammalian)
TRV	=	Toxicity reference value (literature-derived value)
FIR	=	Food ingestion rate (default value)
PSB	=	Portion of soil biota in diet (default value)
BAFworm	=	bioaccumulation factor for earthworm (literature-derived value)
SIR	=	Soil ingestion rate (default value)
RGAF	=	Relative gut absorption factor (literature-derived inputs to chemical equilibrium model)

Effects of Site-specific RGAF on TEE Outputs

Applying the adjusted equation with the model-derived RGAFs, literature-based TRVs and bioaccumulation factors, and default values for food ingestion, soil ingestion, and portion of soil biota in diet, the soil concentrations protective of robin and shrew are 2,110 and 2,570 mg/kg, respectively.

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Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
2.50E-05	1.22E-05	4.87E-01	1.22E-02	100%	4.87E-01
2.56E-05	1.25E-05	4.98E-01	1.25E-02	100%	4.99E-01
2.62E-05	1.28E-05	5.10E-01	1.28E-02	100%	5.10E-01
2.68E-05	1.31E-05	5.22E-01	1.31E-02	100%	5.22E-01
2.74E-05	1.34E-05	5.34E-01	1.34E-02	100%	5.34E-01
2.81E-05	1.37E-05	5.46E-01	1.37E-02	100%	5.47E-01
2.87E-05	1.40E-05	5.59E-01	1.40E-02	100%	5.60E-01
2.94E-05	1.43E-05	5.72E-01	1.43E-02	100%	5.73E-01
3.01E-05	1.46E-05	5.86E-01	1.46E-02	100%	5.86E-01
3.08E-05	1.50E-05	5.99E-01	1.50E-02	100%	5.99E-01
3.15E-05	1.53E-05	6.13E-01	1.53E-02	100%	6.13E-01
3.22E-05	1.57E-05	6.27E-01	1.57E-02	100%	6.28E-01
3.30E-05	1.61E-05	6.42E-01	1.61E-02	100%	6.42E-01
3.37E-05	1.64E-05	6.57E-01	1.64E-02	100%	6.57E-01
3.45E-05	1.68E-05	6.72E-01	1.68E-02	100%	6.73E-01
3.53E-05	1.72E-05	6.88E-01	1.72E-02	100%	6.88E-01
3.61E-05	1.76E-05	7.04E-01	1.76E-02	100%	7.04E-01
3.70E-05	1.80E-05	7.20E-01	1.80E-02	100%	7.21E-01
3.78E-05	1.84E-05	7.37E-01	1.84E-02	100%	7.37E-01
3.87E-05	1.89E-05	7.54E-01	1.89E-02	100%	7.55E-01
3.96E-05	1.93E-05	7.72E-01	1.93E-02	100%	7.72E-01
4.05E-05	1.98E-05	7.90E-01	1.98E-02	100%	7.90E-01
4.15E-05	2.02E-05	8.08E-01	2.02E-02	100%	8.08E-01
4.25E-05	2.07E-05	8.27E-01	2.07E-02	100%	8.27E-01
4.34E-05	2.12E-05	8.46E-01	2.12E-02	100%	8.46E-01
4.45E-05	2.17E-05	8.66E-01	2.17E-02	100%	8.66E-01
4.55E-05	2.22E-05	8.86E-01	2.22E-02	100%	8.86E-01
4.66E-05	2.27E-05	9.07E-01	2.27E-02	100%	9.07E-01
4.76E-05	2.32E-05	9.28E-01	2.32E-02	100%	9.28E-01
4.87E-05	2.37E-05	9.50E-01	2.37E-02	100%	9.50E-01
4.99E-05	2.43E-05	9.72E-01	2.43E-02	100%	9.72E-01
5.10E-05	2.49E-05	9.94E-01	2.49E-02	100%	9.94E-01
5.22E-05	2.54E-05	1.02E+00	2.54E-02	100%	1.02E+00
5.34E-05	2.60E-05	1.04E+00	2.60E-02	100%	1.04E+00
5.47E-05	2.66E-05	1.07E+00	2.66E-02	100%	1.07E+00
5.60E-05	2.73E-05	1.09E+00	2.73E-02	100%	1.09E+00
5.73E-05	2.79E-05	1.12E+00	2.79E-02	100%	1.12E+00
5.86E-05	2.85E-05	1.14E+00	2.85E-02	100%	1.14E+00
6.00E-05	2.92E-05	1.17E+00	2.92E-02	100%	1.17E+00
6.14E-05	2.99E-05	1.20E+00	2.99E-02	100%	1.20E+00
6.28E-05	3.06E-05	1.22E+00	3.06E-02	100%	1.22E+00
6.43E-05	3.13E-05	1.25E+00	3.13E-02	100%	1.25E+00
6.58E-05	3.20E-05	1.28E+00	3.20E-02	100%	1.28E+00
6.73E-05	3.28E-05	1.31E+00	3.28E-02	100%	1.31E+00
6.89E-05	3.35E-05	1.34E+00	3.35E-02	100%	1.34E+00

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
2.50E-05	1.22E-05	0.49	0.012	100%	0.49
2.56E-05	1.25E-05	0.50	0.012	100%	0.50
2.62E-05	1.28E-05	0.51	0.013	100%	0.51
2.68E-05	1.31E-05	0.52	0.013	100%	0.52
2.74E-05	1.34E-05	0.53	0.013	100%	0.53
2.81E-05	1.37E-05	0.55	0.014	100%	0.55
2.87E-05	1.40E-05	0.56	0.014	100%	0.56
2.94E-05	1.43E-05	0.57	0.014	100%	0.57
3.01E-05	1.46E-05	0.59	0.015	100%	0.59
3.08E-05	1.50E-05	0.60	0.015	100%	0.60
3.15E-05	1.53E-05	0.61	0.015	100%	0.61
3.22E-05	1.57E-05	0.63	0.016	100%	0.63
3.30E-05	1.61E-05	0.64	0.016	100%	0.64
3.37E-05	1.64E-05	0.66	0.016	100%	0.66
3.45E-05	1.68E-05	0.67	0.017	100%	0.67
3.53E-05	1.72E-05	0.69	0.017	100%	0.69
3.61E-05	1.76E-05	0.70	0.018	100%	0.70
3.70E-05	1.80E-05	0.72	0.018	100%	0.72
3.78E-05	1.84E-05	0.74	0.018	100%	0.74
3.87E-05	1.89E-05	0.75	0.019	100%	0.75
3.96E-05	1.93E-05	0.77	0.019	100%	0.77
4.05E-05	1.98E-05	0.79	0.020	100%	0.79
4.15E-05	2.02E-05	0.81	0.020	100%	0.81
4.25E-05	2.07E-05	0.83	0.021	100%	0.83
4.34E-05	2.12E-05	0.85	0.021	100%	0.85
4.45E-05	2.17E-05	0.87	0.022	100%	0.87
4.55E-05	2.22E-05	0.89	0.022	100%	0.89
4.66E-05	2.27E-05	0.91	0.023	100%	0.91
4.76E-05	2.32E-05	0.93	0.023	100%	0.93
4.87E-05	2.37E-05	0.95	0.024	100%	0.95
4.99E-05	2.43E-05	0.97	0.024	100%	0.97
5.10E-05	2.49E-05	0.99	0.025	100%	0.99
5.22E-05	2.54E-05	1.02	0.025	100%	1.02
5.34E-05	2.60E-05	1.04	0.026	100%	1.04
5.47E-05	2.66E-05	1.07	0.027	100%	1.07
5.60E-05	2.73E-05	1.09	0.027	100%	1.09
5.73E-05	2.79E-05	1.12	0.028	100%	1.12
5.86E-05	2.85E-05	1.14	0.029	100%	1.14
6.00E-05	2.92E-05	1.17	0.029	100%	1.17
6.14E-05	2.99E-05	1.20	0.030	100%	1.20
6.28E-05	3.06E-05	1.22	0.031	100%	1.22
6.43E-05	3.13E-05	1.25	0.031	100%	1.25
6.58E-05	3.20E-05	1.28	0.032	100%	1.28
6.73E-05	3.28E-05	1.31	0.033	100%	1.31
6.89E-05	3.35E-05	1.34	0.034	100%	1.34

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
7.05E-05	3.43E-05	1.37E+00	3.43E-02	100%	1.37E+00
7.21E-05	3.51E-05	1.40E+00	3.51E-02	100%	1.40E+00
7.38E-05	3.59E-05	1.44E+00	3.59E-02	100%	1.44E+00
7.55E-05	3.68E-05	1.47E+00	3.68E-02	100%	1.47E+00
7.73E-05	3.76E-05	1.50E+00	3.76E-02	100%	1.50E+00
7.91E-05	3.85E-05	1.54E+00	3.85E-02	100%	1.54E+00
8.09E-05	3.94E-05	1.58E+00	3.94E-02	100%	1.58E+00
8.28E-05	4.03E-05	1.61E+00	4.03E-02	100%	1.61E+00
8.47E-05	4.12E-05	1.65E+00	4.12E-02	100%	1.65E+00
8.67E-05	4.22E-05	1.69E+00	4.22E-02	100%	1.69E+00
8.87E-05	4.32E-05	1.73E+00	4.32E-02	100%	1.73E+00
9.08E-05	4.42E-05	1.77E+00	4.42E-02	100%	1.77E+00
9.29E-05	4.52E-05	1.81E+00	4.52E-02	100%	1.81E+00
9.50E-05	4.63E-05	1.85E+00	4.63E-02	100%	1.85E+00
9.73E-05	4.74E-05	1.89E+00	4.74E-02	100%	1.89E+00
9.95E-05	4.85E-05	1.94E+00	4.85E-02	100%	1.94E+00
0.000101845	4.96E-05	1.98E+00	4.96E-02	100%	1.98E+00
0.000104217	5.07E-05	2.03E+00	5.07E-02	100%	2.03E+00
0.000106645	5.19E-05	2.08E+00	5.19E-02	100%	2.08E+00
0.000109129	5.31E-05	2.13E+00	5.31E-02	100%	2.13E+00
0.000111671	5.44E-05	2.18E+00	5.44E-02	100%	2.17E+00
0.000114272	5.56E-05	2.23E+00	5.56E-02	100%	2.23E+00
0.000116934	5.69E-05	2.28E+00	5.69E-02	100%	2.28E+00
0.000119658	5.83E-05	2.33E+00	5.83E-02	100%	2.33E+00
0.000122445	5.96E-05	2.39E+00	5.96E-02	100%	2.38E+00
0.000125297	6.10E-05	2.44E+00	6.10E-02	100%	2.44E+00
0.000128215	6.24E-05	2.50E+00	6.24E-02	100%	2.50E+00
0.000131202	6.39E-05	2.56E+00	6.39E-02	100%	2.55E+00
0.000134258	6.54E-05	2.62E+00	6.54E-02	100%	2.61E+00
0.000137385	6.69E-05	2.68E+00	6.69E-02	100%	2.68E+00
0.000140585	6.84E-05	2.74E+00	6.84E-02	100%	2.74E+00
0.00014386	7.00E-05	2.80E+00	7.00E-02	100%	2.80E+00
0.000147211	7.17E-05	2.87E+00	7.17E-02	100%	2.87E+00
0.00015064	7.33E-05	2.93E+00	7.33E-02	100%	2.93E+00
0.000154149	7.50E-05	3.00E+00	7.50E-02	100%	3.00E+00
0.000157739	7.68E-05	3.07E+00	7.68E-02	100%	3.07E+00
0.000161414	7.86E-05	3.14E+00	7.86E-02	100%	3.14E+00
0.000165173	8.04E-05	3.22E+00	8.04E-02	100%	3.22E+00
0.000169021	8.23E-05	3.29E+00	8.23E-02	100%	3.29E+00
0.000172958	8.42E-05	3.37E+00	8.42E-02	100%	3.37E+00
0.000176986	8.62E-05	3.45E+00	8.62E-02	100%	3.45E+00
0.000181109	8.82E-05	3.53E+00	8.82E-02	100%	3.53E+00
0.000185328	9.02E-05	3.61E+00	9.02E-02	100%	3.61E+00
0.000189644	9.23E-05	3.69E+00	9.23E-02	100%	3.69E+00
0.000194062	9.45E-05	3.78E+00	9.45E-02	100%	3.78E+00

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
7.05E-05	3.43E-05	1.37	0.034	100%	1.37
7.21E-05	3.51E-05	1.40	0.035	100%	1.40
7.38E-05	3.59E-05	1.44	0.036	100%	1.44
7.55E-05	3.68E-05	1.47	0.037	100%	1.47
7.73E-05	3.76E-05	1.50	0.038	100%	1.50
7.91E-05	3.85E-05	1.54	0.038	100%	1.54
8.09E-05	3.94E-05	1.58	0.039	100%	1.58
8.28E-05	4.03E-05	1.61	0.040	100%	1.61
8.47E-05	4.12E-05	1.65	0.041	100%	1.65
8.67E-05	4.22E-05	1.69	0.042	100%	1.69
8.87E-05	4.32E-05	1.73	0.043	100%	1.73
9.08E-05	4.42E-05	1.77	0.044	100%	1.77
9.29E-05	4.52E-05	1.81	0.045	100%	1.81
9.50E-05	4.63E-05	1.85	0.046	100%	1.85
9.73E-05	4.74E-05	1.89	0.047	100%	1.89
9.95E-05	4.85E-05	1.94	0.048	100%	1.94
1.02E-04	4.96E-05	1.98	0.050	100%	1.98
1.04E-04	5.07E-05	2.03	0.051	100%	2.03
1.07E-04	5.19E-05	2.08	0.052	100%	2.08
1.09E-04	5.31E-05	2.13	0.053	100%	2.13
1.12E-04	5.44E-05	2.18	0.054	100%	2.17
1.14E-04	5.56E-05	2.23	0.056	100%	2.23
1.17E-04	5.69E-05	2.28	0.057	100%	2.28
1.20E-04	5.83E-05	2.33	0.058	100%	2.33
1.22E-04	5.96E-05	2.39	0.060	100%	2.38
1.25E-04	6.10E-05	2.44	0.061	100%	2.44
1.28E-04	6.24E-05	2.50	0.062	100%	2.50
1.31E-04	6.39E-05	2.56	0.064	100%	2.55
1.34E-04	6.54E-05	2.62	0.065	100%	2.61
1.37E-04	6.69E-05	2.68	0.067	100%	2.68
1.41E-04	6.84E-05	2.74	0.068	100%	2.74
1.44E-04	7.00E-05	2.80	0.070	100%	2.80
1.47E-04	7.17E-05	2.87	0.072	100%	2.87
1.51E-04	7.33E-05	2.93	0.073	100%	2.93
1.54E-04	7.50E-05	3.00	0.075	100%	3.00
1.58E-04	7.68E-05	3.07	0.077	100%	3.07
1.61E-04	7.86E-05	3.14	0.079	100%	3.14
1.65E-04	8.04E-05	3.22	0.080	100%	3.22
1.69E-04	8.23E-05	3.29	0.082	100%	3.29
1.73E-04	8.42E-05	3.37	0.084	100%	3.37
1.77E-04	8.62E-05	3.45	0.086	100%	3.45
1.81E-04	8.82E-05	3.53	0.088	100%	3.53
1.85E-04	9.02E-05	3.61	0.090	100%	3.61
1.90E-04	9.23E-05	3.69	0.092	100%	3.69
1.94E-04	9.45E-05	3.78	0.094	100%	3.78

Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.000198582	9.67E-05	3.87E+00	9.67E-02	100%	3.87E+00
0.000203208	9.89E-05	3.96E+00	9.89E-02	100%	3.96E+00
0.000207941	0.000101218	4.05E+00	1.01E-01	100%	4.05E+00
0.000212785	0.000103575	4.15E+00	1.04E-01	100%	4.14E+00
0.000217741	0.000105987	4.24E+00	1.06E-01	100%	4.24E+00
0.000222813	0.000108456	4.34E+00	1.08E-01	100%	4.34E+00
0.000228003	0.000110981	4.44E+00	1.11E-01	100%	4.44E+00
0.000233314	0.000113566	4.54E+00	1.14E-01	100%	4.54E+00
0.000238748	0.000116211	4.65E+00	1.16E-01	100%	4.65E+00
0.000244309	0.000118917	4.76E+00	1.19E-01	100%	4.76E+00
0.00025	0.000121687	4.87E+00	1.22E-01	100%	4.87E+00
0.000255823	0.000124521	4.98E+00	1.25E-01	100%	4.98E+00
0.000261782	0.000127421	5.10E+00	1.27E-01	100%	5.10E+00
0.00026788	0.000130389	5.22E+00	1.30E-01	100%	5.22E+00
0.00027412	0.000133425	5.34E+00	1.33E-01	100%	5.34E+00
0.000280505	0.000136533	5.46E+00	1.37E-01	100%	5.46E+00
0.000287038	0.000139712	5.59E+00	1.40E-01	100%	5.59E+00
0.000293724	0.000142966	5.72E+00	1.43E-01	100%	5.72E+00
0.000300566	0.000146296	5.86E+00	1.46E-01	100%	5.85E+00
0.000307567	0.000149703	5.99E+00	1.50E-01	100%	5.99E+00
0.000314731	0.00015319	6.13E+00	1.53E-01	100%	6.13E+00
0.000322062	0.000156758	6.27E+00	1.57E-01	100%	6.27E+00
0.000329564	0.000160409	6.42E+00	1.60E-01	100%	6.42E+00
0.000337241	0.000164145	6.57E+00	1.64E-01	100%	6.57E+00
0.000345096	0.000167968	6.72E+00	1.68E-01	100%	6.72E+00
0.000353134	0.00017188	6.88E+00	1.72E-01	100%	6.88E+00
0.00036136	0.000175883	7.04E+00	1.76E-01	100%	7.04E+00
0.000369777	0.000179979	7.20E+00	1.80E-01	100%	7.20E+00
0.00037839	0.000184171	7.37E+00	1.84E-01	100%	7.37E+00
0.000387204	0.00018846	7.54E+00	1.88E-01	100%	7.54E+00
0.000396223	0.00019285	7.72E+00	1.93E-01	100%	7.71E+00
0.000405453	0.000197341	7.90E+00	1.97E-01	100%	7.89E+00
0.000414897	0.000201938	8.08E+00	2.02E-01	100%	8.08E+00
0.000424561	0.000206641	8.27E+00	2.07E-01	100%	8.27E+00
0.00043445	0.000211454	8.46E+00	2.11E-01	100%	8.46E+00
0.00044457	0.000216379	8.66E+00	2.16E-01	100%	8.66E+00
0.000454925	0.000221418	8.86E+00	2.21E-01	100%	8.86E+00
0.000465522	0.000226575	9.07E+00	2.27E-01	100%	9.06E+00
0.000476365	0.000231852	9.28E+00	2.32E-01	100%	9.27E+00
0.000487461	0.000237253	9.50E+00	2.37E-01	100%	9.49E+00
0.000498816	0.000242778	9.72E+00	2.43E-01	100%	9.71E+00
0.000510434	0.000248433	9.94E+00	2.48E-01	100%	9.94E+00
0.000522324	0.000254219	1.02E+01	2.54E-01	100%	1.02E+01
0.000534491	0.00026014	1.04E+01	2.60E-01	100%	1.04E+01
0.00054694	0.000266199	1.07E+01	2.66E-01	100%	1.06E+01

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
1.99E-04	9.67E-05	3.87	0.097	100%	3.87
2.03E-04	9.89E-05	3.96	0.099	100%	3.96
0.000207941	0.000101218	4.05	0.101	100%	4.05
0.000212785	0.000103575	4.15	0.104	100%	4.14
0.000217741	0.000105987	4.24	0.106	100%	4.24
0.000222813	0.000108456	4.34	0.108	100%	4.34
0.000228003	0.000110981	4.44	0.111	100%	4.44
0.000233314	0.000113566	4.54	0.114	100%	4.54
0.000238748	0.000116211	4.65	0.116	100%	4.65
0.000244309	0.000118917	4.76	0.119	100%	4.76
0.00025	0.000121687	4.87	0.122	100%	4.87
0.000255823	0.000124521	4.98	0.125	100%	4.98
0.000261782	0.000127421	5.10	0.127	100%	5.10
0.00026788	0.000130389	5.22	0.130	100%	5.22
0.00027412	0.000133425	5.34	0.133	100%	5.34
0.000280505	0.000136533	5.46	0.137	100%	5.46
0.000287038	0.000139712	5.59	0.140	100%	5.59
0.000293724	0.000142966	5.72	0.143	100%	5.72
0.000300566	0.000146296	5.86	0.146	100%	5.85
0.000307567	0.000149703	5.99	0.150	100%	5.99
0.000314731	0.00015319	6.13	0.153	100%	6.13
0.000322062	0.000156758	6.27	0.157	100%	6.27
0.000329564	0.000160409	6.42	0.160	100%	6.42
0.000337241	0.000164145	6.57	0.164	100%	6.57
0.000345096	0.000167968	6.72	0.168	100%	6.72
0.000353134	0.00017188	6.88	0.172	100%	6.88
0.00036136	0.000175883	7.04	0.176	100%	7.04
0.000369777	0.000179979	7.20	0.180	100%	7.20
0.00037839	0.000184171	7.37	0.184	100%	7.37
0.000387204	0.00018846	7.54	0.188	100%	7.54
0.000396223	0.00019285	7.72	0.193	100%	7.71
0.000405453	0.000197341	7.90	0.197	100%	7.89
0.000414897	0.000201938	8.08	0.202	100%	8.08
0.000424561	0.000206641	8.27	0.207	100%	8.27
0.00043445	0.000211454	8.46	0.211	100%	8.46
0.00044457	0.000216379	8.66	0.216	100%	8.66
0.000454925	0.000221418	8.86	0.221	100%	8.86
0.000465522	0.000226575	9.07	0.227	100%	9.06
0.000476365	0.000231852	9.28	0.232	100%	9.27
0.000487461	0.000237253	9.50	0.237	100%	9.49
0.000498816	0.000242778	9.72	0.243	100%	9.71
0.000510434	0.000248433	9.94	0.248	100%	9.94
0.000522324	0.000254219	10.17	0.254	100%	10.17
0.000534491	0.00026014	10.41	0.260	100%	10.41
0.00054694	0.000266199	10.65	0.266	100%	10.65

Attachment 2a
Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.00055968	0.0002724	1.09E+01	2.72E-01	100%	1.09E+01
0.000572717	0.000278744	1.12E+01	2.79E-01	100%	1.11E+01
0.000586057	0.000285236	1.14E+01	2.85E-01	100%	1.14E+01
0.000599708	0.00029188	1.17E+01	2.92E-01	100%	1.17E+01
0.000613677	0.000298678	1.20E+01	2.99E-01	100%	1.19E+01
0.000627972	0.000305635	1.22E+01	3.06E-01	100%	1.22E+01
0.000642599	0.000312754	1.25E+01	3.13E-01	100%	1.25E+01
0.000657567	0.000320038	1.28E+01	3.20E-01	100%	1.28E+01
0.000672884	0.000327492	1.31E+01	3.27E-01	100%	1.31E+01
0.000688557	0.00033512	1.34E+01	3.35E-01	100%	1.34E+01
0.000704596	0.000342926	1.37E+01	3.43E-01	100%	1.37E+01
0.000721008	0.000350913	1.40E+01	3.51E-01	100%	1.40E+01
0.000737802	0.000359087	1.44E+01	3.59E-01	100%	1.44E+01
0.000754988	0.00036745	1.47E+01	3.67E-01	100%	1.47E+01
0.000772574	0.000376009	1.50E+01	3.76E-01	100%	1.50E+01
0.000790569	0.000384767	1.54E+01	3.85E-01	100%	1.54E+01
0.000808984	0.000393729	1.58E+01	3.94E-01	100%	1.57E+01
0.000827828	0.000402899	1.61E+01	4.03E-01	100%	1.61E+01
0.00084711	0.000412284	1.65E+01	4.12E-01	100%	1.65E+01
0.000866842	0.000421887	1.69E+01	4.22E-01	100%	1.69E+01
0.000887033	0.000431713	1.73E+01	4.32E-01	100%	1.73E+01
0.000907695	0.000441769	1.77E+01	4.42E-01	100%	1.77E+01
0.000928838	0.000452058	1.81E+01	4.52E-01	100%	1.81E+01
0.000950473	0.000462588	1.85E+01	4.63E-01	100%	1.85E+01
0.000972613	0.000473362	1.89E+01	4.73E-01	100%	1.89E+01
0.000995268	0.000484388	1.94E+01	4.84E-01	100%	1.94E+01
0.001018451	0.00049567	1.98E+01	4.96E-01	100%	1.98E+01
0.001042173	0.000507215	2.03E+01	5.07E-01	100%	2.03E+01
0.001066449	0.00051903	2.08E+01	5.19E-01	100%	2.08E+01
0.00109129	0.000531119	2.13E+01	5.31E-01	100%	2.12E+01
0.001116709	0.00054349	2.18E+01	5.43E-01	100%	2.17E+01
0.00114272	0.000556149	2.23E+01	5.56E-01	100%	2.22E+01
0.001169338	0.000569103	2.28E+01	5.69E-01	100%	2.28E+01
0.001196575	0.000582358	2.33E+01	5.82E-01	100%	2.33E+01
0.001224447	0.000595923	2.39E+01	5.96E-01	100%	2.38E+01
0.001252968	0.000609803	2.44E+01	6.10E-01	100%	2.44E+01
0.001282153	0.000624007	2.50E+01	6.24E-01	100%	2.50E+01
0.001312019	0.000638541	2.56E+01	6.39E-01	100%	2.55E+01
0.001342579	0.000653415	2.62E+01	6.53E-01	100%	2.61E+01
0.001373852	0.000668634	2.68E+01	6.69E-01	100%	2.67E+01
0.001405853	0.000684208	2.74E+01	6.84E-01	100%	2.74E+01
0.0014386	0.000700145	2.80E+01	7.00E-01	100%	2.80E+01
0.001472109	0.000716453	2.87E+01	7.16E-01	100%	2.87E+01
0.001506399	0.000733141	2.93E+01	7.33E-01	100%	2.93E+01
0.001541488	0.000750217	3.00E+01	7.50E-01	100%	3.00E+01

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.00055968	0.0002724	10.90	0.272	100%	10.90
0.000572717	0.000278744	11.16	0.279	100%	11.15
0.000586057	0.000285236	11.42	0.285	100%	11.41
0.000599708	0.00029188	11.68	0.292	100%	11.68
0.000613677	0.000298678	11.95	0.299	100%	11.95
0.000627972	0.000305635	12.23	0.306	100%	12.23
0.000642599	0.000312754	12.52	0.313	100%	12.51
0.000657567	0.000320038	12.81	0.320	100%	12.80
0.000672884	0.000327492	13.11	0.327	100%	13.10
0.000688557	0.00033512	13.41	0.335	100%	13.40
0.000704596	0.000342926	13.73	0.343	100%	13.72
0.000721008	0.000350913	14.05	0.351	100%	14.04
0.000737802	0.000359087	14.37	0.359	100%	14.36
0.000754988	0.00036745	14.71	0.367	100%	14.70
0.000772574	0.000376009	15.05	0.376	100%	15.04
0.000790569	0.000384767	15.40	0.385	100%	15.39
0.000808984	0.000393729	15.76	0.394	100%	15.75
0.000827828	0.000402899	16.13	0.403	100%	16.12
0.00084711	0.000412284	16.50	0.412	100%	16.49
0.000866842	0.000421887	16.89	0.422	100%	16.88
0.000887033	0.000431713	17.28	0.432	100%	17.27
0.000907695	0.000441769	17.68	0.442	100%	17.67
0.000928838	0.000452058	18.09	0.452	100%	18.08
0.000950473	0.000462588	18.52	0.463	100%	18.50
0.000972613	0.000473362	18.95	0.473	100%	18.93
0.000995268	0.000484388	19.39	0.484	100%	19.38
0.001018451	0.00049567	19.84	0.496	100%	19.83
0.001042173	0.000507215	20.30	0.507	100%	20.29
0.001066449	0.00051903	20.77	0.519	100%	20.76
0.00109129	0.000531119	21.26	0.531	100%	21.24
0.001116709	0.00054349	21.75	0.543	100%	21.74
0.00114272	0.000556149	22.26	0.556	100%	22.25
0.001169338	0.000569103	22.78	0.569	100%	22.76
0.001196575	0.000582358	23.31	0.582	100%	23.29
0.001224447	0.000595923	23.85	0.596	100%	23.84
0.001252968	0.000609803	24.41	0.610	100%	24.39
0.001282153	0.000624007	24.98	0.624	100%	24.96
0.001312019	0.000638541	25.56	0.639	100%	25.54
0.001342579	0.000653415	26.15	0.653	100%	26.14
0.001373852	0.000668634	26.76	0.669	100%	26.75
0.001405853	0.000684208	27.39	0.684	100%	27.37
0.0014386	0.000700145	28.02	0.700	100%	28.01
0.001472109	0.000716453	28.68	0.716	100%	28.66
0.001506399	0.000733141	29.34	0.733	100%	29.33
0.001541488	0.000750217	30.03	0.750	100%	30.01

Attachment 2a

Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc	Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg	g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.001577393	0.000767692	3.07E+01	7.68E-01	100%	3.07E+01	0.001577393	0.000767692	30.73	0.768	100%	30.71
0.001614136	0.000785573	3.14E+01	7.86E-01	100%	3.14E+01	0.001614136	0.000785573	31.44	0.786	100%	31.42
0.001651734	0.000803871	3.22E+01	8.04E-01	100%	3.22E+01	0.001651734	0.000803871	32.18	0.804	100%	32.15
0.001690207	0.000822595	3.29E+01	8.23E-01	100%	3.29E+01	0.001690207	0.000822595	32.93	0.823	100%	32.90
0.001729577	0.000841755	3.37E+01	8.42E-01	100%	3.37E+01	0.001729577	0.000841755	33.69	0.842	100%	33.67
0.001769864	0.000861362	3.45E+01	8.61E-01	100%	3.45E+01	0.001769864	0.000861362	34.48	0.861	100%	34.45
0.00181109	0.000881425	3.53E+01	8.81E-01	100%	3.53E+01	0.00181109	0.000881425	35.28	0.881	100%	35.26
0.001853276	0.000901956	3.61E+01	9.02E-01	100%	3.61E+01	0.001853276	0.000901956	36.10	0.902	100%	36.08
0.001896444	0.000922965	3.69E+01	9.23E-01	100%	3.69E+01	0.001896444	0.000922965	36.94	0.923	100%	36.92
0.001940618	0.000944463	3.78E+01	9.44E-01	100%	3.78E+01	0.001940618	0.000944463	37.80	0.944	100%	37.78
0.001985821	0.000966462	3.87E+01	9.66E-01	100%	3.87E+01	0.001985821	0.000966462	38.68	0.966	100%	38.66
0.002032076	0.000988973	3.96E+01	9.89E-01	100%	3.96E+01	0.002032076	0.000988973	39.58	0.989	100%	39.56
0.002079409	0.001012009	4.05E+01	1.01E+00	100%	4.05E+01	0.002079409	0.001012009	40.51	1.012	100%	40.48
0.002127845	0.001035581	4.15E+01	1.04E+00	100%	4.14E+01	0.002127845	0.001035581	41.45	1.036	100%	41.42
0.002177409	0.001059702	4.24E+01	1.06E+00	100%	4.24E+01	0.002177409	0.001059702	42.42	1.060	100%	42.39
0.002228127	0.001084386	4.34E+01	1.08E+00	100%	4.34E+01	0.002228127	0.001084386	43.40	1.084	100%	43.38
0.002280027	0.001109644	4.44E+01	1.11E+00	100%	4.44E+01	0.002280027	0.001109644	44.41	1.110	100%	44.39
0.002333136	0.00113549	4.54E+01	1.14E+00	100%	4.54E+01	0.002333136	0.00113549	45.45	1.135	100%	45.42
0.002387481	0.001161939	4.65E+01	1.16E+00	100%	4.65E+01	0.002387481	0.001161939	46.51	1.162	100%	46.48
0.002443093	0.001189003	4.76E+01	1.19E+00	100%	4.76E+01	0.002443093	0.001189003	47.59	1.189	100%	47.56
0.0025	0.001216698	4.87E+01	1.22E+00	100%	4.87E+01	0.0025	0.001216698	48.70	1.217	100%	48.67
0.002558232	0.001245038	4.98E+01	1.25E+00	100%	4.98E+01	0.002558232	0.001245038	49.83	1.245	100%	49.80
0.002617821	0.001274039	5.10E+01	1.27E+00	100%	5.10E+01	0.002617821	0.001274039	51.00	1.274	100%	50.96
0.002678798	0.001303714	5.22E+01	1.30E+00	100%	5.21E+01	0.002678798	0.001303714	52.18	1.304	100%	52.15
0.002741195	0.001334081	5.34E+01	1.33E+00	100%	5.34E+01	0.002741195	0.001334081	53.40	1.334	100%	53.36
0.002805046	0.001365156	5.46E+01	1.37E+00	100%	5.46E+01	0.002805046	0.001365156	54.64	1.365	100%	54.61
0.002870384	0.001396954	5.59E+01	1.40E+00	100%	5.59E+01	0.002870384	0.001396954	55.92	1.397	100%	55.88
0.002937244	0.001429493	5.72E+01	1.43E+00	100%	5.72E+01	0.002937244	0.001429493	57.22	1.429	100%	57.18
0.003005661	0.001462789	5.86E+01	1.46E+00	100%	5.85E+01	0.003005661	0.001462789	58.55	1.463	100%	58.51
0.003075672	0.001496862	5.99E+01	1.50E+00	100%	5.99E+01	0.003075672	0.001496862	59.91	1.497	100%	59.87
0.003147314	0.001531728	6.13E+01	1.53E+00	100%	6.13E+01	0.003147314	0.001531728	61.31	1.532	100%	61.27
0.003220624	0.001567406	6.27E+01	1.57E+00	100%	6.27E+01	0.003220624	0.001567406	62.74	1.567	100%	62.70
0.003295642	0.001603915	6.42E+01	1.60E+00	100%	6.42E+01	0.003295642	0.001603915	64.20	1.604	100%	64.16
0.003372407	0.001641274	6.57E+01	1.64E+00	100%	6.57E+01	0.003372407	0.001641274	65.69	1.641	100%	65.65
0.003450961	0.001679504	6.72E+01	1.68E+00	100%	6.72E+01	0.003450961	0.001679504	67.22	1.680	100%	67.18
0.003531344	0.001718624	6.88E+01	1.72E+00	100%	6.87E+01	0.003531344	0.001718624	68.79	1.719	100%	68.74
0.003613599	0.001758656	7.04E+01	1.76E+00	100%	7.03E+01	0.003613599	0.001758656	70.39	1.759	100%	70.35
0.003697771	0.00179962	7.20E+01	1.80E+00	100%	7.20E+01	0.003697771	0.00179962	72.03	1.800	100%	71.98
0.003783903	0.001841538	7.37E+01	1.84E+00	100%	7.37E+01	0.003783903	0.001841538	73.71	1.842	100%	73.66
0.003872042	0.001884432	7.54E+01	1.88E+00	100%	7.54E+01	0.003872042	0.001884432	75.43	1.884	100%	75.38
0.003962233	0.001928326	7.72E+01	1.93E+00	100%	7.71E+01	0.003962233	0.001928326	77.18	1.928	100%	77.13
0.004054525	0.001973242	7.90E+01	1.97E+00	100%	7.89E+01	0.004054525	0.001973242	78.98	1.973	100%	78.93
0.004148967	0.002019204	8.08E+01	2.02E+00	100%	8.08E+01	0.004148967	0.002019204	80.82	2.019	100%	80.77
0.004245609	0.002066237	8.27E+01	2.07E+00	100%	8.26E+01	0.004245609	0.002066237	82.70	2.066	100%	82.65
0.004344502	0.002114365	8.46E+01	2.11E+00	100%	8.46E+01	0.004344502	0.002114365	84.63	2.114	100%	84.57

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc	Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg	g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.004445699	0.002163615	8.66E+01	2.16E+00	100%	8.65E+01	0.004445699	0.002163615	86.60	2.164	100%	86.54
0.004549252	0.002214012	8.86E+01	2.21E+00	100%	8.86E+01	0.004549252	0.002214012	88.62	2.214	100%	88.56
0.004655218	0.002265582	9.07E+01	2.27E+00	100%	9.06E+01	0.004655218	0.002265582	90.68	2.266	100%	90.62
0.004763652	0.002318354	9.28E+01	2.32E+00	100%	9.27E+01	0.004763652	0.002318354	92.80	2.318	100%	92.73
0.004874611	0.002372355	9.50E+01	2.37E+00	100%	9.49E+01	0.004874611	0.002372355	94.96	2.372	100%	94.89
0.004988156	0.002427614	9.72E+01	2.43E+00	100%	9.71E+01	0.004988156	0.002427614	97.17	2.428	100%	97.10
0.005104345	0.002484159	9.94E+01	2.48E+00	100%	9.94E+01	0.005104345	0.002484159	99.43	2.484	100%	99.37
0.00522324	0.002542023	1.02E+02	2.54E+00	100%	1.02E+02	0.00522324	0.002542023	101.75	2.542	100%	101.68
0.005344905	0.002601233	1.04E+02	2.60E+00	100%	1.04E+02	0.005344905	0.002601233	104.12	2.601	100%	104.05
0.005469404	0.002661823	1.07E+02	2.66E+00	100%	1.06E+02	0.005469404	0.002661823	106.54	2.662	100%	106.47
0.005596803	0.002723825	1.09E+02	2.72E+00	100%	1.09E+02	0.005596803	0.002723825	109.03	2.724	100%	108.95
0.005727169	0.00278727	1.12E+02	2.79E+00	100%	1.11E+02	0.005727169	0.00278727	111.57	2.787	100%	111.49
0.005860572	0.002852194	1.14E+02	2.85E+00	100%	1.14E+02	0.005860572	0.002852194	114.16	2.852	100%	114.09
0.005997082	0.00291863	1.17E+02	2.92E+00	100%	1.17E+02	0.005997082	0.00291863	116.82	2.919	100%	116.75
0.006136772	0.002986613	1.20E+02	2.99E+00	100%	1.19E+02	0.006136772	0.002986613	119.54	2.987	100%	119.46
0.006279716	0.003056179	1.22E+02	3.06E+00	100%	1.22E+02	0.006279716	0.003056179	122.33	3.056	100%	122.25
0.006425989	0.003127367	1.25E+02	3.13E+00	100%	1.25E+02	0.006425989	0.003127367	125.18	3.127	100%	125.09
0.00657567	0.003200212	1.28E+02	3.20E+00	100%	1.28E+02	0.00657567	0.003200212	128.09	3.200	100%	128.01
0.006728837	0.003274754	1.31E+02	3.27E+00	100%	1.31E+02	0.006728837	0.003274754	131.08	3.275	100%	130.99
0.006885572	0.003351032	1.34E+02	3.35E+00	100%	1.34E+02	0.006885572	0.003351032	134.13	3.351	100%	134.04
0.007045957	0.003429087	1.37E+02	3.43E+00	100%	1.37E+02	0.007045957	0.003429087	137.26	3.429	100%	137.16
0.007210079	0.003508961	1.40E+02	3.51E+00	100%	1.40E+02	0.007210079	0.003508961	140.45	3.509	100%	140.36
0.007378023	0.003590694	1.44E+02	3.59E+00	100%	1.44E+02	0.007378023	0.003590694	143.72	3.591	100%	143.63
0.007549879	0.003674332	1.47E+02	3.67E+00	100%	1.47E+02	0.007549879	0.003674332	147.07	3.674	100%	146.97
0.007725739	0.003759918	1.50E+02	3.76E+00	100%	1.50E+02	0.007725739	0.003759918	150.50	3.760	100%	150.40
0.007905694	0.003847497	1.54E+02	3.85E+00	100%	1.54E+02	0.007905694	0.003847497	154.00	3.847	100%	153.90
0.008089841	0.003937116	1.58E+02	3.94E+00	100%	1.57E+02	0.008089841	0.003937116	157.59	3.937	100%	157.48
0.008278278	0.004028823	1.61E+02	4.03E+00	100%	1.61E+02	0.008278278	0.004028823	161.26	4.029	100%	161.15
0.008471104	0.004122666	1.65E+02	4.12E+00	100%	1.65E+02	0.008471104	0.004122666	165.02	4.123	100%	164.91
0.008668421	0.004218695	1.69E+02	4.22E+00	100%	1.69E+02	0.008668421	0.004218695	168.86	4.219	100%	168.75
0.008870335	0.00431696	1.73E+02	4.32E+00	100%	1.73E+02	0.008870335	0.00431696	172.79	4.317	100%	172.68
0.009076951	0.004417515	1.77E+02	4.42E+00	100%	1.77E+02	0.009076951	0.004417515	176.82	4.418	100%	176.70
0.009288381	0.004520412	1.81E+02	4.52E+00	100%	1.81E+02	0.009288381	0.004520412	180.94	4.520	100%	180.82
0.009504735	0.004625705	1.85E+02	4.63E+00	100%	1.85E+02	0.009504735	0.004625705	185.15	4.626	100%	185.03
0.009726129	0.004733451	1.89E+02	4.73E+00	100%	1.89E+02	0.009726129	0.004733451	189.46	4.733	100%	189.34
0.009952679	0.004843707	1.94E+02	4.84E+00	100%	1.94E+02	0.009952679	0.004843707	193.88	4.844	100%	193.75
0.010184507	0.004956531	1.98E+02	4.96E+00	100%	1.98E+02	0.010184507	0.004956531	198.39	4.957	100%	198.26
0.010421735	0.005071983	2.03E+02	5.07E+00	100%	2.03E+02	0.010421735	0.005071983	203.02	5.072	100%	202.88
0.010664488	0.005190124	2.08E+02	5.19E+00	100%	2.08E+02	0.010664488	0.005190124	207.74	5.190	100%	207.60
0.010912896	0.005311017	2.13E+02	5.31E+00	100%	2.12E+02	0.010912896	0.005311017	212.58	5.311	100%	212.44
0.01116709	0.005434726	2.18E+02	5.43E+00	100%	2.17E+02	0.01116709	0.005434726	217.53	5.435	100%	217.39
0.011427205	0.005561317	2.23E+02	5.56E+00	100%	2.22E+02	0.011427205	0.005561317	222.60	5.561	100%	222.45
0.011693379	0.005690856	2.28E+02	5.69E+00	100%	2.28E+02	0.011693379	0.005690856	227.79	5.691	100%	227.63
0.011965752	0.005823413	2.33E+02	5.82E+00	100%	2.33E+02	0.011965752	0.005823413	233.09	5.823	100%	232.94
0.01224447	0.005959057	2.39E+02	5.96E+00	100%	2.38E+02	0.01224447	0.005959057	238.52	5.959	100%	238.36

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.012529681	0.006097861	2.44E+02	6.10E+00	100%	2.44E+02
0.012821535	0.006239898	2.50E+02	6.24E+00	100%	2.50E+02
0.013120187	0.006385243	2.56E+02	6.39E+00	100%	2.55E+02
0.013425795	0.006533974	2.62E+02	6.53E+00	100%	2.61E+02
0.013738522	0.00668617	2.68E+02	6.69E+00	100%	2.67E+02
0.014058533	0.00684191	2.74E+02	6.84E+00	100%	2.74E+02
0.014385998	0.007001278	2.80E+02	7.00E+00	100%	2.80E+02
0.014721091	0.007164358	2.87E+02	7.16E+00	100%	2.87E+02
0.01506399	0.007331237	2.93E+02	7.33E+00	100%	2.93E+02
0.015414875	0.007502003	3.00E+02	7.50E+00	100%	3.00E+02
0.015773934	0.007676747	3.07E+02	7.68E+00	100%	3.07E+02
0.016141356	0.007855561	3.14E+02	7.86E+00	100%	3.14E+02
0.016517336	0.00803854	3.22E+02	8.04E+00	100%	3.22E+02
0.016902074	0.008225781	3.29E+02	8.23E+00	100%	3.29E+02
0.017295774	0.008417384	3.37E+02	8.42E+00	100%	3.37E+02
0.017698645	0.008613449	3.45E+02	8.61E+00	100%	3.45E+02
0.018110899	0.008814082	3.53E+02	8.81E+00	100%	3.53E+02
0.018532756	0.009019388	3.61E+02	9.02E+00	100%	3.61E+02
0.018964439	0.009229476	3.69E+02	9.23E+00	100%	3.69E+02
0.019406178	0.009444458	3.78E+02	9.44E+00	100%	3.78E+02
0.019858206	0.009664447	3.87E+02	9.66E+00	100%	3.87E+02
0.020320763	0.00988956	3.96E+02	9.89E+00	100%	3.96E+02
0.020794094	0.010119917	4.05E+02	1.01E+01	100%	4.05E+02
0.021278451	0.01035564	4.15E+02	1.04E+01	100%	4.14E+02
0.02177409	0.010596853	4.24E+02	1.06E+01	100%	4.24E+02
0.022281273	0.010843685	4.34E+02	1.08E+01	100%	4.34E+02
0.022800271	0.011096267	4.44E+02	1.11E+01	100%	4.44E+02
0.023331358	0.011354732	4.54E+02	1.14E+01	100%	4.54E+02
0.023874815	0.011619217	4.65E+02	1.16E+01	100%	4.65E+02
0.024430931	0.011889863	4.76E+02	1.19E+01	100%	4.76E+02
0.025	0.012166813	4.87E+02	1.22E+01	100%	4.87E+02
0.025582325	0.012450214	4.98E+02	1.25E+01	100%	4.98E+02
0.026178214	0.012740216	5.10E+02	1.27E+01	100%	5.10E+02
0.026787983	0.013036974	5.22E+02	1.30E+01	100%	5.21E+02
0.027411955	0.013340643	5.34E+02	1.33E+01	100%	5.34E+02
0.028050461	0.013651386	5.46E+02	1.37E+01	100%	5.46E+02
0.028703841	0.013969367	5.59E+02	1.40E+01	100%	5.59E+02
0.029372439	0.014294755	5.72E+02	1.43E+01	100%	5.72E+02
0.030056611	0.014627723	5.86E+02	1.46E+01	100%	5.85E+02
0.030756719	0.014968446	5.99E+02	1.50E+01	100%	5.99E+02
0.031473135	0.015317105	6.13E+02	1.53E+01	100%	6.13E+02
0.032206239	0.015673886	6.27E+02	1.57E+01	100%	6.27E+02
0.032956418	0.016038977	6.42E+02	1.60E+01	100%	6.42E+02
0.033724072	0.016412572	6.57E+02	1.64E+01	100%	6.57E+02
0.034509607	0.01679487	6.72E+02	1.68E+01	100%	6.72E+02

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.012529681	0.006097861	244.08	6.098	100%	243.91
0.012821535	0.006239898	249.76	6.240	100%	249.60
0.013120187	0.006385243	255.58	6.385	100%	255.41
0.013425795	0.006533974	261.53	6.534	100%	261.36
0.013738522	0.00668617	267.63	6.686	100%	267.45
0.014058533	0.00684191	273.86	6.842	100%	273.68
0.014385998	0.007001278	280.24	7.001	100%	280.05
0.014721091	0.007164358	286.77	7.164	100%	286.57
0.01506399	0.007331237	293.45	7.331	100%	293.25
0.015414875	0.007502003	300.28	7.502	100%	300.08
0.015773934	0.007676747	307.28	7.677	100%	307.07
0.016141356	0.007855561	314.43	7.856	100%	314.22
0.016517336	0.00803854	321.76	8.039	100%	321.54
0.016902074	0.008225781	329.25	8.226	100%	329.03
0.017295774	0.008417384	336.92	8.417	100%	336.70
0.017698645	0.008613449	344.77	8.613	100%	344.54
0.018110899	0.008814082	352.80	8.814	100%	352.56
0.018532756	0.009019388	361.02	9.019	100%	360.78
0.018964439	0.009229476	369.43	9.229	100%	369.18
0.019406178	0.009444458	378.03	9.444	100%	377.78
0.019858206	0.009664447	386.84	9.664	100%	386.58
0.020320763	0.00988956	395.85	9.890	100%	395.58
0.020794094	0.010119917	405.07	10.120	100%	404.80
0.021278451	0.01035564	414.50	10.356	100%	414.23
0.02177409	0.010596853	424.16	10.597	100%	423.87
0.022281273	0.010843685	434.04	10.844	100%	433.75
0.022800271	0.011096267	444.15	11.096	100%	443.85
0.023331358	0.011354732	454.49	11.355	100%	454.19
0.023874815	0.011619217	465.08	11.619	100%	464.77
0.024430931	0.011889863	475.91	11.890	100%	475.59
0.025	0.012166813	487.00	12.167	100%	486.67
0.025582325	0.012450214	498.34	12.450	100%	498.01
0.026178214	0.012740216	509.95	12.740	100%	509.61
0.026787983	0.013036974	521.83	13.037	100%	521.48
0.027411955	0.013340643	533.98	13.341	100%	533.63
0.028050461	0.013651386	546.42	13.651	100%	546.06
0.028703841	0.013969367	559.15	13.969	100%	558.77
0.029372439	0.014294755	572.18	14.295	100%	571.79
0.030056611	0.014627723	585.50	14.628	100%	585.11
0.030756719	0.014968446	599.14	14.968	100%	598.74
0.031473135	0.015317105	613.10	15.317	100%	612.68
0.032206239	0.015673886	627.38	15.674	100%	626.96
0.032956418	0.016038977	641.99	16.039	100%	641.56
0.033724072	0.016369759	656.94	16.370	100%	654.79
0.034509607	0.016369759	672.25	16.370	97%	654.79

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.035313439	0.017186072	6.88E+02	1.72E+01	100%	6.87E+02
0.036135994	0.017586387	7.04E+02	1.76E+01	100%	7.03E+02
0.03697771	0.017996026	7.20E+02	1.80E+01	100%	7.20E+02
0.037839031	0.018415207	7.37E+02	1.84E+01	100%	7.37E+02
0.038720415	0.018844152	7.54E+02	1.88E+01	100%	7.54E+02
0.03962233	0.019283088	7.72E+02	1.93E+01	100%	7.71E+02
0.040545252	0.019732248	7.90E+02	1.97E+01	100%	7.89E+02
0.041489673	0.020191871	8.08E+02	2.02E+01	100%	8.08E+02
0.042456091	0.0206622	8.27E+02	2.07E+01	100%	8.26E+02
0.043445021	0.021143484	8.46E+02	2.11E+01	100%	8.46E+02
0.044456985	0.021635978	8.66E+02	2.16E+01	100%	8.65E+02
0.045492521	0.022139944	8.86E+02	2.21E+01	100%	8.86E+02
0.046552178	0.022655649	9.07E+02	2.27E+01	100%	9.06E+02
0.047636518	0.023183367	9.28E+02	2.32E+01	100%	9.27E+02
0.048746115	0.023723376	9.50E+02	2.37E+01	100%	9.49E+02
0.049881558	0.024275964	9.72E+02	2.43E+01	100%	9.71E+02
0.051043449	0.024841424	9.94E+02	2.48E+01	100%	9.94E+02
0.052232403	0.025420054	1.02E+03	2.54E+01	100%	1.02E+03
0.053449052	0.026012163	1.04E+03	2.60E+01	100%	1.04E+03
0.054694041	0.026618064	1.07E+03	2.66E+01	100%	1.06E+03
0.055968028	0.027238078	1.09E+03	2.72E+01	100%	1.09E+03
0.057271691	0.027872534	1.12E+03	2.79E+01	100%	1.11E+03
0.05860572	0.028521768	1.14E+03	2.85E+01	100%	1.14E+03
0.059970823	0.029186125	1.17E+03	2.92E+01	100%	1.17E+03
0.061367723	0.029865956	1.20E+03	2.99E+01	100%	1.19E+03
0.062797161	0.030561623	1.22E+03	3.06E+01	100%	1.22E+03
0.064259895	0.031273495	1.25E+03	3.13E+01	100%	1.25E+03
0.0657567	0.032001948	1.28E+03	3.20E+01	100%	1.28E+03
0.06728837	0.032747368	1.31E+03	3.27E+01	100%	1.31E+03
0.068855718	0.033510152	1.34E+03	3.35E+01	100%	1.34E+03
0.070459573	0.034290703	1.37E+03	3.43E+01	100%	1.37E+03
0.072100788	0.035089436	1.40E+03	3.51E+01	100%	1.40E+03
0.073780231	0.035906773	1.44E+03	3.59E+01	100%	1.44E+03
0.075498793	0.036743149	1.47E+03	3.67E+01	100%	1.47E+03
0.077257386	0.037599007	1.50E+03	3.76E+01	100%	1.50E+03
0.079056942	0.0384748	1.54E+03	3.85E+01	100%	1.54E+03
0.080898414	0.039370992	1.58E+03	3.94E+01	100%	1.57E+03
0.08278278	0.04028806	1.61E+03	4.03E+01	100%	1.61E+03
0.084711039	0.041226489	1.65E+03	4.12E+01	100%	1.65E+03
0.086684213	0.042186777	1.69E+03	4.22E+01	100%	1.69E+03
0.088703347	0.043169433	1.73E+03	4.32E+01	100%	1.73E+03
0.090769514	0.044174978	1.77E+03	4.42E+01	100%	1.77E+03
0.092883807	0.045203945	1.81E+03	4.52E+01	100%	1.81E+03
0.095047349	0.046256879	1.85E+03	4.63E+01	100%	1.85E+03
0.097261286	0.04733434	1.89E+03	4.73E+01	100%	1.89E+03

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.035313439	0.016369759	687.91	16.370	95%	654.79
0.036135994	0.016369759	703.93	16.370	93%	654.79
0.03697771	0.016369759	720.33	16.370	91%	654.79
0.037839031	0.016369759	737.10	16.370	89%	654.79
0.038720415	0.016369759	754.27	16.370	87%	654.79
0.03962233	0.016369759	771.84	16.370	85%	654.79
0.040545252	0.016369759	789.82	16.370	83%	654.79
0.041489673	0.016369759	808.22	16.370	81%	654.79
0.042456091	0.016369759	827.04	16.370	79%	654.79
0.043445021	0.016369759	846.31	16.370	77%	654.79
0.044456985	0.016369759	866.02	16.370	76%	654.79
0.045492521	0.016369759	886.19	16.370	74%	654.79
0.046552178	0.016369759	906.84	16.370	72%	654.79
0.047636518	0.016369759	927.96	16.370	71%	654.79
0.048746115	0.016369759	949.57	16.370	69%	654.79
0.049881558	0.016369759	971.69	16.370	67%	654.79
0.051043449	0.016369759	994.33	16.370	66%	654.79
0.052232403	0.016369759	1017.49	16.370	64%	654.79
0.053449052	0.016369759	1041.19	16.370	63%	654.79
0.054694041	0.016369759	1065.44	16.370	61%	654.79
0.055968028	0.016369759	1090.26	16.370	60%	654.79
0.057271691	0.016369759	1115.65	16.370	59%	654.79
0.05860572	0.016369759	1141.64	16.370	57%	654.79
0.059970823	0.016369759	1168.23	16.370	56%	654.79
0.061367723	0.016369759	1195.44	16.370	55%	654.79
0.062797161	0.016369759	1223.29	16.370	54%	654.79
0.064259895	0.016369759	1251.78	16.370	52%	654.79
0.0657567	0.016369759	1280.94	16.370	51%	654.79
0.06728837	0.016369759	1310.78	16.370	50%	654.79
0.068855718	0.016369759	1341.31	16.370	49%	654.79
0.070459573	0.016369759	1372.55	16.370	48%	654.79
0.072100788	0.016369759	1404.52	16.370	47%	654.79
0.073780231	0.016369759	1437.24	16.370	46%	654.79
0.075498793	0.016369759	1470.72	16.370	45%	654.79
0.077257386	0.016369759	1504.97	16.370	44%	654.79
0.079056942	0.016369759	1540.03	16.370	43%	654.79
0.080898414	0.016369759	1575.90	16.370	42%	654.79
0.08278278	0.016369759	1612.61	16.370	41%	654.79
0.084711039	0.016369759	1650.17	16.370	40%	654.79
0.086684213	0.016369759	1688.61	16.370	39%	654.79
0.088703347	0.016369759	1727.94	16.370	38%	654.79
0.090769514	0.016369759	1768.19	16.370	37%	654.79
0.092883807	0.016369759	1809.38	16.370	36%	654.79
0.095047349	0.016369759	1851.52	16.370	35%	654.79
0.097261286	0.016369759	1894.65	16.370	35%	654.79

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.099526793	0.048436898	1.94E+03	4.84E+01	100%	1.94E+03
0.101845069	0.049565138	1.98E+03	4.96E+01	100%	1.98E+03
0.104217346	0.050719658	2.03E+03	5.07E+01	100%	2.03E+03
0.10664488	0.05190107	2.08E+03	5.19E+01	100%	2.08E+03
0.109128958	0.053110001	2.13E+03	5.31E+01	100%	2.12E+03
0.111670898	0.054347091	2.18E+03	5.43E+01	100%	2.17E+03
0.114272047	0.055612997	2.23E+03	5.56E+01	100%	2.22E+03
0.116933785	0.05690839	2.28E+03	5.69E+01	100%	2.28E+03
0.119657523	0.058233956	2.33E+03	5.82E+01	100%	2.33E+03
0.122444705	0.059590398	2.39E+03	5.96E+01	100%	2.38E+03
0.125296808	0.060978437	2.44E+03	6.10E+01	100%	2.44E+03
0.128215346	0.062398807	2.50E+03	6.24E+01	100%	2.50E+03
0.131201865	0.063852261	2.56E+03	6.39E+01	100%	2.55E+03
0.134257949	0.065339571	2.62E+03	6.53E+01	100%	2.61E+03
0.137385218	0.066861524	2.68E+03	6.69E+01	100%	2.67E+03
0.140585331	0.068418929	2.74E+03	6.84E+01	100%	2.74E+03
0.143859984	0.07001261	2.80E+03	7.00E+01	100%	2.80E+03
0.147210914	0.071643413	2.87E+03	7.16E+01	100%	2.87E+03
0.150639897	0.073312202	2.93E+03	7.33E+01	100%	2.93E+03
0.15414875	0.075019862	3.00E+03	7.50E+01	100%	3.00E+03
0.157739336	0.076767299	3.07E+03	7.68E+01	100%	3.07E+03
0.161413557	0.078555438	3.14E+03	7.86E+01	100%	3.14E+03
0.165173362	0.080385229	3.22E+03	8.04E+01	100%	3.22E+03
0.169020744	0.082257641	3.29E+03	8.23E+01	100%	3.29E+03
0.172957743	0.084173667	3.37E+03	8.42E+01	100%	3.37E+03
0.176986446	0.086134323	3.45E+03	8.61E+01	100%	3.45E+03
0.18110899	0.088140649	3.53E+03	8.81E+01	100%	3.53E+03
0.18532756	0.090193708	3.61E+03	9.02E+01	100%	3.61E+03
0.189644394	0.092294589	3.69E+03	9.23E+01	100%	3.69E+03
0.194061779	0.094444406	3.78E+03	9.44E+01	100%	3.78E+03
0.198582059	0.096644298	3.87E+03	9.66E+01	100%	3.87E+03
0.203207629	0.098895433	3.96E+03	9.89E+01	100%	3.96E+03
0.207940943	0.101199003	4.05E+03	1.01E+02	100%	4.05E+03
0.21278451	0.10355623	4.15E+03	1.04E+02	100%	4.14E+03
0.217740897	0.105968364	4.24E+03	1.06E+02	100%	4.24E+03
0.222812735	0.108436684	4.34E+03	1.08E+02	100%	4.34E+03
0.22800271	0.110962498	4.44E+03	1.11E+02	100%	4.44E+03
0.233313575	0.113547146	4.54E+03	1.14E+02	100%	4.54E+03
0.238748147	0.116191999	4.65E+03	1.16E+02	100%	4.65E+03
0.244309305	0.118898458	4.76E+03	1.19E+02	100%	4.76E+03
0.25	0.121667958	4.87E+03	1.22E+02	100%	4.87E+03
0.255823248	0.124501968	4.98E+03	1.25E+02	100%	4.98E+03
0.261782137	0.127401991	5.10E+03	1.27E+02	100%	5.10E+03
0.267879826	0.130369564	5.22E+03	1.30E+02	100%	5.21E+03
0.274119549	0.133406261	5.34E+03	1.33E+02	100%	5.34E+03

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.099526793	0.016369759	1938.78	16.370	34%	654.79
0.101845069	0.016369759	1983.94	16.370	33%	654.79
0.104217346	0.016369759	2030.15	16.370	32%	654.79
0.10664488	0.016369759	2077.44	16.370	32%	654.79
0.109128958	0.016369759	2125.83	16.370	31%	654.79
0.111670898	0.016369759	2175.35	16.370	30%	654.79
0.114272047	0.016369759	2226.02	16.370	29%	654.79
0.116933785	0.016369759	2277.87	16.370	29%	654.79
0.119657523	0.016369759	2330.93	16.370	28%	654.79
0.122444705	0.016369759	2385.22	16.370	27%	654.79
0.125296808	0.016369759	2440.78	16.370	27%	654.79
0.128215346	0.016369759	2497.63	16.370	26%	654.79
0.131201865	0.016369759	2555.81	16.370	26%	654.79
0.134257949	0.016369759	2615.34	16.370	25%	654.79
0.137385218	0.016369759	2676.26	16.370	24%	654.79
0.140585331	0.016369759	2738.60	16.370	24%	654.79
0.143859984	0.016369759	2802.39	16.370	23%	654.79
0.147210914	0.016369759	2867.67	16.370	23%	654.79
0.150639897	0.016369759	2934.47	16.370	22%	654.79
0.15414875	0.016369759	3002.82	16.370	22%	654.79
0.157739336	0.016369759	3072.76	16.370	21%	654.79
0.161413557	0.016369759	3144.34	16.370	21%	654.79
0.165173362	0.016369759	3217.58	16.370	20%	654.79
0.169020744	0.016369759	3292.52	16.370	20%	654.79
0.172957743	0.016369759	3369.22	16.370	19%	654.79
0.176986446	0.016369759	3447.70	16.370	19%	654.79
0.18110899	0.016369759	3528.00	16.370	19%	654.79
0.18532756	0.016369759	3610.18	16.370	18%	654.79
0.189644394	0.016369759	3694.27	16.370	18%	654.79
0.194061779	0.016369759	3780.32	16.370	17%	654.79
0.198582059	0.016369759	3868.38	16.370	17%	654.79
0.203207629	0.016369759	3958.48	16.370	17%	654.79
0.207940943	0.016369759	4050.69	16.370	16%	654.79
0.21278451	0.016369759	4145.04	16.370	16%	654.79
0.217740897	0.016369759	4241.59	16.370	15%	654.79
0.222812735	0.016369759	4340.39	16.370	15%	654.79
0.22800271	0.016369759	4441.49	16.370	15%	654.79
0.233313575	0.016369759	4544.95	16.370	14%	654.79
0.238748147	0.016369759	4650.81	16.370	14%	654.79
0.244309305	0.016369759	4759.15	16.370	14%	654.79
0.25	0.016369759	4870.00	16.370	13%	654.79
0.255823248	0.016369759	4983.44	16.370	13%	654.79
0.261782137	0.016369759	5099.52	16.370	13%	654.79
0.267879826	0.016369759	5218.30	16.370	13%	654.79
0.274119549	0.016369759	5339.85	16.370	12%	654.79

Attachment 2a

Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.280504614	0.136513692	5.46E+03	1.37E+02	100%	5.46E+03
0.287038405	0.13651286	5.59E+03	1.37E+02	98%	5.46E+03
0.293724389	0.13651286	5.72E+03	1.37E+02	95%	5.46E+03
0.300566109	0.13651286	5.86E+03	1.37E+02	93%	5.46E+03
0.307567193	0.13651286	5.99E+03	1.37E+02	91%	5.46E+03
0.314731353	0.13651286	6.13E+03	1.37E+02	89%	5.46E+03
0.322062388	0.13651286	6.27E+03	1.37E+02	87%	5.46E+03
0.329564185	0.13651286	6.42E+03	1.37E+02	85%	5.46E+03
0.337240721	0.13651286	6.57E+03	1.37E+02	83%	5.46E+03
0.345096066	0.13651286	6.72E+03	1.37E+02	81%	5.46E+03
0.353134386	0.13651286	6.88E+03	1.37E+02	79%	5.46E+03
0.361359943	0.13651286	7.04E+03	1.37E+02	78%	5.46E+03
0.369777097	0.13651286	7.20E+03	1.37E+02	76%	5.46E+03
0.378390312	0.13651286	7.37E+03	1.37E+02	74%	5.46E+03
0.387204155	0.13651286	7.54E+03	1.37E+02	72%	5.46E+03
0.396223298	0.13651286	7.72E+03	1.37E+02	71%	5.46E+03
0.405452524	0.13651286	7.90E+03	1.37E+02	69%	5.46E+03
0.414896727	0.13651286	8.08E+03	1.37E+02	68%	5.46E+03
0.424560913	0.13651286	8.27E+03	1.37E+02	66%	5.46E+03
0.434450207	0.13651286	8.46E+03	1.37E+02	65%	5.46E+03
0.444569853	0.13651286	8.66E+03	1.37E+02	63%	5.46E+03
0.454925215	0.13651286	8.86E+03	1.37E+02	62%	5.46E+03
0.465521784	0.13651286	9.07E+03	1.37E+02	60%	5.46E+03
0.476365179	0.13651286	9.28E+03	1.37E+02	59%	5.46E+03
0.48746115	0.13651286	9.50E+03	1.37E+02	58%	5.46E+03
0.498815579	0.13651286	9.72E+03	1.37E+02	56%	5.46E+03
0.510434486	0.13651286	9.94E+03	1.37E+02	55%	5.46E+03
0.522324033	0.13651286	1.02E+04	1.37E+02	54%	5.46E+03
0.534490522	0.13651286	1.04E+04	1.37E+02	52%	5.46E+03
0.546940406	0.13651286	1.07E+04	1.37E+02	51%	5.46E+03
0.559680285	0.13651286	1.09E+04	1.37E+02	50%	5.46E+03
0.572716913	0.13651286	1.12E+04	1.37E+02	49%	5.46E+03
0.586057204	0.13651286	1.14E+04	1.37E+02	48%	5.46E+03
0.59970823	0.13651286	1.17E+04	1.37E+02	47%	5.46E+03
0.613677229	0.13651286	1.20E+04	1.37E+02	46%	5.46E+03
0.627971608	0.13651286	1.22E+04	1.37E+02	45%	5.46E+03
0.642598946	0.13651286	1.25E+04	1.37E+02	44%	5.46E+03
0.657566998	0.13651286	1.28E+04	1.37E+02	43%	5.46E+03
0.672883701	0.13651286	1.31E+04	1.37E+02	42%	5.46E+03
0.688557176	0.13651286	1.34E+04	1.37E+02	41%	5.46E+03
0.704595733	0.13651286	1.37E+04	1.37E+02	40%	5.46E+03
0.721007876	0.13651286	1.40E+04	1.37E+02	39%	5.46E+03
0.737802307	0.13651286	1.44E+04	1.37E+02	38%	5.46E+03
0.75498793	0.13651286	1.47E+04	1.37E+02	37%	5.46E+03
0.772573858	0.13651286	1.50E+04	1.37E+02	36%	5.46E+03

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.280504614	0.016369759	5464.23	16.370	12%	654.79
0.287038405	0.016369759	5591.51	16.370	12%	654.79
0.293724389	0.016369759	5721.75	16.370	11%	654.79
0.300566109	0.016369759	5855.03	16.370	11%	654.79
0.307567193	0.016369759	5991.41	16.370	11%	654.79
0.314731353	0.016369759	6130.97	16.370	11%	654.79
0.322062388	0.016369759	6273.78	16.370	10%	654.79
0.329564185	0.016369759	6419.91	16.370	10%	654.79
0.337240721	0.016369759	6569.45	16.370	10%	654.79
0.345096066	0.016369759	6722.47	16.370	10%	654.79
0.353134386	0.016369759	6879.06	16.370	10%	654.79
0.361359943	0.016369759	7039.29	16.370	9%	654.79
0.369777097	0.016369759	7203.26	16.370	9%	654.79
0.378390312	0.016369759	7371.04	16.370	9%	654.79
0.387204155	0.016369759	7542.74	16.370	9%	654.79
0.396223298	0.016369759	7718.43	16.370	8%	654.79
0.405452524	0.016369759	7898.22	16.370	8%	654.79
0.414896727	0.016369759	8082.19	16.370	8%	654.79
0.424560913	0.016369759	8270.45	16.370	8%	654.79
0.434450207	0.016369759	8463.09	16.370	8%	654.79
0.444569853	0.016369759	8660.22	16.370	8%	654.79
0.454925215	0.016369759	8861.94	16.370	7%	654.79
0.465521784	0.016369759	9068.36	16.370	7%	654.79
0.476365179	0.016369759	9279.59	16.370	7%	654.79
0.48746115	0.016369759	9495.74	16.370	7%	654.79
0.498815579	0.016369759	9716.93	16.370	7%	654.79
0.510434486	0.016369759	9943.26	16.370	7%	654.79
0.522324033	0.016369759	10174.87	16.370	6%	654.79
0.534490522	0.016369759	10411.88	16.370	6%	654.79
0.546940406	0.016369759	10654.40	16.370	6%	654.79
0.559680285	0.016369759	10902.57	16.370	6%	654.79
0.572716913	0.016369759	11156.53	16.370	6%	654.79
0.586057204	0.016369759	11416.39	16.370	6%	654.79
0.59970823	0.016369759	11682.32	16.370	6%	654.79
0.613677229	0.016369759	11954.43	16.370	5%	654.79
0.627971608	0.016369759	12232.89	16.370	5%	654.79
0.642598946	0.016369759	12517.83	16.370	5%	654.79
0.657566998	0.016369759	12809.41	16.370	5%	654.79
0.672883701	0.016369759	13107.77	16.370	5%	654.79
0.688557176	0.016369759	13413.09	16.370	5%	654.79
0.704595733	0.016369759	13725.52	16.370	5%	654.79
0.721007876	0.016369759	14045.23	16.370	5%	654.79
0.737802307	0.016369759	14372.39	16.370	5%	654.79
0.75498793	0.016369759	14707.16	16.370	4%	654.79
0.772573858	0.016369759	15049.74	16.370	4%	654.79

Attachment 2a

Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc	Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg	g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
0.790569415	0.13651286	1.54E+04	1.37E+02	35%	5.46E+03	0.790569415	0.016369759	15400.29	16.370	4%	654.79
0.808984142	0.13651286	1.58E+04	1.37E+02	35%	5.46E+03	0.808984142	0.016369759	15759.01	16.370	4%	654.79
0.827827804	0.13651286	1.61E+04	1.37E+02	34%	5.46E+03	0.827827804	0.016369759	16126.09	16.370	4%	654.79
0.84711039	0.13651286	1.65E+04	1.37E+02	33%	5.46E+03	0.84711039	0.016369759	16501.71	16.370	4%	654.79
0.866842126	0.13651286	1.69E+04	1.37E+02	32%	5.46E+03	0.866842126	0.016369759	16886.08	16.370	4%	654.79
0.887033473	0.13651286	1.73E+04	1.37E+02	32%	5.46E+03	0.887033473	0.016369759	17279.41	16.370	4%	654.79
0.907695137	0.13651286	1.77E+04	1.37E+02	31%	5.46E+03	0.907695137	0.016369759	17681.90	16.370	4%	654.79
0.928838073	0.13651286	1.81E+04	1.37E+02	30%	5.46E+03	0.928838073	0.016369759	18093.77	16.370	4%	654.79
0.950473491	0.13651286	1.85E+04	1.37E+02	29%	5.46E+03	0.950473491	0.016369759	18515.22	16.370	4%	654.79
0.972612862	0.13651286	1.89E+04	1.37E+02	29%	5.46E+03	0.972612862	0.016369759	18946.50	16.370	3%	654.79
0.995267926	0.13651286	1.94E+04	1.37E+02	28%	5.46E+03	0.995267926	0.016369759	19387.82	16.370	3%	654.79
1.018450695	0.13651286	1.98E+04	1.37E+02	28%	5.46E+03	1.018450695	0.016369759	19839.42	16.370	3%	654.79
1.042173459	0.13651286	2.03E+04	1.37E+02	27%	5.46E+03	1.042173459	0.016369759	20301.54	16.370	3%	654.79
1.066448797	0.13651286	2.08E+04	1.37E+02	26%	5.46E+03	1.066448797	0.016369759	20774.42	16.370	3%	654.79
1.091289581	0.13651286	2.13E+04	1.37E+02	26%	5.46E+03	1.091289581	0.016369759	21258.32	16.370	3%	654.79
1.11670898	0.13651286	2.18E+04	1.37E+02	25%	5.46E+03	1.11670898	0.016369759	21753.49	16.370	3%	654.79
1.142720474	0.13651286	2.23E+04	1.37E+02	25%	5.46E+03	1.142720474	0.016369759	22260.19	16.370	3%	654.79
1.169337853	0.13651286	2.28E+04	1.37E+02	24%	5.46E+03	1.169337853	0.016369759	22778.70	16.370	3%	654.79
1.196575231	0.13651286	2.33E+04	1.37E+02	23%	5.46E+03	1.196575231	0.016369759	23309.29	16.370	3%	654.79
1.224447048	0.13651286	2.39E+04	1.37E+02	23%	5.46E+03	1.224447048	0.016369759	23852.23	16.370	3%	654.79
1.252968084	0.13651286	2.44E+04	1.37E+02	22%	5.46E+03	1.252968084	0.016369759	24407.82	16.370	3%	654.79
1.28215346	0.13651286	2.50E+04	1.37E+02	22%	5.46E+03	1.28215346	0.016369759	24976.35	16.370	3%	654.79
1.312018651	0.13651286	2.56E+04	1.37E+02	21%	5.46E+03	1.312018651	0.016369759	25558.12	16.370	3%	654.79
1.342579491	0.13651286	2.62E+04	1.37E+02	21%	5.46E+03	1.342579491	0.016369759	26153.45	16.370	3%	654.79
1.373852185	0.13651286	2.68E+04	1.37E+02	20%	5.46E+03	1.373852185	0.016369759	26762.64	16.370	2%	654.79
1.405853313	0.13651286	2.74E+04	1.37E+02	20%	5.46E+03	1.405853313	0.016369759	27386.02	16.370	2%	654.79
1.438599843	0.13651286	2.80E+04	1.37E+02	19%	5.46E+03	1.438599843	0.016369759	28023.92	16.370	2%	654.79
1.472109138	0.13651286	2.87E+04	1.37E+02	19%	5.46E+03	1.472109138	0.016369759	28676.69	16.370	2%	654.79
1.506398965	0.13651286	2.93E+04	1.37E+02	19%	5.46E+03	1.506398965	0.016369759	29344.65	16.370	2%	654.79
1.541487505	0.13651286	3.00E+04	1.37E+02	18%	5.46E+03	1.541487505	0.016369759	30028.18	16.370	2%	654.79
1.577393361	0.13651286	3.07E+04	1.37E+02	18%	5.46E+03	1.577393361	0.016369759	30727.62	16.370	2%	654.79
1.614135573	0.13651286	3.14E+04	1.37E+02	17%	5.46E+03	1.614135573	0.016369759	31443.36	16.370	2%	654.79
1.65173362	0.13651286	3.22E+04	1.37E+02	17%	5.46E+03	1.65173362	0.016369759	32175.77	16.370	2%	654.79
1.690207438	0.13651286	3.29E+04	1.37E+02	17%	5.46E+03	1.690207438	0.016369759	32925.24	16.370	2%	654.79
1.729577427	0.13651286	3.37E+04	1.37E+02	16%	5.46E+03	1.729577427	0.016369759	33692.17	16.370	2%	654.79
1.769864461	0.13651286	3.45E+04	1.37E+02	16%	5.46E+03	1.769864461	0.016369759	34476.96	16.370	2%	654.79
1.8110899	0.13651286	3.53E+04	1.37E+02	15%	5.46E+03	1.8110899	0.016369759	35280.03	16.370	2%	654.79
1.853275603	0.13651286	3.61E+04	1.37E+02	15%	5.46E+03	1.853275603	0.016369759	36101.81	16.370	2%	654.79
1.896443938	0.13651286	3.69E+04	1.37E+02	15%	5.46E+03	1.896443938	0.016369759	36942.73	16.370	2%	654.79
1.940617792	0.13651286	3.78E+04	1.37E+02	14%	5.46E+03	1.940617792	0.016369759	37803.23	16.370	2%	654.79
1.985820587	0.13651286	3.87E+04	1.37E+02	14%	5.46E+03	1.985820587	0.016369759	38683.79	16.370	2%	654.79
2.03207629	0.13651286	3.96E+04	1.37E+02	14%	5.46E+03	2.03207629	0.016369759	39584.85	16.370	2%	654.79
2.079409428	0.13651286	4.05E+04	1.37E+02	13%	5.46E+03	2.079409428	0.016369759	40506.90	16.370	2%	654.79
2.127845096	0.13651286	4.15E+04	1.37E+02	13%	5.46E+03	2.127845096	0.016369759	41450.42	16.370	2%	654.79
2.177408975	0.13651286	4.24E+04	1.37E+02	13%	5.46E+03	2.177408975	0.016369759	42415.93	16.370	2%	654.79

Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
2.228127345	0.13651286	4.34E+04	1.37E+02	13%	5.46E+03
2.280027098	0.13651286	4.44E+04	1.37E+02	12%	5.46E+03
2.333135752	0.13651286	4.54E+04	1.37E+02	12%	5.46E+03
2.387481465	0.13651286	4.65E+04	1.37E+02	12%	5.46E+03
2.443093052	0.13651286	4.76E+04	1.37E+02	11%	5.46E+03
2.5	0.13651286	4.87E+04	1.37E+02	11%	5.46E+03
2.558232481	0.13651286	4.98E+04	1.37E+02	11%	5.46E+03
2.61782137	0.13651286	5.10E+04	1.37E+02	11%	5.46E+03
2.678798263	0.13651286	5.22E+04	1.37E+02	10%	5.46E+03
2.74119549	0.13651286	5.34E+04	1.37E+02	10%	5.46E+03
2.805046136	0.13651286	5.46E+04	1.37E+02	10%	5.46E+03
2.870384054	0.13651286	5.59E+04	1.37E+02	10%	5.46E+03
2.937243887	0.13651286	5.72E+04	1.37E+02	10%	5.46E+03
3.005661087	0.13651286	5.86E+04	1.37E+02	9%	5.46E+03
3.075671927	0.13651286	5.99E+04	1.37E+02	9%	5.46E+03
3.147313529	0.13651286	6.13E+04	1.37E+02	9%	5.46E+03
3.220623879	0.13651286	6.27E+04	1.37E+02	9%	5.46E+03
3.295641846	0.13651286	6.42E+04	1.37E+02	9%	5.46E+03
3.372407206	0.13651286	6.57E+04	1.37E+02	8%	5.46E+03
3.450960662	0.13651286	6.72E+04	1.37E+02	8%	5.46E+03
3.531343862	0.13651286	6.88E+04	1.37E+02	8%	5.46E+03
3.613599427	0.13651286	7.04E+04	1.37E+02	8%	5.46E+03
3.69777097	0.13651286	7.20E+04	1.37E+02	8%	5.46E+03
3.783903121	0.13651286	7.37E+04	1.37E+02	7%	5.46E+03
3.872041547	0.13651286	7.54E+04	1.37E+02	7%	5.46E+03
3.962232981	0.13651286	7.72E+04	1.37E+02	7%	5.46E+03
4.054525243	0.13651286	7.90E+04	1.37E+02	7%	5.46E+03
4.148967269	0.13651286	8.08E+04	1.37E+02	7%	5.46E+03
4.245609131	0.13651286	8.27E+04	1.37E+02	7%	5.46E+03
4.344502072	0.13651286	8.46E+04	1.37E+02	6%	5.46E+03
4.445698525	0.13651286	8.66E+04	1.37E+02	6%	5.46E+03
4.549252147	0.13651286	8.86E+04	1.37E+02	6%	5.46E+03
4.655217842	0.13651286	9.07E+04	1.37E+02	6%	5.46E+03
4.763651795	0.13651286	9.28E+04	1.37E+02	6%	5.46E+03
4.874611499	0.13651286	9.50E+04	1.37E+02	6%	5.46E+03
4.988155787	0.13651286	9.72E+04	1.37E+02	6%	5.46E+03
5.104344862	0.13651286	9.94E+04	1.37E+02	5%	5.46E+03
5.223240327	0.13651286	1.02E+05	1.37E+02	5%	5.46E+03
5.344905224	0.13651286	1.04E+05	1.37E+02	5%	5.46E+03
5.46940406	0.13651286	1.07E+05	1.37E+02	5%	5.46E+03
5.596802846	0.13651286	1.09E+05	1.37E+02	5%	5.46E+03
5.727169132	0.13651286	1.12E+05	1.37E+02	5%	5.46E+03
5.860572038	0.13651286	1.14E+05	1.37E+02	5%	5.46E+03
5.997082298	0.13651286	1.17E+05	1.37E+02	5%	5.46E+03
6.136772289	0.13651286	1.20E+05	1.37E+02	5%	5.46E+03

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
2.228127345	0.016369759	43403.92	16.370	2%	654.79
2.280027098	0.016369759	44414.93	16.370	1%	654.79
2.333135752	0.016369759	45449.48	16.370	1%	654.79
2.387481465	0.016369759	46508.14	16.370	1%	654.79
2.443093052	0.016369759	47591.45	16.370	1%	654.79
2.5	0.016369759	48700.00	16.370	1%	654.79
2.558232481	0.016369759	49834.37	16.370	1%	654.79
2.61782137	0.016369759	50995.16	16.370	1%	654.79
2.678798263	0.016369759	52182.99	16.370	1%	654.79
2.74119549	0.016369759	53398.49	16.370	1%	654.79
2.805046136	0.016369759	54642.30	16.370	1%	654.79
2.870384054	0.016369759	55915.08	16.370	1%	654.79
2.937243887	0.016369759	57217.51	16.370	1%	654.79
3.005661087	0.016369759	58550.28	16.370	1%	654.79
3.075671927	0.016369759	59914.09	16.370	1%	654.79
3.147313529	0.016369759	61309.67	16.370	1%	654.79
3.220623879	0.016369759	62737.75	16.370	1%	654.79
3.295641846	0.016369759	64199.10	16.370	1%	654.79
3.372407206	0.016369759	65694.49	16.370	1%	654.79
3.450960662	0.016369759	67224.71	16.370	1%	654.79
3.531343862	0.016369759	68790.58	16.370	1%	654.79
3.613599427	0.016369759	70392.92	16.370	1%	654.79
3.69777097	0.016369759	72032.58	16.370	1%	654.79
3.783903121	0.016369759	73710.43	16.370	1%	654.79
3.872041547	0.016369759	75427.37	16.370	1%	654.79
3.962232981	0.016369759	77184.30	16.370	1%	654.79
4.054525243	0.016369759	78982.15	16.370	1%	654.79
4.148967269	0.016369759	80821.88	16.370	1%	654.79
4.245609131	0.016369759	82704.47	16.370	1%	654.79
4.344502072	0.016369759	84630.90	16.370	1%	654.79
4.445698525	0.016369759	86602.21	16.370	1%	654.79
4.549252147	0.016369759	88619.43	16.370	1%	654.79
4.655217842	0.016369759	90683.64	16.370	1%	654.79
4.763651795	0.016369759	92795.94	16.370	1%	654.79
4.874611499	0.016369759	94957.43	16.370	1%	654.79
4.988155787	0.016369759	97169.27	16.370	1%	654.79
5.104344862	0.016369759	99432.64	16.370	1%	654.79
5.223240327	0.016369759	101748.72	16.370	1%	654.79
5.344905224	0.016369759	104118.75	16.370	1%	654.79
5.46940406	0.016369759	106543.99	16.370	1%	654.79
5.596802846	0.016369759	109025.72	16.370	1%	654.79
5.727169132	0.016369759	111565.25	16.370	1%	654.79
5.860572038	0.016369759	114163.94	16.370	1%	654.79
5.997082298	0.016369759	116823.16	16.370	1%	654.79
6.136772289	0.016369759	119544.32	16.370	1%	654.79

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
6.279716079	0.13651286	1.22E+05	1.37E+02	4%	5.46E+03
6.425989457	0.13651286	1.25E+05	1.37E+02	4%	5.46E+03
6.57566998	0.13651286	1.28E+05	1.37E+02	4%	5.46E+03
6.72883701	0.13651286	1.31E+05	1.37E+02	4%	5.46E+03
6.885571758	0.13651286	1.34E+05	1.37E+02	4%	5.46E+03
7.045957328	0.13651286	1.37E+05	1.37E+02	4%	5.46E+03
7.210078758	0.13651286	1.40E+05	1.37E+02	4%	5.46E+03
7.378023067	0.13651286	1.44E+05	1.37E+02	4%	5.46E+03
7.549879301	0.13651286	1.47E+05	1.37E+02	4%	5.46E+03
7.725738581	0.13651286	1.50E+05	1.37E+02	4%	5.46E+03
7.90569415	0.13651286	1.54E+05	1.37E+02	4%	5.46E+03
8.089841423	0.13651286	1.58E+05	1.37E+02	3%	5.46E+03
8.278278037	0.13651286	1.61E+05	1.37E+02	3%	5.46E+03
8.471103903	0.13651286	1.65E+05	1.37E+02	3%	5.46E+03
8.668421261	0.13651286	1.69E+05	1.37E+02	3%	5.46E+03
8.870334731	0.13651286	1.73E+05	1.37E+02	3%	5.46E+03
9.076951369	0.13651286	1.77E+05	1.37E+02	3%	5.46E+03
9.288380727	0.13651286	1.81E+05	1.37E+02	3%	5.46E+03
9.504734908	0.13651286	1.85E+05	1.37E+02	3%	5.46E+03
9.726128625	0.13651286	1.89E+05	1.37E+02	3%	5.46E+03
9.952679264	0.13651286	1.94E+05	1.37E+02	3%	5.46E+03
10.18450695	0.13651286	1.98E+05	1.37E+02	3%	5.46E+03
10.42173459	0.13651286	2.03E+05	1.37E+02	3%	5.46E+03
10.66448797	0.13651286	2.08E+05	1.37E+02	3%	5.46E+03
10.91289581	0.13651286	2.13E+05	1.37E+02	3%	5.46E+03
11.1670898	0.13651286	2.18E+05	1.37E+02	3%	5.46E+03
11.42720474	0.13651286	2.23E+05	1.37E+02	2%	5.46E+03
11.69337853	0.13651286	2.28E+05	1.37E+02	2%	5.46E+03
11.96575231	0.13651286	2.33E+05	1.37E+02	2%	5.46E+03
12.24447048	0.13651286	2.39E+05	1.37E+02	2%	5.46E+03
12.52968084	0.13651286	2.44E+05	1.37E+02	2%	5.46E+03
12.8215346	0.13651286	2.50E+05	1.37E+02	2%	5.46E+03
13.12018651	0.13651286	2.56E+05	1.37E+02	2%	5.46E+03
13.42579491	0.13651286	2.62E+05	1.37E+02	2%	5.46E+03
13.73852185	0.13651286	2.68E+05	1.37E+02	2%	5.46E+03
14.05853313	0.13651286	2.74E+05	1.37E+02	2%	5.46E+03
14.38599843	0.13651286	2.80E+05	1.37E+02	2%	5.46E+03
14.72109138	0.13651286	2.87E+05	1.37E+02	2%	5.46E+03
15.06398965	0.13651286	2.93E+05	1.37E+02	2%	5.46E+03
15.41487505	0.13651286	3.00E+05	1.37E+02	2%	5.46E+03
15.77393361	0.13651286	3.07E+05	1.37E+02	2%	5.46E+03
16.14135573	0.13651286	3.14E+05	1.37E+02	2%	5.46E+03
16.5173362	0.13651286	3.22E+05	1.37E+02	2%	5.46E+03
16.90207438	0.13651286	3.29E+05	1.37E+02	2%	5.46E+03
17.29577427	0.13651286	3.37E+05	1.37E+02	2%	5.46E+03

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
6.279716079	0.016369759	122328.87	16.370	1%	654.79
6.425989457	0.016369759	125178.27	16.370	1%	654.79
6.57566998	0.016369759	128094.05	16.370	1%	654.79
6.72883701	0.016369759	131077.74	16.370	0%	654.79
6.885571758	0.016369759	134130.94	16.370	0%	654.79
7.045957328	0.016369759	137255.25	16.370	0%	654.79
7.210078758	0.016369759	140452.33	16.370	0%	654.79
7.378023067	0.016369759	143723.89	16.370	0%	654.79
7.549879301	0.016369759	147071.65	16.370	0%	654.79
7.725738581	0.016369759	150497.39	16.370	0%	654.79
7.90569415	0.016369759	154002.92	16.370	0%	654.79
8.089841423	0.016369759	157590.11	16.370	0%	654.79
8.278278037	0.016369759	161260.86	16.370	0%	654.79
8.471103903	0.016369759	165017.10	16.370	0%	654.79
8.668421261	0.016369759	168860.85	16.370	0%	654.79
8.870334731	0.016369759	172794.12	16.370	0%	654.79
9.076951369	0.016369759	176819.01	16.370	0%	654.79
9.288380727	0.016369759	180937.66	16.370	0%	654.79
9.504734908	0.016369759	185152.24	16.370	0%	654.79
9.726128625	0.016369759	189464.99	16.370	0%	654.79
9.952679264	0.016369759	193878.19	16.370	0%	654.79
10.18450695	0.016369759	198394.20	16.370	0%	654.79
10.42173459	0.016369759	203015.39	16.370	0%	654.79
10.66448797	0.016369759	207744.23	16.370	0%	654.79
10.91289581	0.016369759	212583.21	16.370	0%	654.79
11.1670898	0.016369759	217534.91	16.370	0%	654.79
11.42720474	0.016369759	222601.95	16.370	0%	654.79
11.69337853	0.016369759	227787.01	16.370	0%	654.79
11.96575231	0.016369759	233092.85	16.370	0%	654.79
12.24447048	0.016369759	238522.29	16.370	0%	654.79
12.52968084	0.016369759	244078.18	16.370	0%	654.79
12.8215346	0.016369759	249763.49	16.370	0%	654.79
13.12018651	0.016369759	255581.23	16.370	0%	654.79
13.42579491	0.016369759	261534.48	16.370	0%	654.79
13.73852185	0.016369759	267626.41	16.370	0%	654.79
14.05853313	0.016369759	273860.23	16.370	0%	654.79
14.38599843	0.016369759	280239.25	16.370	0%	654.79
14.72109138	0.016369759	286766.86	16.370	0%	654.79
15.06398965	0.016369759	293446.52	16.370	0%	654.79
15.41487505	0.016369759	300281.77	16.370	0%	654.79
15.77393361	0.016369759	307276.23	16.370	0%	654.79
16.14135573	0.016369759	314433.61	16.370	0%	654.79
16.5173362	0.016369759	321757.71	16.370	0%	654.79
16.90207438	0.016369759	329252.41	16.370	0%	654.79
17.29577427	0.016369759	336921.68	16.370	0%	654.79

Attachment 2a

Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
17.69864461	0.13651286	3.45E+05	1.37E+02	2%	5.46E+03
18.110899	0.13651286	3.53E+05	1.37E+02	2%	5.46E+03
18.53275603	0.13651286	3.61E+05	1.37E+02	2%	5.46E+03
18.96443938	0.13651286	3.69E+05	1.37E+02	1%	5.46E+03
19.40617792	0.13651286	3.78E+05	1.37E+02	1%	5.46E+03
19.85820587	0.13651286	3.87E+05	1.37E+02	1%	5.46E+03
20.3207629	0.13651286	3.96E+05	1.37E+02	1%	5.46E+03
20.79409428	0.13651286	4.05E+05	1.37E+02	1%	5.46E+03
21.27845096	0.13651286	4.15E+05	1.37E+02	1%	5.46E+03
21.77408975	0.13651286	4.24E+05	1.37E+02	1%	5.46E+03
22.28127345	0.13651286	4.34E+05	1.37E+02	1%	5.46E+03
22.80027098	0.13651286	4.44E+05	1.37E+02	1%	5.46E+03
23.33135752	0.13651286	4.54E+05	1.37E+02	1%	5.46E+03
23.87481465	0.13651286	4.65E+05	1.37E+02	1%	5.46E+03
24.43093052	0.13651286	4.76E+05	1.37E+02	1%	5.46E+03
25	0.13651286	4.87E+05	1.37E+02	1%	5.46E+03

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
17.69864461	0.016369759	344769.60	16.370	0%	654.79
18.110899	0.016369759	352800.31	16.370	0%	654.79
18.53275603	0.016369759	361018.09	16.370	0%	654.79
18.96443938	0.016369759	369427.28	16.370	0%	654.79
19.40617792	0.016369759	378032.35	16.370	0%	654.79
19.85820587	0.016369759	386837.85	16.370	0%	654.79
20.3207629	0.016369759	395848.46	16.370	0%	654.79
20.79409428	0.016369759	405068.96	16.370	0%	654.79
21.27845096	0.016369759	414504.22	16.370	0%	654.79
21.77408975	0.016369759	424159.27	16.370	0%	654.79
22.28127345	0.016369759	434039.21	16.370	0%	654.79
22.80027098	0.016369759	444149.28	16.370	0%	654.79
23.33135752	0.016369759	454494.84	16.370	0%	654.79
23.87481465	0.016369759	465081.39	16.370	0%	654.79
24.43093052	0.016369759	475914.53	16.370	0%	654.79
25	0.016369759	487000.00	16.370	0%	654.79

Attachment 2a

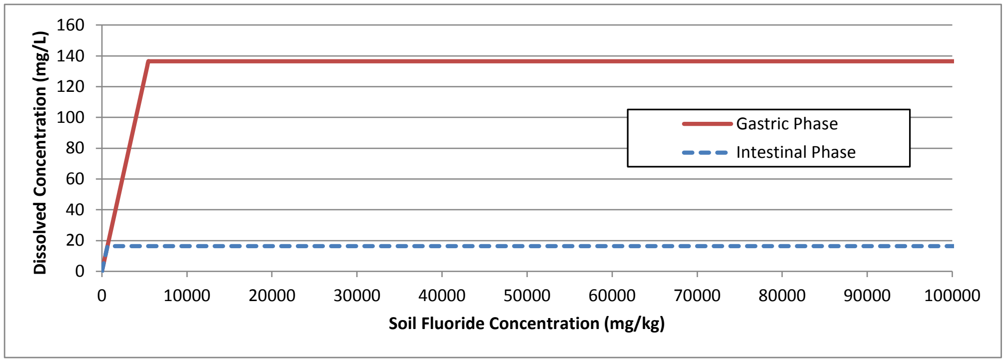
Simulated Fluoride Bioavailability in Shrew and Robin Gut

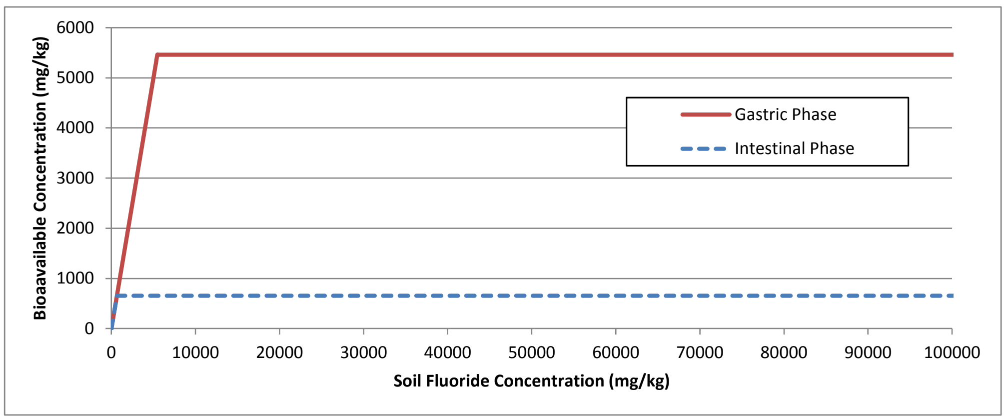
Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF_2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
Gastric Phase					
L/S = 40					
T = 37 C					
pH = 1.8 (HCl)					
0.4 M glycine					

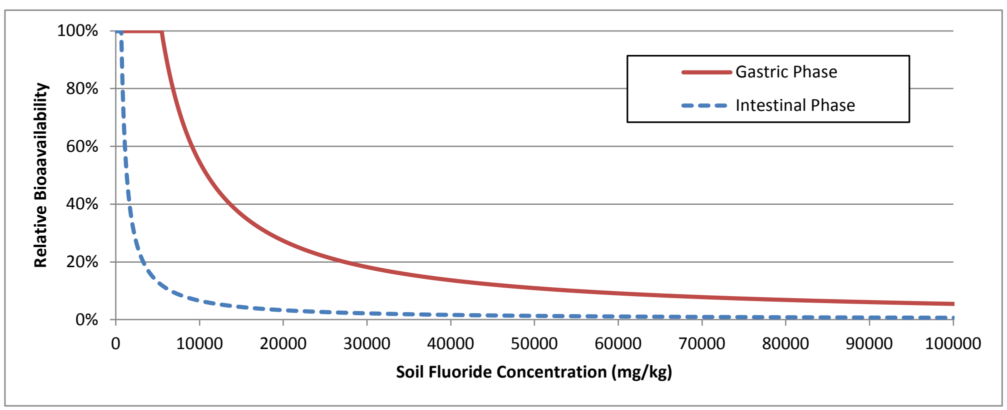
Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF_2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg
Intestinal Phase					
L/S = 40					
T = 37 C					
pH = 7 (Na_2CO_3)					
0.4 M glycine					

Attachment 2a
Simulated Fluoride Bioavailability in Shrew and Robin Gut

Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc	Fluorite reacted	Soluble Fluoride	Total Fluoride Concentration	Dissolved Fluoride	% soluble	Bioavailable Conc
g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg	g CaF2 per L fluid	g F per L fluid	mg/kg	mg/L		mg/kg







Reference:
Arsenic Speciation, Distribution, and Bioaccessibility in Shrews and Their Food
MM Moriarty, I Koch, KJ Reimer
Arch Environ Contam Toxicol (2012) 62:529–538
DOI 10.1007/s00244-011-9715-6

Attachment 2b

Simulated Earthworm Gut Fluoride Concentrations

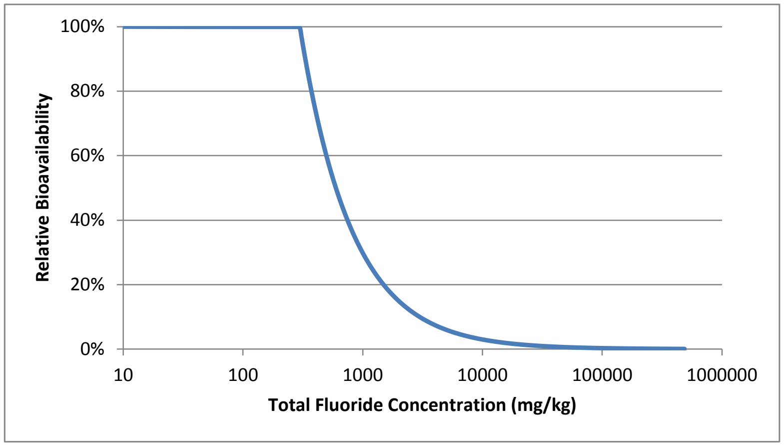
Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
10		1.00E-04	0.10	100%	10
48.7	1.00E-03	4.87E-04	0.49	100%	48.7
49.8	1.02E-03	4.98E-04	0.50	100%	49.8
51.0	1.05E-03	5.10E-04	0.51	100%	51.0
52.2	1.07E-03	5.21E-04	0.52	100%	52.1
53.4	1.10E-03	5.34E-04	0.53	100%	53.4
54.6	1.12E-03	5.46E-04	0.55	100%	54.6
55.9	1.15E-03	5.59E-04	0.56	100%	55.9
57.2	1.17E-03	5.72E-04	0.57	100%	57.2
58.6	1.20E-03	5.85E-04	0.59	100%	58.5
59.9	1.23E-03	5.99E-04	0.60	100%	59.9
61.3	1.26E-03	6.13E-04	0.61	100%	61.3
62.7	1.29E-03	6.27E-04	0.63	100%	62.7
64.2	1.32E-03	6.42E-04	0.64	100%	64.2
65.7	1.35E-03	6.57E-04	0.66	100%	65.7
67.2	1.38E-03	6.72E-04	0.67	100%	67.2
68.8	1.41E-03	6.87E-04	0.69	100%	68.7
70.4	1.45E-03	7.03E-04	0.70	100%	70.3
72.0	1.48E-03	7.20E-04	0.72	100%	72.0
73.7	1.51E-03	7.37E-04	0.74	100%	73.7
75.4	1.55E-03	7.54E-04	0.75	100%	75.4
77.2	1.58E-03	7.71E-04	0.77	100%	77.1
79.0	1.62E-03	7.89E-04	0.79	100%	78.9
80.8	1.66E-03	8.08E-04	0.81	100%	80.8
82.7	1.70E-03	8.27E-04	0.83	100%	82.7
84.6	1.74E-03	8.46E-04	0.85	100%	84.6
86.6	1.78E-03	8.65E-04	0.87	100%	86.5
88.6	1.82E-03	8.86E-04	0.89	100%	88.6
90.7	1.86E-03	9.06E-04	0.91	100%	90.6
92.8	1.91E-03	9.27E-04	0.93	100%	92.7
95.0	1.95E-03	9.49E-04	0.95	100%	94.9
97.2	2.00E-03	9.71E-04	0.97	100%	97.1
99.4	2.04E-03	9.94E-04	0.99	100%	99.4
101.7	2.09E-03	1.02E-03	1.02	100%	101.7
104.1	2.14E-03	1.04E-03	1.04	100%	104.1

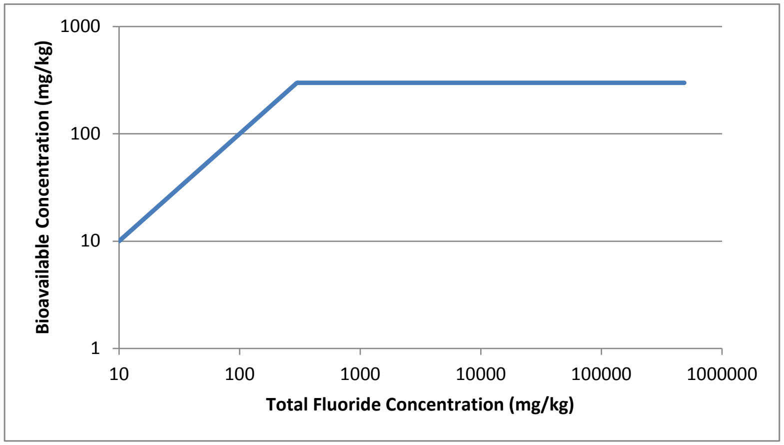
SEG: L/S = 100

0.01 M $CaCl_2$

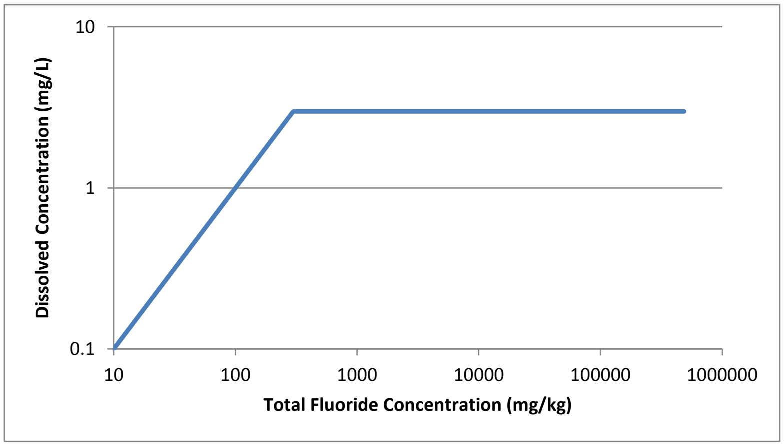
pH = 7

T = 25 C





Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
106.5	2.19E-03	1.06E-03	1.06	100%	106.5
109.0	2.24E-03	1.09E-03	1.09	100%	109.0
111.6	2.29E-03	1.11E-03	1.11	100%	111.5
114.2	2.34E-03	1.14E-03	1.14	100%	114.1
116.8	2.40E-03	1.17E-03	1.17	100%	116.7
119.5	2.45E-03	1.19E-03	1.19	100%	119.5
122.3	2.51E-03	1.22E-03	1.22	100%	122.2
125.2	2.57E-03	1.25E-03	1.25	100%	125.1
128.1	2.63E-03	1.28E-03	1.28	100%	128.0
131.1	2.69E-03	1.31E-03	1.31	100%	131.0
134.1	2.75E-03	1.34E-03	1.34	100%	134.0
137.3	2.82E-03	1.37E-03	1.37	100%	137.2
140.5	2.88E-03	1.40E-03	1.40	100%	140.4
143.7	2.95E-03	1.44E-03	1.44	100%	143.6
147.1	3.02E-03	1.47E-03	1.47	100%	147.0
150.5	3.09E-03	1.50E-03	1.50	100%	150.4
154.0	3.16E-03	1.54E-03	1.54	100%	153.9
157.6	3.24E-03	1.57E-03	1.57	100%	157.5
161.3	3.31E-03	1.61E-03	1.61	100%	161.2
165.0	3.39E-03	1.65E-03	1.65	100%	164.9
168.9	3.47E-03	1.69E-03	1.69	100%	168.7
172.8	3.55E-03	1.73E-03	1.73	100%	172.7
176.8	3.63E-03	1.77E-03	1.77	100%	176.7
180.9	3.72E-03	1.81E-03	1.81	100%	180.8
185.2	3.80E-03	1.85E-03	1.85	100%	185.0
189.5	3.89E-03	1.89E-03	1.89	100%	189.3
193.9	3.98E-03	1.94E-03	1.94	100%	193.7
198.4	4.07E-03	1.98E-03	1.98	100%	198.3
203.0	4.17E-03	2.03E-03	2.03	100%	202.9
207.7	4.27E-03	2.08E-03	2.08	100%	207.6
212.6	4.37E-03	2.12E-03	2.12	100%	212.4
217.5	4.47E-03	2.17E-03	2.17	100%	217.4
222.6	4.57E-03	2.22E-03	2.22	100%	222.5
227.8	4.68E-03	2.28E-03	2.28	100%	227.6
233.1	4.79E-03	2.33E-03	2.33	100%	232.9
238.5	4.90E-03	2.38E-03	2.38	100%	238.4
244.1	5.01E-03	2.44E-03	2.44	100%	243.9
249.8	5.13E-03	2.50E-03	2.50	100%	249.6
255.6	5.25E-03	2.55E-03	2.55	100%	255.4
261.5	5.37E-03	2.61E-03	2.61	100%	261.4
267.6	5.50E-03	2.67E-03	2.67	100%	267.4
273.9	5.62E-03	2.74E-03	2.74	100%	273.7
280.2	5.75E-03	2.80E-03	2.80	100%	280.1



Attachment 2b

Simulated Earthworm Gut Fluoride Concentrations

Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
286.8	5.89E-03	2.87E-03	2.87	100%	286.6
293.4	6.03E-03	2.93E-03	2.93	100%	293.3
300.3	6.17E-03	2.98E-03	2.98	99%	298.5
307.3	6.31E-03	2.98E-03	2.98	97%	298.5
314.4	6.46E-03	2.98E-03	2.98	95%	298.5
321.8	6.61E-03	2.98E-03	2.98	93%	298.5
329.3	6.76E-03	2.98E-03	2.98	91%	298.5
336.9	6.92E-03	2.98E-03	2.98	89%	298.5
344.8	7.08E-03	2.98E-03	2.98	87%	298.5
352.8	7.24E-03	2.98E-03	2.98	85%	298.5
361.0	7.41E-03	2.98E-03	2.98	83%	298.5
369.4	7.59E-03	2.98E-03	2.98	81%	298.5
378.0	7.76E-03	2.98E-03	2.98	79%	298.5
386.8	7.94E-03	2.98E-03	2.98	77%	298.5
395.8	8.13E-03	2.98E-03	2.98	75%	298.5
405.1	8.32E-03	2.98E-03	2.98	74%	298.5
414.5	8.51E-03	2.98E-03	2.98	72%	298.5
424.2	8.71E-03	2.98E-03	2.98	70%	298.5
434.0	8.91E-03	2.98E-03	2.98	69%	298.5
444.1	9.12E-03	2.98E-03	2.98	67%	298.5
454.5	9.33E-03	2.98E-03	2.98	66%	298.5
465.1	9.55E-03	2.98E-03	2.98	64%	298.5
475.9	9.77E-03	2.98E-03	2.98	63%	298.5
487.0	1.00E-02	2.98E-03	2.98	61%	298.5
498.3	1.02E-02	2.98E-03	2.98	60%	298.5
510.0	1.05E-02	2.98E-03	2.98	59%	298.5
521.8	1.07E-02	2.98E-03	2.98	57%	298.5
534.0	1.10E-02	2.98E-03	2.98	56%	298.5
546.4	1.12E-02	2.98E-03	2.98	55%	298.5
559.2	1.15E-02	2.98E-03	2.98	53%	298.5
572.2	1.17E-02	2.98E-03	2.98	52%	298.5
585.5	1.20E-02	2.98E-03	2.98	51%	298.5
599.1	1.23E-02	2.98E-03	2.98	50%	298.5
613.1	1.26E-02	2.98E-03	2.98	49%	298.5
627.4	1.29E-02	2.98E-03	2.98	48%	298.5
642.0	1.32E-02	2.98E-03	2.98	46%	298.5
656.9	1.35E-02	2.98E-03	2.98	45%	298.5
672.2	1.38E-02	2.98E-03	2.98	44%	298.5
687.9	1.41E-02	2.98E-03	2.98	43%	298.5
703.9	1.45E-02	2.98E-03	2.98	42%	298.5
720.3	1.48E-02	2.98E-03	2.98	41%	298.5
737.1	1.51E-02	2.98E-03	2.98	40%	298.5
754.3	1.55E-02	2.98E-03	2.98	40%	298.5

Simulated Earthworm Gut Fluoride Concentrations

Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
771.8	1.58E-02	2.98E-03	2.98	39%	298.5
789.8	1.62E-02	2.98E-03	2.98	38%	298.5
808.2	1.66E-02	2.98E-03	2.98	37%	298.5
827.0	1.70E-02	2.98E-03	2.98	36%	298.5
846.3	1.74E-02	2.98E-03	2.98	35%	298.5
866.0	1.78E-02	2.98E-03	2.98	34%	298.5
886.2	1.82E-02	2.98E-03	2.98	34%	298.5
906.8	1.86E-02	2.98E-03	2.98	33%	298.5
928.0	1.91E-02	2.98E-03	2.98	32%	298.5
949.6	1.95E-02	2.98E-03	2.98	31%	298.5
971.7	2.00E-02	2.98E-03	2.98	31%	298.5
994.3	2.04E-02	2.98E-03	2.98	30%	298.5
1,017.5	2.09E-02	2.98E-03	2.98	29%	298.5
1,041.2	2.14E-02	2.98E-03	2.98	29%	298.5
1,065.4	2.19E-02	2.98E-03	2.98	28%	298.5
1,090.3	2.24E-02	2.98E-03	2.98	27%	298.5
1,115.7	2.29E-02	2.98E-03	2.98	27%	298.5
1,141.6	2.34E-02	2.98E-03	2.98	26%	298.5
1,168.2	2.40E-02	2.98E-03	2.98	26%	298.5
1,195.4	2.45E-02	2.98E-03	2.98	25%	298.5
1,223.3	2.51E-02	2.98E-03	2.98	24%	298.5
1,251.8	2.57E-02	2.98E-03	2.98	24%	298.5
1,280.9	2.63E-02	2.98E-03	2.98	23%	298.5
1,310.8	2.69E-02	2.98E-03	2.98	23%	298.5
1,341.3	2.75E-02	2.98E-03	2.98	22%	298.5
1,372.6	2.82E-02	2.98E-03	2.98	22%	298.5
1,404.5	2.88E-02	2.98E-03	2.98	21%	298.5
1,437.2	2.95E-02	2.98E-03	2.98	21%	298.5
1,470.7	3.02E-02	2.98E-03	2.98	20%	298.5
1,505.0	3.09E-02	2.98E-03	2.98	20%	298.5
1,540.0	3.16E-02	2.98E-03	2.98	19%	298.5
1,575.9	3.24E-02	2.98E-03	2.98	19%	298.5
1,612.6	3.31E-02	2.98E-03	2.98	19%	298.5
1,650.2	3.39E-02	2.98E-03	2.98	18%	298.5
1,688.6	3.47E-02	2.98E-03	2.98	18%	298.5
1,727.9	3.55E-02	2.98E-03	2.98	17%	298.5
1,768.2	3.63E-02	2.98E-03	2.98	17%	298.5
1,809.4	3.72E-02	2.98E-03	2.98	16%	298.5
1,851.5	3.80E-02	2.98E-03	2.98	16%	298.5
1,894.6	3.89E-02	2.98E-03	2.98	16%	298.5
1,938.8	3.98E-02	2.98E-03	2.98	15%	298.5
1,983.9	4.07E-02	2.98E-03	2.98	15%	298.5
2,030.2	4.17E-02	2.98E-03	2.98	15%	298.5

Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
2,077.4	4.27E-02	2.98E-03	2.98	14%	298.5
2,125.8	4.37E-02	2.98E-03	2.98	14%	298.5
2,175.3	4.47E-02	2.98E-03	2.98	14%	298.5
2,226.0	4.57E-02	2.98E-03	2.98	13%	298.5
2,277.9	4.68E-02	2.98E-03	2.98	13%	298.5
2,330.9	4.79E-02	2.98E-03	2.98	13%	298.5
2,385.2	4.90E-02	2.98E-03	2.98	13%	298.5
2,440.8	5.01E-02	2.98E-03	2.98	12%	298.5
2,497.6	5.13E-02	2.98E-03	2.98	12%	298.5
2,555.8	5.25E-02	2.98E-03	2.98	12%	298.5
2,615.3	5.37E-02	2.98E-03	2.98	11%	298.5
2,676.3	5.50E-02	2.98E-03	2.98	11%	298.5
2,738.6	5.62E-02	2.98E-03	2.98	11%	298.5
2,802.4	5.75E-02	2.98E-03	2.98	11%	298.5
2,867.7	5.89E-02	2.98E-03	2.98	10%	298.5
2,934.5	6.03E-02	2.98E-03	2.98	10%	298.5
3,002.8	6.17E-02	2.98E-03	2.98	10%	298.5
3,072.8	6.31E-02	2.98E-03	2.98	10%	298.5
3,144.3	6.46E-02	2.98E-03	2.98	9%	298.5
3,217.6	6.61E-02	2.98E-03	2.98	9%	298.5
3,292.5	6.76E-02	2.98E-03	2.98	9%	298.5
3,369.2	6.92E-02	2.98E-03	2.98	9%	298.5
3,447.7	7.08E-02	2.98E-03	2.98	9%	298.5
3,528.0	7.24E-02	2.98E-03	2.98	8%	298.5
3,610.2	7.41E-02	2.98E-03	2.98	8%	298.5
3,694.3	7.59E-02	2.98E-03	2.98	8%	298.5
3,780.3	7.76E-02	2.98E-03	2.98	8%	298.5
3,868.4	7.94E-02	2.98E-03	2.98	8%	298.5
3,958.5	8.13E-02	2.98E-03	2.98	8%	298.5
4,050.7	8.32E-02	2.98E-03	2.98	7%	298.5
4,145.0	8.51E-02	2.98E-03	2.98	7%	298.5
4,241.6	8.71E-02	2.98E-03	2.98	7%	298.5
4,340.4	8.91E-02	2.98E-03	2.98	7%	298.5
4,441.5	9.12E-02	2.98E-03	2.98	7%	298.5
4,544.9	9.33E-02	2.98E-03	2.98	7%	298.5
4,650.8	9.55E-02	2.98E-03	2.98	6%	298.5
4,759.1	9.77E-02	2.98E-03	2.98	6%	298.5
4,870.0	1.00E-01	2.98E-03	2.98	6%	298.5
4,983.4	1.02E-01	2.98E-03	2.98	6%	298.5
5,099.5	1.05E-01	2.98E-03	2.98	6%	298.5
5,218.3	1.07E-01	2.98E-03	2.98	6%	298.5
5,339.8	1.10E-01	2.98E-03	2.98	6%	298.5
5,464.2	1.12E-01	2.98E-03	2.98	5%	298.5

Attachment 2b
Simulated Earthworm Gut Fluoride Concentrations

Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
5,591.5	1.15E-01	2.98E-03	2.98	5%	298.5
5,721.8	1.17E-01	2.98E-03	2.98	5%	298.5
5,855.0	1.20E-01	2.98E-03	2.98	5%	298.5
5,991.4	1.23E-01	2.98E-03	2.98	5%	298.5
6,131.0	1.26E-01	2.98E-03	2.98	5%	298.5
6,273.8	1.29E-01	2.98E-03	2.98	5%	298.5
6,419.9	1.32E-01	2.98E-03	2.98	5%	298.5
6,569.4	1.35E-01	2.98E-03	2.98	5%	298.5
6,722.5	1.38E-01	2.98E-03	2.98	4%	298.5
6,879.1	1.41E-01	2.98E-03	2.98	4%	298.5
7,039.3	1.45E-01	2.98E-03	2.98	4%	298.5
7,203.3	1.48E-01	2.98E-03	2.98	4%	298.5
7,371.0	1.51E-01	2.98E-03	2.98	4%	298.5
7,542.7	1.55E-01	2.98E-03	2.98	4%	298.5
7,718.4	1.58E-01	2.98E-03	2.98	4%	298.5
7,898.2	1.62E-01	2.98E-03	2.98	4%	298.5
8,082.2	1.66E-01	2.98E-03	2.98	4%	298.5
8,270.4	1.70E-01	2.98E-03	2.98	4%	298.5
8,463.1	1.74E-01	2.98E-03	2.98	4%	298.5
8,660.2	1.78E-01	2.98E-03	2.98	3%	298.5
8,861.9	1.82E-01	2.98E-03	2.98	3%	298.5
9,068.4	1.86E-01	2.98E-03	2.98	3%	298.5
9,279.6	1.91E-01	2.98E-03	2.98	3%	298.5
9,495.7	1.95E-01	2.98E-03	2.98	3%	298.5
9,716.9	2.00E-01	2.98E-03	2.98	3%	298.5
9,943.3	2.04E-01	2.98E-03	2.98	3%	298.5
10,174.9	2.09E-01	2.98E-03	2.98	3%	298.5
10,411.9	2.14E-01	2.98E-03	2.98	3%	298.5
10,654.4	2.19E-01	2.98E-03	2.98	3%	298.5
10,902.6	2.24E-01	2.98E-03	2.98	3%	298.5
11,156.5	2.29E-01	2.98E-03	2.98	3%	298.5
11,416.4	2.34E-01	2.98E-03	2.98	3%	298.5
11,682.3	2.40E-01	2.98E-03	2.98	3%	298.5
11,954.4	2.45E-01	2.98E-03	2.98	2%	298.5
12,232.9	2.51E-01	2.98E-03	2.98	2%	298.5
12,517.8	2.57E-01	2.98E-03	2.98	2%	298.5
12,809.4	2.63E-01	2.98E-03	2.98	2%	298.5
13,107.8	2.69E-01	2.98E-03	2.98	2%	298.5
13,413.1	2.75E-01	2.98E-03	2.98	2%	298.5
13,725.5	2.82E-01	2.98E-03	2.98	2%	298.5
14,045.2	2.88E-01	2.98E-03	2.98	2%	298.5
14,372.4	2.95E-01	2.98E-03	2.98	2%	298.5
14,707.2	3.02E-01	2.98E-03	2.98	2%	298.5

Attachment 2b
Simulated Earthworm Gut Fluoride Concentrations

Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
15,049.7	3.09E-01	2.98E-03	2.98	2%	298.5
15,400.3	3.16E-01	2.98E-03	2.98	2%	298.5
15,759.0	3.24E-01	2.98E-03	2.98	2%	298.5
16,126.1	3.31E-01	2.98E-03	2.98	2%	298.5
16,501.7	3.39E-01	2.98E-03	2.98	2%	298.5
16,886.1	3.47E-01	2.98E-03	2.98	2%	298.5
17,279.4	3.55E-01	2.98E-03	2.98	2%	298.5
17,681.9	3.63E-01	2.98E-03	2.98	2%	298.5
18,093.8	3.72E-01	2.98E-03	2.98	2%	298.5
18,515.2	3.80E-01	2.98E-03	2.98	2%	298.5
18,946.5	3.89E-01	2.98E-03	2.98	2%	298.5
19,387.8	3.98E-01	2.98E-03	2.98	2%	298.5
19,839.4	4.07E-01	2.98E-03	2.98	2%	298.5
20,301.5	4.17E-01	2.98E-03	2.98	1%	298.5
20,774.4	4.27E-01	2.98E-03	2.98	1%	298.5
21,258.3	4.37E-01	2.98E-03	2.98	1%	298.5
21,753.5	4.47E-01	2.98E-03	2.98	1%	298.5
22,260.2	4.57E-01	2.98E-03	2.98	1%	298.5
22,778.7	4.68E-01	2.98E-03	2.98	1%	298.5
23,309.3	4.79E-01	2.98E-03	2.98	1%	298.5
23,852.2	4.90E-01	2.98E-03	2.98	1%	298.5
24,407.8	5.01E-01	2.98E-03	2.98	1%	298.5
24,976.3	5.13E-01	2.98E-03	2.98	1%	298.5
25,558.1	5.25E-01	2.98E-03	2.98	1%	298.5
26,153.4	5.37E-01	2.98E-03	2.98	1%	298.5
26,762.6	5.50E-01	2.98E-03	2.98	1%	298.5
27,386.0	5.62E-01	2.98E-03	2.98	1%	298.5
28,023.9	5.75E-01	2.98E-03	2.98	1%	298.5
28,676.7	5.89E-01	2.98E-03	2.98	1%	298.5
29,344.7	6.03E-01	2.98E-03	2.98	1%	298.5
30,028.2	6.17E-01	2.98E-03	2.98	1%	298.5
30,727.6	6.31E-01	2.98E-03	2.98	1%	298.5
31,443.4	6.46E-01	2.98E-03	2.98	1%	298.5
32,175.8	6.61E-01	2.98E-03	2.98	1%	298.5
32,925.2	6.76E-01	2.98E-03	2.98	1%	298.5
33,692.2	6.92E-01	2.98E-03	2.98	1%	298.5
34,477.0	7.08E-01	2.98E-03	2.98	1%	298.5
35,280.0	7.24E-01	2.98E-03	2.98	1%	298.5
36,101.8	7.41E-01	2.98E-03	2.98	1%	298.5
36,942.7	7.59E-01	2.98E-03	2.98	1%	298.5
37,803.2	7.76E-01	2.98E-03	2.98	1%	298.5
38,683.8	7.94E-01	2.98E-03	2.98	1%	298.5
39,584.8	8.13E-01	2.98E-03	2.98	1%	298.5

Attachment 2b
Simulated Earthworm Gut Fluoride Concentrations

Total Fluoride Concentration mg/kg	Fluorite reacted g CaF2 per L fluid	Soluble Fluoride g F per L fluid	mg/L	% soluble	Bioavailable Conc mg/kg
40,506.9	8.32E-01	2.98E-03	2.98	1%	298.5
41,450.4	8.51E-01	2.98E-03	2.98	1%	298.5
42,415.9	8.71E-01	2.98E-03	2.98	1%	298.5
43,403.9	8.91E-01	2.98E-03	2.98	1%	298.5
44,414.9	9.12E-01	2.98E-03	2.98	1%	298.5
45,449.5	9.33E-01	2.98E-03	2.98	1%	298.5
46,508.1	9.55E-01	2.98E-03	2.98	1%	298.5
47,591.5	9.77E-01	2.98E-03	2.98	1%	298.5
48,700.0	1.00E+00	2.98E-03	2.98	1%	298.5
49,834.4	1.02E+00	2.98E-03	2.98	1%	298.5
50,995.2	1.05E+00	2.98E-03	2.98	1%	298.5
52,183.0	1.07E+00	2.98E-03	2.98	1%	298.5
53,398.5	1.10E+00	2.98E-03	2.98	1%	298.5
54,642.3	1.12E+00	2.98E-03	2.98	1%	298.5
55,915.1	1.15E+00	2.98E-03	2.98	1%	298.5
57,217.5	1.17E+00	2.98E-03	2.98	1%	298.5
58,550.3	1.20E+00	2.98E-03	2.98	1%	298.5
59,914.1	1.23E+00	2.98E-03	2.98	0%	298.5
61,309.7	1.26E+00	2.98E-03	2.98	0%	298.5
62,737.8	1.29E+00	2.98E-03	2.98	0%	298.5
64,199.1	1.32E+00	2.98E-03	2.98	0%	298.5
65,694.5	1.35E+00	2.98E-03	2.98	0%	298.5
67,224.7	1.38E+00	2.98E-03	2.98	0%	298.5
68,790.6	1.41E+00	2.98E-03	2.98	0%	298.5
70,392.9	1.45E+00	2.98E-03	2.98	0%	298.5
72,032.6	1.48E+00	2.98E-03	2.98	0%	298.5
73,710.4	1.51E+00	2.98E-03	2.98	0%	298.5
75,427.4	1.55E+00	2.98E-03	2.98	0%	298.5
77,184.3	1.58E+00	2.98E-03	2.98	0%	298.5
78,982.2	1.62E+00	2.98E-03	2.98	0%	298.5
80,821.9	1.66E+00	2.98E-03	2.98	0%	298.5
82,704.5	1.70E+00	2.98E-03	2.98	0%	298.5
84,630.9	1.74E+00	2.98E-03	2.98	0%	298.5
86,602.2	1.78E+00	2.98E-03	2.98	0%	298.5
88,619.4	1.82E+00	2.98E-03	2.98	0%	298.5
90,683.6	1.86E+00	2.98E-03	2.98	0%	298.5
92,795.9	1.91E+00	2.98E-03	2.98	0%	298.5
94,957.4	1.95E+00	2.98E-03	2.98	0%	298.5
97,169.3	2.00E+00	2.98E-03	2.98	0%	298.5
99,432.6	2.04E+00	2.98E-03	2.98	0%	298.5

ATTACHMENT 3
PROUCL SOFTWARE EXPOSURE POINT CALCULATIONS

General UCL Statistics: U Ditch Data Set

User Selected Options

From File	WorkSheet.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

U-Ditch_Soil_Fluoride

General Statistics

Number of Valid Observations	56	Number of Distinct Observations	53
Raw Statistics		**Log-transformed Statistics**	
Minimum	125	Minimum of Log Data	4.828
Maximum	2450	Maximum of Log Data	7.804
Mean	690.7	Mean of log Data	6.213
Median	506	SD of log Data	0.828
SD	569.2		
Std. Error of Mean	76.06		
Coefficient of Variation	0.824		
Skewness	1.32		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.183	Lilliefors Test Statistic	0.107
Lilliefors Critical Value	0.118	Lilliefors Critical Value	0.118
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	817.9	95% H-UCL	894.5
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1079
95% Adjusted-CLT UCL (Chen-1995)	830.1	97.5% Chebyshev (MVUE) UCL	1243
95% Modified-t UCL (Johnson-1978)	820.2	99% Chebyshev (MVUE) UCL	1567
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	1.608	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	429.5		
MLE of Mean	690.7		
MLE of Standard Deviation	544.6		
nu star	180.1		
Approximate Chi Square Value (.05)	150.1	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0457	95% CLT UCL	815.8
Adjusted Chi Square Value	149.4	95% Jackknife UCL	817.9
		95% Standard Bootstrap UCL	812.6
Anderson-Darling Test Statistic	0.902	95% Bootstrap-t UCL	836.9
Anderson-Darling 5% Critical Value	0.766	95% Hall's Bootstrap UCL	838
Kolmogorov-Smirnov Test Statistic	0.0995	95% Percentile Bootstrap UCL	827.9
Kolmogorov-Smirnov 5% Critical Value	0.121	95% BCA Bootstrap UCL	832.9
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1022
		97.5% Chebyshev(Mean, Sd) UCL	1166
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1447
95% Approximate Gamma UCL	828.9		
95% Adjusted Gamma UCL	832.9		
Potential UCL to Use		Use 95% Approximate Gamma UCL	828.9

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

General UCL Statistics for Full Data Set

User Selected Options

From File	WorkSheet.wst
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

C0

General Statistics

Number of Valid Observations	82	Number of Distinct Observations	79
Raw Statistics		**Log-transformed Statistics**	
Minimum	9.1	Minimum of Log Data	2.208
Maximum	2450	Maximum of Log Data	7.804
Mean	601.7	Mean of log Data	6.076
Median	441	SD of log Data	0.873
SD	502.2		
Coefficient of Variation	0.835		
Skewness	1.689		

Relevant UCL Statistics

Normal Distribution Test		**Lognormal Distribution Test**	
Lilliefors Test Statistic	0.175	Lilliefors Test Statistic	0.0586
Lilliefors Critical Value	0.0978	Lilliefors Critical Value	0.0978
Data not Normal at 5% Significance Level		**Data appear Lognormal at 5% Significance Level**	
Assuming Normal Distribution		**Assuming Lognormal Distribution**	
95% Student's-t UCL	694	95% H-UCL	782.4
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	940
95% Adjusted-CLT UCL (Chen-1995)	704	97.5% Chebyshev (MVUE) UCL	1073
95% Modified-t UCL (Johnson-1978)	695.7	99% Chebyshev (MVUE) UCL	1334
Gamma Distribution Test		**Data Distribution**	
k star (bias corrected)	1.636	**Data Follow Appr. Gamma Distribution at 5% Significance Level**	
Theta Star	367.7		
MLE of Mean	601.7		
MLE of Standard Deviation	470.4		
nu star	268.4		
Approximate Chi Square Value (.05)	231.4	**Nonparametric Statistics**	
Adjusted Level of Significance	0.0471	95% CLT UCL	693
Adjusted Chi Square Value	230.8	95% Jackknife UCL	694
		95% Standard Bootstrap UCL	692.4
Anderson-Darling Test Statistic	0.77	95% Bootstrap-t UCL	713.6
Anderson-Darling 5% Critical Value	0.768	95% Hall's Bootstrap UCL	710.5
Kolmogorov-Smirnov Test Statistic	0.0783	95% Percentile Bootstrap UCL	693.4
Kolmogorov-Smirnov 5% Critical Value	0.1	95% BCA Bootstrap UCL	700.8
Data follow Appr. Gamma Distribution at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	843.5
		97.5% Chebyshev(Mean, Sd) UCL	948.1
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1154
95% Approximate Gamma UCL	697.8		
95% Adjusted Gamma UCL	699.6		
Potential UCL to Use		Use 95% Approximate Gamma UCL	697.8

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL. These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002) and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.

UCL Statistics for Data Sets with Non-Detects

User Selected Options	
Date/Time of Computation	12/20/2013 9:22:22 AM
From File	PCB_BAP_for_ProUCL_a.xls
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

BAP

General Statistics

Total Number of Observations	85	Number of Distinct Observations	81
Number of Detects	69	Number of Non-Detects	16
Number of Distinct Detects	67	Number of Distinct Non-Detects	15
Minimum Detect	2.45	Minimum Non-Detect	3.64
Maximum Detect	62000	Maximum Non-Detect	66
Variance Detects	88076432	Percent Non-Detects	18.82%
Mean Detects	3144	SD Detects	9385
Median Detects	41.8	CV Detects	2.985
Skewness Detects	4.63	Kurtosis Detects	24.44
Mean of Logged Detects	4.81	SD of Logged Detects	2.819

Normal GOF Test on Detects Only

Shapiro Wilk Test Statistic	0.396	**Normal GOF Test on Detected Observations Only**
5% Shapiro Wilk P Value	0	Detected Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.369	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.107	Detected Data Not Normal at 5% Significance Level

Detected Data Not Normal at 5% Significance Level

Kaplan-Meier (KM) Statistics using Normal Critical Values and other Nonparametric UCLs

Mean	2554	Standard Error of Mean	926.9
SD	8483	95% KM (BCA) UCL	4145
95% KM (t) UCL	4095	95% KM (Percentile Bootstrap) UCL	4277
95% KM (z) UCL	4078	95% KM Bootstrap t UCL	5479
90% KM Chebyshev UCL	5334	95% KM Chebyshev UCL	6594
97.5% KM Chebyshev UCL	8342	99% KM Chebyshev UCL	11776

Gamma GOF Tests on Detected Observations Only

A-D Test Statistic	4.875	**Anderson-Darling GOF Test**
5% A-D Critical Value	0.903	Detected Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.223	**Kolmogrov-Smirnoff GOF**
5% K-S Critical Value	0.118	Detected Data Not Gamma Distributed at 5% Significance Level

Detected Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics on Detected Data Only

k hat (MLE)	0.223	k star (bias corrected MLE)	0.223
Theta hat (MLE)	14099	Theta star (bias corrected MLE)	14101
nu hat (MLE)	30.78	nu star (bias corrected)	30.77
MLE Mean (bias corrected)	3144	MLE Sd (bias corrected)	6659

Gamma Kaplan-Meier (KM) Statistics

k hat (KM)	0.0906	nu hat (KM)	15.41
Approximate Chi Square Value (15.41, α)	7.544	Adjusted Chi Square Value (15.41, β)	7.449
95% Gamma Approximate KM-UCL (use when n>=50)	5215	95% Gamma Adjusted KM-UCL (use when n<50)	5281

Gamma (KM) may not be used when k hat (KM) is < 0.1

Gamma ROS Statistics using Imputed Non-Detects

GROS may not be used when data set has > 50% NDs with many tied observations at multiple DLs

GROS may not be used when kstar of detected data is small such as < 0.1

For such situations, GROS method tends to yield inflated values of UCLs and BTVs

For gamma distributed detected data, BTVs and UCLs may be computed using gamma distribution on KM estimates

Minimum	0.01	Mean	2553
Maximum	62000	Median	24.1
SD	8534	CV	3.343
k hat (MLE)	0.159	k star (bias corrected MLE)	0.161
Theta hat (MLE)	16096	Theta star (bias corrected MLE)	15872
nu hat (MLE)	26.96	nu star (bias corrected)	27.34
MLE Mean (bias corrected)	2553	MLE Sd (bias corrected)	6365
		Adjusted Level of Significance (β)	0.0472
Approximate Chi Square Value (27.34, α)	16.42	Adjusted Chi Square Value (27.34, β)	16.27
95% Gamma Approximate UCL (use when n>=50)	4251	95% Gamma Adjusted UCL (use when n<50)	4290

Lognormal GOF Test on Detected Observations Only

Lilliefors Test Statistic	0.156	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.107	Detected Data Not Lognormal at 5% Significance Level

Detected Data Not Lognormal at 5% Significance Level

Lognormal ROS Statistics Using Imputed Non-Detects

Mean in Original Scale	2553	Mean in Log Scale	3.997
SD in Original Scale	8534	SD in Log Scale	3.093
95% t UCL (assumes normality of ROS data)	4093	95% Percentile Bootstrap UCL	4161
95% BCA Bootstrap UCL	4869	95% Bootstrap t UCL	5371
95% H-UCL (Log ROS)	32998		

DL/2 Statistics

DL/2 Normal		**DL/2 Log-Transformed**	
Mean in Original Scale	2554	Mean in Log Scale	4.178
SD in Original Scale	8533	SD in Log Scale	2.905
95% t UCL (Assumes normality)	4094	95% H-Stat UCL	18832

DL/2 is not a recommended method, provided for comparisons and historical reasons

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution at 5% Significance Level

Suggested UCL to Use

97.5% KM (Chebyshev) UCL 8342

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
Recommendations are based upon data size, data distribution, and skewness.
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).
However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.

UCL Statistics for Data Sets with Non-Detects

User Selected Options	
Date/Time of Computation	12/20/2013 9:06:39 AM
From File	PCB_BAP_for_ProUCL.xls
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

PCB

General Statistics

Total Number of Observations	25	Number of Distinct Observations	25
Number of Detects	17	Number of Non-Detects	8
Number of Distinct Detects	17	Number of Distinct Non-Detects	8
Minimum Detect	31.22	Minimum Non-Detect	4.64
Maximum Detect	2209	Maximum Non-Detect	33
Variance Detects	273676	Percent Non-Detects	32%
Mean Detects	368.8	SD Detects	523.1
Median Detects	174.5	CV Detects	1.418
Skewness Detects	3.054	Kurtosis Detects	10.42
Mean of Logged Detects	5.32	SD of Logged Detects	1.073

Normal GOF Test on Detects Only

Shapiro Wilk Test Statistic	0.607	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.892	Detected Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.259	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.215	Detected Data Not Normal at 5% Significance Level

Detected Data Not Normal at 5% Significance Level

Kaplan-Meier (KM) Statistics using Normal Critical Values and other Nonparametric UCLs

Mean	252.6	Standard Error of Mean	93.09
SD	451.5	95% KM (BCA) UCL	430.4
95% KM (t) UCL	411.9	95% KM (Percentile Bootstrap) UCL	411.4
95% KM (z) UCL	405.7	95% KM Bootstrap t UCL	603.2
90% KM Chebyshev UCL	531.9	95% KM Chebyshev UCL	658.4
97.5% KM Chebyshev UCL	833.9	99% KM Chebyshev UCL	1179

Gamma GOF Tests on Detected Observations Only

A-D Test Statistic	0.628	**Anderson-Darling GOF Test**
5% A-D Critical Value	0.767	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.187	**Kolmogrov-Smirnoff GOF**
5% K-S Critical Value	0.215	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics on Detected Data Only

k hat (MLE)	0.98	k star (bias corrected MLE)	0.846
Theta hat (MLE)	376.4	Theta star (bias corrected MLE)	435.9
nu hat (MLE)	33.32	nu star (bias corrected)	28.77
MLE Mean (bias corrected)	368.8	MLE Sd (bias corrected)	401

Gamma Kaplan-Meier (KM) Statistics

k hat (KM)	0.313	nu hat (KM)	15.65
Approximate Chi Square Value (15.65, α)	7.715	Adjusted Chi Square Value (15.65, β)	7.337
95% Gamma Approximate KM-UCL (use when n>=50)	512.4	95% Gamma Adjusted KM-UCL (use when n<50)	538.8

Gamma ROS Statistics using Imputed Non-Detects

GROS may not be used when data set has > 50% NDs with many tied observations at multiple DLs
GROS may not be used when kstar of detected data is small such as < 0.1
For such situations, GROS method tends to yield inflated values of UCLs and BTVs
For gamma distributed detected data, BTVs and UCLs may be computed using gamma distribution on KM estimates

Minimum	0.01	Mean	250.8
Maximum	2209	Median	113.6
SD	461.8	CV	1.841
k hat (MLE)	0.215	k star (bias corrected MLE)	0.216
Theta hat (MLE)	1166	Theta star (bias corrected MLE)	1161
nu hat (MLE)	10.76	nu star (bias corrected)	10.8
MLE Mean (bias corrected)	250.8	MLE Sd (bias corrected)	539.6
		Adjusted Level of Significance (β)	0.0395
Approximate Chi Square Value (10.80, α)	4.449	Adjusted Chi Square Value (10.80, β)	4.173
95% Gamma Approximate UCL (use when n>=50)	609	95% Gamma Adjusted UCL (use when n<50)	649.2

Lognormal GOF Test on Detected Observations Only

Shapiro Wilk Test Statistic	0.981	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.892	Detected Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.121	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.215	Detected Data appear Lognormal at 5% Significance Level	

Detected Data appear Lognormal at 5% Significance Level

Lognormal ROS Statistics Using Imputed Non-Detects

Mean in Original Scale	256	Mean in Log Scale	4.51
SD in Original Scale	458.9	SD in Log Scale	1.49
95% t UCL (assumes normality of ROS data)	413.1	95% Percentile Bootstrap UCL	423.3
95% BCA Bootstrap UCL	506.8	95% Bootstrap t UCL	619.3
95% H-UCL (Log ROS)	726.6		

UCLs using Lognormal Distribution and KM Estimates when Detected data are Lognormally Distributed

KM Mean (logged)	4.13	95% H-UCL (KM -Log)	1931
KM SD (logged)	1.945	95% Critical H Value (KM-Log)	3.888
KM Standard Error of Mean (logged)	0.403		

DL/2 Statistics

DL/2 Normal		**DL/2 Log-Transformed**	
Mean in Original Scale	253.1	Mean in Log Scale	4.161
SD in Original Scale	460.6	SD in Log Scale	1.977
95% t UCL (Assumes normality)	410.7	95% H-Stat UCL	2220

DL/2 is not a recommended method, provided for comparisons and historical reasons

Nonparametric Distribution Free UCL Statistics

Detected Data appear Gamma Distributed at 5% Significance Level

Suggested UCL to Use

95% KM (BCA) UCL	430.4	95% GROS Adjusted Gamma UCL	649.2
95% Adjusted Gamma KM-UCL	538.8		

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
Recommendations are based upon data size, data distribution, and skewness.
These recommendations are based upon the results of the simulation studies summarized in Singh, Maichle, and Lee (2006).
However, simulations results will not cover all Real World data sets; for additional insight the user may want to consult a statistician.

APPENDIX I-2
HUMAN HEALTH RISK SCREENING OF SEDIMENT DATA

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LIST OF ACRONYMS AND ABBREVIATIONS

μg	microgram
95% UPL	95th percentile upper prediction limit
BSAF	biota-sediment accumulation factor
CAP	Cleanup Action Plan
cPAH	carcinogenic polycyclic aromatic hydrocarbon
cm	centimeter
dw	dry weight
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
ELCR	excess lifetime cancer risk
EMPC	estimated maximum possible concentration
EPA	U.S. Environmental Protection Agency
ERDC	Environmental Research Development Center
FS	Feasibility Study
K_{oc}	partitioning coefficient
kg	kilogram
mg	milligram
MTCA	Model Toxics Control Act
ng	nanogram
OC	organic carbon
ORD	Office of Research and Development
PCB	polychlorinated biphenyl
PQL	Practical Quantitation Limit
Reynolds Facility	Former Reynolds Metals Reduction Plant
RI	Remedial Investigation
SMS	Sediment Management Standards
SQO	sediment quality objective

SWAC	surface weighted average concentration
TEF	Toxicity Equivalency Factor
TEQ	Toxicity Equivalent Concentration
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
WAC	Washington Administrative Code
ww	wet weight

SUMMARY

The Remedial Investigation and Feasibility Study (RI/FS) included extensive characterization of Columbia River sediments adjacent to the former Reynolds Metals Reduction Plant (Reynolds Facility). The results of that testing are described in Section 5 of the RI/FS report, including the findings of chemical testing and the findings of bioassay testing used to evaluate the protection of benthic organisms. This appendix describes the screening of the sediment chemistry data against Washington State criteria for the protection of human health.

As directed by the Washington State Department of Ecology (Ecology), the screening of sediments for protection of human health was conducted consistent with the procedures in the Sediment Management Standards (SMS). These regulations, as updated in February 2013, include rigorous screening procedures developed to protect people who consume seafood from chemical-related health effects. Consistent with those regulations, the measured concentrations of polychlorinated biphenyl (PCB) congeners and for carcinogenic polycyclic aromatic hydrocarbons (cPAHs) were both screened against these criteria.

Under SMS rules, the Practical Quantitation Limit (PQL) established by Ecology (2012) represents the lower limit for cleanup levels under SMS regulations. The measured concentration of PCB congeners in all samples tested was below the applicable PQL (5.0 nanograms per kilogram [ng/kg]), meaning that the measured concentrations of these compounds comply with SMS requirements for the protection of human health. Concentrations of cPAH compounds were greater than their respective PQLs. Therefore, an additional more detailed screening step was conducted for these compounds.

The additional screening for cPAH compounds assessed whether measured chemical concentrations in sediments have the potential to affect the health of people who harvest fish or shellfish from the RI/FS Study Area. That evaluation conservatively considered the potential carcinogenic risks associated with harvesting and consuming the freshwater clams (*Corbicula* species), which are known to be present within the RI/FS Study Area. Consistent with SMS regulations, the evaluation considered area-wide sediment cPAH concentrations within the RI/FS Study Area (Washington Administrative Code [WAC] Chapter 173-204-

560(7)(c)). Potential sediment to seafood transfer rates for cPAH compounds were estimated using published data from the U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (USACE). Seafood consumption rates used for this evaluation are consistent with those used in human health risk evaluations conducted by Ecology for the former aluminum smelter cleanup in Vancouver, Washington (Ecology 2008), and with those used by EPA for the Lower Willamette River (Kennedy/Jenks 2013) in Portland, Oregon.

As summarized in this appendix, the cPAH concentrations within the RI/FS Study Area are below levels that could pose a potentially significant human health risk. Estimated incremental carcinogenic risks (0.8×10^{-6}) were well below both of the most stringent of the risk limits (lower limit 1×10^{-6}, upper limit 1×10^{-5}) established under the updated SMS regulations. As described in the uncertainty analysis, actual human health risks are likely lower due to the conservative assumptions used in the health risk screening.

As an additional point of reference, the RI/FS Study Area sediment data were compared to available upstream and reference area datasets. The RI/FS Study Area cPAH concentrations were comparable to or less than both of these datasets.

1 INTRODUCTION

This appendix summarizes the screening of the Columbia River sediment data against Washington State criteria established for protection of human health. This analysis screening included an initial assessment for both polychlorinated biphenyls (PCB) congeners and for carcinogenic polycyclic aromatic hydrocarbons (cPAHs) and a detailed assessment for cPAH compounds. This analysis was conducted consistent with the procedures in the Sediment Management Standards (SMS), as updated in February 2013.

The screening for PCB compounds was completed, as directed by Washington State Department of Ecology (Ecology). The carcinogenic risks of PCB congeners were evaluated using the 2,3,7,8-tetrachloro p-dibenzodioxin Toxicity Equivalent Concentration (TEQ). Measured PCB congener concentrations (maximum value 2.76 nanograms [ng] TEQ per kilogram [TEQ/kg]; U=1/2, estimated maximum possible concentration [EMPC]=0) were all below the 5.0 ng TEQ/kg value established by Ecology as the Practical Quantitation Limit (PQL; Ecology 2012). Under Model Toxics Control Act (MTCA) and SMS regulations, the sediment quality objective (SQO) shall not be established lower than the PQL. Therefore, no additional human health screening was performed for PCB congeners.

For the cPAH compounds, the measured concentrations exceeded Ecology's established PQL values. Therefore, a detailed screening was performed using human health risk assessment procedures consistent with SMS and MTCA requirements. This screening included assessment of potential impacts of sediment cPAH concentrations on potential consumers of seafood gathered from the Remedial Investigation/Feasibility Study (RI/FS) Study Area. Specifically, the evaluation assessed potential human health risks associated with consumption of sessile organisms (the freshwater clam, *Corbicula*) that are present in Columbia River sediments within the RI/FS Study Area. Vertebrate species were not assessed because the measured cPAH concentrations are very low, and these species metabolize PAH compounds except at high exposure levels. The compounds are more persistent in invertebrate species, such as *Corbicula*.

Potential *Corbicula* tissue cPAH concentrations were modeled using existing sediment cPAH concentrations and biota-sediment accumulation factors (BSAFs). Tissue concentrations of cPAHs were determined by applying the literature BSAFs to sediment surface weighted average concentrations (SWACs) of cPAHs and total organic carbon (TOC). The methods used in this evaluation were consistent with those used previously by Ecology to evaluate potential human health risks associated with sediments at the Alcoa Vancouver Smelter cleanup site, as described in the Vancouver Cleanup Action Plan (CAP; Ecology 2008). The seafood consumption rates in that evaluation are consistent with those evaluated recently as part of the risk assessment for the Lower Willamette River (Kennedy/Jenks 2013) in Portland, Oregon.

The procedures used for the evaluation are described in the subsequent sections and include the following:

- Risk calculation methods and input parameters
- BSAF selection
- Risk characterization
- Uncertainty discussion

As an additional point of reference, the cPAH data from the RI/FS Study Area were also compared to available upstream and reference datasets. Upstream data includes those from the Columbia River upstream of the RI/FS Study Area. A reference dataset was also available from the Lower Willamette River RI/FS, including testing performed in the Willamette River upstream from Portland Harbor. These reference datasets are provided for information only. The reference data were not used to adjust or modify the risk estimates described in this appendix.

As summarized in Section 7, the average sediment cPAH concentrations within the RI/FS Study Area are very low and are comparable to upriver and clean reference area cPAH concentrations. These concentrations are below levels that would pose a potential human health risk (i.e., potential human health risks are less than the 1×10^{-6} and 1×10^{-5} risk levels used as the basis for human health protection under the SMS and MTCA regulations).

2 RISK CALCULATION METHODS AND INPUT PARAMETERS

To evaluate risk to people consuming *Corbicula* from the RI/FS Study Area, the modeled tissue concentrations were input into the standard MTCA incremental human cancer risk equation (Chapter 173-340-708 Washington Administrative Code [WAC]) using the following parameters:

- 18 grams per day upper-bound freshwater shellfish consumption rate from the U.S. Environmental Protection Agency (EPA) Lower Willamette River RI *Final Baseline Human Health Risk Assessment* (Kennedy/Jenks 2013)
- 70 kilograms (kg) average body weight (MTCA default value)
- 30 years exposure duration (MTCA default value)
- 75 years averaging time (MTCA default value)
- 25 percent site-specific diet fraction; this diet fraction value is consistent with the Alcoa Vancouver CAP and is appropriate to the RI/FS Study Area. The RI/FS Study Area is located in an industrial area with restricted public access. Finer-grained substrate at depths suitable for shellfish production and harvesting are limited at the site.
- 7.3 (milligrams per kilogram [mg/kg] per day)$^{-1}$ benzo(a)pyrene cancer potency slope (MTCA default value) applied as a total cPAH TEQ using MTCA Toxicity Equivalency Factors (TEFs).

Calculations used to develop risk estimates are presented in Table I-2-1. The tissue calculation applies the SWAC-based exposure concentration and a BSAF to estimate wet weight (ww) *Corbicula* tissue concentrations. The tissue calculation is as follows:

$$C_{tissue} = C_{sed} * BSAF * F_{lipid}$$

where:

C_{tissue} = Concentration in shellfish tissue (mg/kg ww)

C_{sed} = Concentration in sediment (mg/kg organic carbon [OC] dry weight [dw])

BSAF = biota-sediment accumulation factor (kg OC dw/kg lipid ww)

F_{lipid} = fraction lipid (ww)

The sediment concentrations for cPAH compounds were determined individually, as described in Attachment 1. Sediment SWACs for the site were calculated using recent high-quality surface sediment data within the RI/FS Study Area. Ecology specified which samples were included in the SWAC analysis. This excluded the extreme upstream and downstream samples, composite samples, and samples collected from adjacent upstream study areas. In cases where both 0- to 10-centimeter (cm) and 0- to 2-cm sample data were available, the dataset used for SWAC development included only the 0- to 10-cm sampling interval.

The resulting SWACs for individual cPAH compounds are provided in Table I-2-2 and are presented on Figures I-2-1 to I-2-7.

The lipid fraction in *Corbicula* was estimated at 2 percent, consistent with typical values and with the analysis performed in the Alcoa Vancouver CAP. The site-specific average TOC was measured at 0.4 percent, based on spatial analysis of the recently collected 0- to 10-cm sediment data.

3 BIOTA-SEDIMENT ACCUMULATION FACTORS

The BSAFs that were used to model *Corbicula* tissue concentrations were developed using BSAF data from the following two sources:

- EPA Office of Research and Development (ORD) BSAF database of synoptic tissue and sediment data from a subset of national Superfund sites
- U.S. Army Corps of Engineers (USACE) Environmental Research Development Center (ERDC) BSAF database of literature-reported studies

BSAF data specifically used for this analysis were for the bivalve, *Mytilus* sp., which is primarily a filter feeder that also occasionally deposit feeds (Theisen 1972). This behavior is similar to the feeding strategy of *Corbicula* (Thorp and Covich 1991). The compound-specific BSAF value was derived as the mean value of the *Mytilus* BSAF estimate. This rich dataset included more than 100 individual BSAF estimates for cPAH compounds. As described in Section 6, studies of PAH bioavailability at aluminum smelter sites indicate low levels of bioavailability, such that the use of the mean BSAF value is conservative and produces a high bias in the estimated human health risk levels.

Suitable individual BSAF values for benzo(b)fluoranthene and benzo(k)fluoranthene were not available in the ORD or ERDC databases, so the evaluation of these BSAF values were selected on the basis of partitioning coefficient (K_{oc}) values reported by EPA (2003). The cPAH compound with the closest matching K_{oc} for benzo(b)fluoranthene and benzo(k)fluoranthene was benzo(a)pyrene. Therefore the BSAFs for these compounds were set equal to the BSAFs for benzo(a)pyrene.

The K_{oc} and literature-derived BSAFs are provided in Table I-2-3. These were used along with the sediment concentration data to develop estimated tissue concentrations of cPAH in *Corbicula*, as shown in Table I-2-4.

4 RISK CHARACTERIZATION

The resulting upper-bound baseline incremental human excess lifetime cancer risks (ELCR) associated with consumption of clams from near the Reynolds Facility were calculated for cPAHs, as shown in Table I-2-5. These risks were estimated at 0.8×10^{-6}. This conservative upper-bound ELCR is below the acceptable range defined in the SMS. SMS defines an acceptable range between the 1×10^{-6} risk threshold (SQO) and the 1×10^{-5} risk threshold (Cleanup Screening Level).

5 UNCERTAINTY DISCUSSION

The assumptions and input data for this evaluation were designed to be conservative and as such, are likely to overestimate risk. The two primary areas of uncertainty are related to the depth of sediment testing (in comparison to the feeding behavior of *Corbicula*) and the bioavailability of cPAHs, as estimated using the ORD and ERDC BSAF data.

5.1 Conservatism of Sediment Exposure Estimates

Corbicula feed primarily from the water column, taking in phytoplankton, bacteria, and fine detritus through the siphon, which is extended above the sediment mudline (see Figure I-2-8). However, *Corbicula* can also obtain carbon through pedal deposit feeding, in which sediment detrital particles are drawn in dorsally over the ciliated foot epithelium into the mantle cavity (Thorp and Covich 1991). As such, the exposure to sediment-associated contamination is likely to be associated with near bottom water column, nepheloid layer, or surface sediment carbon sources.

In contrast, the risk screening used sediment data representative of the thicker 0- to 10-cm sediment layer, rather than data only for the thinner nepheloid layer. Comparison of the 0- to 10-cm samples with the 0- to 2-cm samples showed that the use of the deeper samples will produce a high bias of the risk estimates in comparison to an analysis using only surficial sediments with lower analyte concentrations. These surface sediments are more likely to be entrained in the water column and consumed by *Corbicula*.

5.2 Conservatism of cPAH BSAF Estimates

A second source of conservatism in the risk screening is the conservative estimate of bioavailability, as defined by the BSAFs (see Table I-2-3). These values likely over estimate actual PAH bioavailability and associated human health risks.

Studies at aluminum smelter sites have documented that site-associated PAHs tend to be present predominantly in pyrogenic source materials containing soot carbon or black carbon. These materials have a lower PAH bioavailability than other common PAH-containing sources, such as petroleum or stormwater (Hawthorne et al. 2007). The biological effects from PAH contaminated sediments associated with aluminum smelters have been observed to be less than expected based on the concentration of PAH in the sediment (Paine et al. 1996). Studies indicate that natural and black carbons have different sorption kinetics and that some hydrophobic contaminants may desorb more slowly from black carbon than natural carbon (Cornelissen et al. 2005). In addition, pyrogenic PAH may be "occluded" with soot during coincident PAH and soot formation (i.e., during incomplete combustion of organic matter), thereby limiting the bioavailability of cPAHs (Lima et al. 2005).

The majority of data used to develop the BSAFs were from the ORD database and were from investigations at the Naval Education and Training Center, McAllister Point Landfill and Naval Education and Training Center, and the Old Fire Fighting Training Area. These include substantial contributions of petrogenic PAHs, which typically have a higher bioavailability than pyrogenic sources associated with smelter facilities. Cornelissen et al. (2005) report that adsorption of organic compounds to carbonaceous materials, like black carbon, generally exceeds adsorption in natural organic carbon by a factor of 10 to 100. Therefore, it is likely that the mollusk BSAFs derived from ORD and ERDC databases significantly over estimate the bioavailability and BSAFs and the resulting risk estimates.

6 EVALUATION OF UPSTREAM AND REFERENCE DATASETS

Based on the human health risk evaluation, sediment cPAH concentrations are not above SMS and MTCA levels of potential concern. As an additional point of reference, the sediment data were compared to available upstream Columbia River sediment data and clean reference area datasets from portions of the Willamette River.

These comparisons are provided for information purposes only and were not used to adjust or modify the risk estimates developed in this appendix.

The evaluation of reference datasets indicates that cPAH concentrations within the RI/FS Study Area are similar to or lower than these other datasets. The RI/FS Study Area SWAC estimates for cPAH compounds are within the range of the Willamette River reference dataset and is lower than the upstream dataset, as shown in Table I-2-6.

6.1 Willamette River Upstream Data

The RI/FS Study Area SWACs were compared to the reference area dataset developed for the Portland Harbor Draft FS. These data are presented in Table I-2-7 using EPA 1993 TEFs. Values are presented for both central tendency and upper threshold statistics.

The Willamette River upstream dataset was developed during the Portland Harbor RI/FS (Integral et al. 2011). The dataset included samples collected between Willamette river mile 15.3 and 28.4, upstream of the Portland Harbor site. Sample locations were selected in consultation with EPA, the Oregon Department of Environmental Quality, and multiple tribes. The reference area selected was considered generally representative of Willamette River watershed conditions and included urbanized areas but would not be affected by the Portland Harbor site. Only the data meeting the specified quality objectives were included in the dataset.

cPAH concentrations, expressed as cPAH TEQ were calculated using the EPA (1993) potency equivalent factors (hereafter referred to as TEFs) and were summed by treating non-detects at one-half the detection limit. The cPAH TEQ dataset included 71 samples (59 detected results and 12 non-detects; Kennedy/Jenks 2013). Outlier analysis was performed to identify results not representative of background conditions. One cPAH result was identified as a primary outlier.

The statistics calculated for the Portland Harbor RI/FS included the upper 95th percentile and the 95th percentile upper prediction limit (95% UPL). The 95% UPL is the 95 percent upper prediction limit on the 90th percentile. In other words, there is a 95 percent likelihood that the results above the 95% UPL are greater than the 90th percentile of the dataset. The Portland Harbor RI also calculated central tendency statistics, including the 95th percentile upper confidence limit and the sample mean. The dry weight reported data with primary outliers removed are summarized in Table I-2-7.

6.2 Columbia River Upstream Data

The cPAH concentrations within the RI/FS Study Area were also compared to surface sediment samples collected upstream of the site. The Lower Columbia River Upstream data were compiled from the Ecology Environmental Information Management (EIM) database and other available sources. Available locations were screened for recency and data quality. The screened data are presented in Table I-2-8, and the locations of these samples are shown on Figures I-2-9a and I-2-9b.

Surface sediment samples considered acceptable for inclusion in the Lower Columbia River Upstream dataset were from 1993 to current and had a sample depth interval of no greater than 0 to approximately 1 foot. The dataset is composed of 28 samples in total—23 are from Ecology EIM, 4 samples were from a Weyerhaeuser 2009 Dredged Material Management Plan Suitability Report, and 1 sample was from a 2003 USACE Report on the Lower Cowlitz River (see Table I-2-8). The remaining 15 samples were located between the Weyerhaeuser property and the confluence with the Lower Willamette River (see Figures I-2-9a and I-2-9b).

The same statistics that were calculated for the Portland Harbor RI were calculated for the Columbia River Upstream dataset using ProUCL, including the 50th and 90th percentile and 95% UPL values (see Tables I-2-7 and I-2-9). For samples compiled from EIM, sample replicates were averaged if both replicates were detected, or the detected value was selected if one replicate was non-detect and the other was detected. For samples that were re-extracted based on the detection of bis(2-ethylhexyl)phthalate above the screening level, the initial sample values were used. cPAH TEQs were calculated for the dataset on a U=0 and U=1/2 basis, using both the MTCA TEFs and the EPA 1993 TEFs[1] to facilitate the comparison to the Lower Willamette River statistics. The cPAH TEQ statistics calculated using the MTCA TEFs were approximately 5 to 9 percent lower than the cPAH TEQ statistics calculated using the EPA 1993 TEFs for the U=0 and U=1/2 data treatments, respectively.

[1] If benzo(b,k)fluoranthenes were reported instead of the individual benzo(b)fluoranthene (TEF 0.1)and benzo(k)fluoranthene (0.01), the more conservative EPA 1993 TEF of 0.1 was used.

7 SUMMARY

Sediment chemical concentrations for the potential bioaccumulative compounds, PCBs and cPAH, were screened for potential significance using the procedures defined in the 2013 updates to the SMS regulations. PCB congener concentrations were below the applicable PQL value established by Ecology (2012). A detailed screening was conducted for cPAH compounds using a tribal seafood consumption scenario. That evaluation determined that the sediment cPAH concentrations within the RI/FS Study Area (i.e., the SWAC) were below levels that could result in a potentially significant human health risk. The updated SMS regulations identify an acceptable risk range at between $1x10^{-6}$ and $1x10^{-5}$ risk levels for carcinogenic compounds. The analysis as conducted was conservative and used conservative estimates of sediment concentrations and cPAH bioavailability. Estimated risks were less than $1x10^{-6}$ even with these conservative biases to the analysis.

For information purposes, the RI/FS Study Area sediment quality data were also compared to available upriver and reference area datasets. Results of that comparison indicate that the average cPAH concentrations within the RI/FS Study Area are within or below the range of data in these reference datasets.

8 REFERENCES

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TABLES

Table I-2-1
Risk Calculation Equations and Input Parameters

Step 1. Determine Tissue Concentrations using Sediment Biota Sediment Accumulation Factor

$$BSAF = \frac{Ct/flip}{C_{sed}/foc} \qquad Ct = \frac{C_{sed}}{f_{oc}} \text{ x } BSAF \text{ x } f_{lip}$$

Where:

Ct =	Chemical concentration in clam tissue (mg/kg, wet-weight basis)
BSAF =	Biota Sediment Accumulation Factor; see BSAF Data Summary tab in this workbook
f_{lip} =	Clam tissue fraction lipid; see Tissue Concentrations tab in this workbook
C_{sed} =	Sediment surface-weighted average concentration (SWAC; µg/kg dry weight)
f_{oc} =	Fraction total organic carbon (TOC) in sediment

Step 2. Compute Total Daily Intake (TDI)

$$TDI = \frac{Ct \text{ x } IRt \text{ x } DF \text{ x } CF \text{ x } EF \text{ x } ED}{BW \text{ x } AT}$$

Where:

TDI = Total Daily Intake (mg/kg body weight per day)

Variable	Input Value	
IRt	18	Fish ingestion rate (g/day, wet-weight basis)
DF	25%	Diet Fraction (percent)
CF	0.001	Correction Factor (1kg/1000g x 1g/1000mg)
EF	365	Exposure frequency (days/year)
ED	30	Exposure duration (years)
BW	70	Body weight (kg)
AT	27375	Averaging time (days)

Step 3. Calculate Excess Lifetime Cancer Risk

$$ECLR = TDI \text{ x } CSF$$

Where:

ECLR =	Excess lifetime cancer risk (unitless)
TDI =	Total Daily Intake (mg/kg body weight per day)
CSF =	Cancer Slope Factor [(mg/kg body weight per day)$^{-1}$].

CSF data obtained from Ecology CLARC database; see Risk Calcuations tab in this workbook

Notes:
µg/kg = micrograms per kilogram
g/day = gram per day
mg/kg = milligrams per kilogram
CLARC = Cleanup Levels and Risk Calculation

Table I-2-2
Sediment cPAH Surface-weighted Average Concentrations (Dry Weight and TOC-Normalized)

	Dry Weight (C_{sed})	TOC Normalized
Analyte	0 to 10cm SWAC[1] (ug/kg)	0 to 10cm SWAC[2] (mg/kg OC)
Benzo(a)anthracene	14.02	3.51
Benzo(a)pyrene	16.05	4.01
Benzo(b)fluoranthene	22.50	5.63
Benzo(k)fluoranthene	9.99	2.50
Chrysene	23.71	5.93
Dibenzo(a,h)anthracene	5.27	1.32
Indeno(1,2,3-c,d)pyrene	11.42	2.86

Notes:

1 = SWAC based on interpolated sediment quality data within the RI/FS study area adjacent to the facility as described in Appendix I-2 of the Draft RI/FS report (September 2013).

2 = TOC-normalized concentrations based on interpolated average TOC concentration of 0.4% as described in Appendix I-2 of the Draft RI/FS Report (September 2013). The equation for TOC normalized data is provided in tab Equations and Intake Data in this workbook.

cPAH = carcinogenic polycyclic aromatic hydrocarbon

SWAC = surface-weighted average concentration

TEQ = toxicity equivalent concentation

TOC = total organic carbon

Table I-2-3
Summary of BSAF Data from ORD and ERDC Databases

Data Source	Site	CAS No.	Chemical	Organism	Common Name	BSAF	Tissue	Average BSAF
ERDC	NA	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.004	whole body	
ERDC	NA	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.0256	whole body	
ERDC	NA	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.07	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.000135038	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.000147496	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.000597282	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.000787617	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.000818758	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.003649449	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.025204237	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.028847963	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.063332959	whole body	0.0975
ORD	Naval Education & Training Center, McAllister Point Landfill	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.07388855	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.081125729	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.088685086	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.116890947	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.126756468	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.180182142	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.200180982	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.20631144	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.210447094	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.360811741	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	56-55-3	benzo(a)anthracene	Mytilus edulis	blue mussel	0.375233472	whole body	
ERDC	NA	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.016	whole body	
ERDC	NA	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.0388	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.000162546	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.000163462	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.000368314	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.000629549	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.000869863	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.001704545	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.002839335	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.004699959	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.008364246	whole body	0.0230
ORD	Naval Education & Training Center, McAllister Point Landfill	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.019100236	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.022449746	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.025479434	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.031296731	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.031478496	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.043299848	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.045327457	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.049069201	whole body	

Table I-2-3
Summary of BSAF Data from ORD and ERDC Databases

Data Source	Site	CAS No.	Chemical	Organism	Common Name	BSAF	Tissue	Average BSAF
ORD	Naval Education & Training Center, Derecktor Shipyard	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.066207151	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	50-32-8	benzo(a)pyrene	Mytilus edulis	blue mussel	0.074104867	whole body	
ERDC	NA	218-01-9	chrysene	Mytilus edulis	blue mussel	0.004	whole body	0.1545
ERDC	NA	218-01-9	chrysene	Mytilus edulis	blue mussel	0.0076	whole body	
ERDC	NA	218-01-9	chrysene	Mytilus edulis	blue mussel	0.0336	whole body	
ERDC	NA	218-01-9	chrysene	Mytilus edulis	blue mussel	0.0784	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.015832184	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.024519539	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.061254854	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.091559483	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.104957907	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.142567719	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.171959747	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.174311721	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.196000656	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.2475404	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	218-01-9	chrysene	Mytilus edulis	blue mussel	0.294392736	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.301331411	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.408481878	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	218-01-9	chrysene	Mytilus edulis	blue mussel	0.422958168	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	3.72818E-05	whole body	0.0554
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.000166288	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.000260606	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.000347371	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.001610633	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.023561119	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.033479175	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.034011628	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.035881567	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.057868787	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.062660402	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.137156672	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.16250795	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	53-70-3	dibenzo(a,h)anthracene	Mytilus edulis	blue mussel	0.225378911	whole body	

Table I-2-3
Summary of BSAF Data from ORD and ERDC Databases

Data Source	Site	CAS No.	Chemical	Organism	Common Name	BSAF	Tissue	Average BSAF
ERDC	NA	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.0044	whole body	0.0353
ERDC	NA	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.0104	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	6.02912E-05	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.000111111	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.000454761	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.000659411	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.000735542	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.001847264	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.00255468	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.017830001	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.021902292	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.030307033	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.031416055	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.042960526	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.054794522	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.060413997	whole body	
ORD	Naval Education & Training Center, Old Fire Fighting Training Area	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.066979586	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.083862052	whole body	
ORD	Naval Education & Training Center, McAllister Point Landfill	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.112863535	whole body	
ORD	Naval Education & Training Center, Derecktor Shipyard	193-39-5	indeno(1,2,3-cd)pyrene	Mytilus edulis	blue mussel	0.160808954	whole body	

Notes:
ERDC = U.S. Army Corps of Engineers, Engineer Research Development Center Environmental Laboratory. 2010. BSAF Database. http://el.erdc.usace.army.mil/bsafnew/bsaf.html, Charles H. Lutz, editor.
NA = ERDC data are compiled from the literature. Site location was not reported in the ERDC database.
ORD = U.S. Environmental Protection Agency. 2007. BSAF (Biota-Sediment Accumulation Factor) Data Set – Version 1.0. Office of Research and Development, National Health and Environmental Research Laboratory, Mid-Continent Ecology Division, Duluth, MN.

Table I-2-4
Estimated Tissue Concentrations Using BSAF Model

Chemical	CAS No.	Clam BSAF [1]	Estimated Tissue Concentrations (Ct)		
			Sediment SWAC (mg/kg-OC) [2]	Estimated Tissue Lipid Fraction (f_{lip}) [3]	Calculated Tissue Concentration (mg/kg wet wt.)
Benzo(a)anthracene	56-55-3	0.0975	3.51	0.02	0.0068
Benzo(a)pyrene	50-32-8	0.0230	4.01	0.02	0.0018
Benzo(b)fluoranthene	205-99-2	0.0230	5.63	0.02	0.0026
Benzo(k)fluoranthene	207-08-9	0.0230	2.50	0.02	0.0011
Chrysene	218-01-9	0.1545	5.93	0.02	0.0183
Dibenzo(a,h)anthracene	53-70-3	0.0554	1.32	0.02	0.0015
Indeno(1,2,3-c,d)pyrene	193-39-5	0.0353	2.86	0.02	0.0020

Notes:

1 = The clam BSAF values for Benzo(b)fluoranthene and Benzo(k)fluoranthene were selected on the basis of the Koc.The cPAH compound with the closest matching Koc was Benzo(a)pyrene. Koc values obtained from EPA (2003; Table 3-4). Procedures for the Derivation of Equilibrium Partitioning Sediment Benchmarks (ESBs) for the Protection of Benthic Organisms: PAH Mixtures. EPA-600-R-02-013.

2 = SWAC were based on interpolated sediment quality data within the RI/FS study area adjacent to the facility as described in Appendix I-2 of the Draft RI/FS report (September 2013).

figure.

BSAF = biota-sediment accumulation factor

mg/kg = milligrams per kilogram

OC = organic carbon normalized

SWAC = surface-weighted average concentration

wt. = weight

Table I-2-5
Excess Lifetime Cancer Risk Estimation from Clam Consumption

Analyte Name	CAS No.	Tissue Concentration (mg/kg-wet wt.) [1]	Lifetime Intake Oral (mg/kg-day) [2]	Cancer Slope Factor (CLARC Database)	Estimated ECLR from Clam Consumption
Benzo(a)anthracene	56-55-3	0.0068	1.76E-07	0.73	0.1E-6
Benzo(a)pyrene	50-32-8	0.0018	4.75E-08	7.3	0.3E-6
Benzo(b)fluoranthene	205-99-2	0.0026	6.65E-08	0.73	0.05E-6
Benzo(k)fluoranthene	207-08-9	0.0011	2.95E-08	0.073	0.002E-6
Chrysene	218-01-9	0.0183	4.71E-07	0.0073	0.003E-6
Dibenzo(a,h)anthracene	53-70-3	0.0015	3.75E-08	7.3	0.3E-6
Indeno(1,2,3-c,d)pyrene	193-39-5	0.0020	5.18E-08	0.73	0.04E-6
				Cumulative Risk =	0.8E-6

Notes:

1 = Tissue concentration computed using BSAF model. See Tissue Concentrations tab in this workbook.

2 = Computed using Total Daily Intake (TDI) equation. See Equations and Intake Data tab in this workbook.

CAS = Chemical Abstracts Service

CLARC Database = Toxicity data from Ecology Cleanup Levels and Risk Calculation Database (https://fortress.wa.gov/ecy/clarc/)

ELCR = excess lifetime cancer risk

mg/kg = milligrams per kilogram

wt. = weight

Table I-2-6

Concise Summary of Upstream and Reference Datasets Total cPAH TEQ Calculated with EPA 1993 TEFs

Dataset	Central Tendency (95% UCL on Mean)	Upper Threshold Statistics	
		95% UPL	90th Percentile or 4 x 50th Percentile
Willamette River Reference Dataset	9.86	21.5	26.52 (4 x 50th Percentile)
Upstream Columbia River Data	20.34	50.04	28.09 (90th Percentile)

Notes:

All units are micrograms per kilogram (µg/kg).

Refer to Tables I-2-7, I-2-8, and I-2-9 for detailed data summaries and statistics.

cPAH = carcinogenic polycyclic aromatic hydrocarbon

EPA = U.S. Environmental Protection Agency

TEF = Toxicity Equivalency Factor

TEQ = Toxicity Equivalent Concentration

UCL = upper confidence limit

UPL = upper prediction limit

Table I-2-7

Summary of Statistics for Regional Datasets Total cPAH TEQ Calculated with EPA 1993 TEFs[a]

Regional Dataset	Statistics for Datasets Including Non-Detects										
	Summary Statistics				Upper Threshold Statistics			Central Tendency Statistics		MTCA Statistics	
	Minimum	Maximum	Median	Mean	95th percentile	95-UPL	Statistic	95-UCL	Statistic	4x50th percentile	90th percentile
U=1/2											
Willamette River Upstream/Background Dataset (Portland Harbor Draft FS, 2012) (Primary Outliers Removed)	0.39[a]	40.1[b]	6.63[b]	8.44[b]	25.8[c]	21.5[c]	95%KM UPL(t)	9.86[c]	95% KM(BCA) UCL	26.52	--
Columbia River Upstream Dataset (see Table 5)	0.5	89.37	7.02[d,e]	15.99[d,e]	--	50.04[d]	95%KM UPL(t)	20.34[d]	95% KM(BCA) UCL	28.09[d,e]	45.58[d,e]
U=0											
Columbia River Upstream Dataset (see Table 5)	0.0007	89.37	5.93[d,e]	14.37[d,e]	--	47.17[d]	95%KM UPL(t)	18.76[d]	95% KM(BCA) UCL	23.73[d,e]	40.95[d,e]

Notes:

All units are micrograms per kilogram (µg/kg).

a = For samples with only total benzofluoranthenes reported, a TEF of 0.1 was used.

b = Statistics from the Draft Portland Harbor FS Appendix A Table 1.3-3.

c = Statistics from the Draft Portland Harbor FS Appendix A Table 1.3-5b.

d = Statistics calculated with ProUCL 4.1.

e = Raw summary statistics.

BCA = bias corrected accelerated

cPAH = carcinogenic polycyclic aromatic hydrocarbon

EPA = U.S. Environmental Protection Agency

FS = Feasibility Study

KM = Kaplan-Meier

MTCA = Model Toxics Control Act

TEF = Toxicity Equivalency Factor

TEQ = Toxicity Equivalent Concentration

UCL = upper confidence limit

UPL = upper prediction limit

Table I-2-8
Summary of Columbia River Upstream Samples

Sample ID	Field Activity Start Date	Sample Interval Upper Depth	Sample Interval Lower Depth	Sample Interval Unit of Measure	Non-detect Qualifier[1]	MTCA cPAH TEQ (U=0.5)	MTCA cPAH TEQ (U=0)	EPA 1993 cPAH TEQ[2] (U=0.5)	EPA 1993 cPAH TEQ[2] (U=0 TEQ)	Data Source	Notes
CR-BC-41	6/3/1997	0	18	cm	U	0.5	0.5	0.5	0.5	EIM	
CR-BC-52	6/4/1997	0	23	cm	U	0.5	0.5	0.5	0.5	EIM	
CR-BC-55	6/4/1997	0	15	cm	--	0.422	0.007	0.614	0.001	EIM	
CR-BC-56	6/4/1997	0	18	cm	--	5.84	5.84	8.05	8.05	EIM	
CR-BC-57	6/4/1997	0	20	cm	--	88.2	88.2	89.4	89.4	EIM	
CR-BC-59	6/4/1997	0	18	cm	--	0.801	0.666	0.967	0.607	EIM	
CR-BC-61	6/4/1997	0	18	cm	U	0.5	0.5	0.5	0.5	EIM	
CR-BC-73	6/5/1997	0	18	cm	--	0.478	0.120	0.898	0.570	EIM	Detected laboratory replicate reported.
CR-BC-74	6/5/1997	0	18	cm	--	0.768	0.700	1.19	1.15	EIM	Detected laboratory replicate reported.
CR-BC-75	6/5/1997	0	18	cm	U	0.5	0.5	0.5	0.5	EIM	Both laboratory replicates ND (same detection limit).
CR-BC-76	6/5/1997	0	18	cm	--	46.8	46.8	51.4	51.4	EIM	Average of two laboratory replicates.
PSY60SC	4/6/1998	0	10	cm	U	10	10	10	10	EIM	
HS-C1	9/17/1998	0	30.5	cm	U	20	20	20	20	EIM	
8-S	6/24/1993	0	2	cm	--	23.5	23.5	26.4	26.4	EIM	
OMCR-BC-04	9/10/2003	0	15.2	cm	U	3.51	3.51	3.51	3.51	Old Cowlitz River Federal Project Sediment Quality Evaluation Report (December 2003)	Located near mouth of the Old Cowlitz River
C1	1/13/2010	0	11	cm	--	14.1	0.110	23.0	0.011	EIM	Normal and re-extract data available. Normal data used.
C1-Z(0-1)	1/13/2010	0	30.5	cm	U	20	20	20	20	EIM	Normal and re-extract data available. Normal data used.
C2	1/13/2010	0	11	cm	--	21.7	19.7	30.5	19.5	EIM	Normal and re-extract data available. Normal data used.
C3	1/13/2010	0	11	cm	--	40.9	39.9	49.7	39.7	EIM	Normal and re-extract data available. Normal data used.
C4	1/13/2010	0	11	cm	U	19	19	19	19	EIM	Normal and re-extract data available. Normal data used.
C5	1/13/2010	0	11	cm	U	19	19	19	19	EIM	Normal and re-extract data available. Normal data used.
C1_U*	9/30/2002	0	30.5	cm	--	8.62	8.62	11.1	11.1	EIM	
C2_U*	9/30/2002	0	30.5	cm	--	3.13	3.13	5.99	5.99	EIM	
C3_U*	9/30/2002	0	30.5	cm	--	3.10	3.10	5.87	5.87	EIM	
DMMU-10-C10	9/2/2008	0	10	cm	U	1.9	1.9	1.9	1.9	Weyerhaeuser Property - Longview DMMP Suitability Determination (January 2, 2009)	
DMMU-6-C6	9/2/2008	0	10	cm	--	36.5	36.5	43.8	43.8	Weyerhaeuser Property - Longview DMMP Suitability Determination (January 2, 2009)	
DMMU-8-C8	9/2/2008	0	10	cm	U	1.7	1.7	1.7	1.7	Weyerhaeuser Property - Longview DMMP Suitability Determination (January 2, 2009)	
DMMU-9-C9	9/2/2008	0	10	cm	U	1.7	1.7	1.7	1.7	Weyerhaeuser Property - Longview DMMP Suitability Determination (January 2, 2009)	

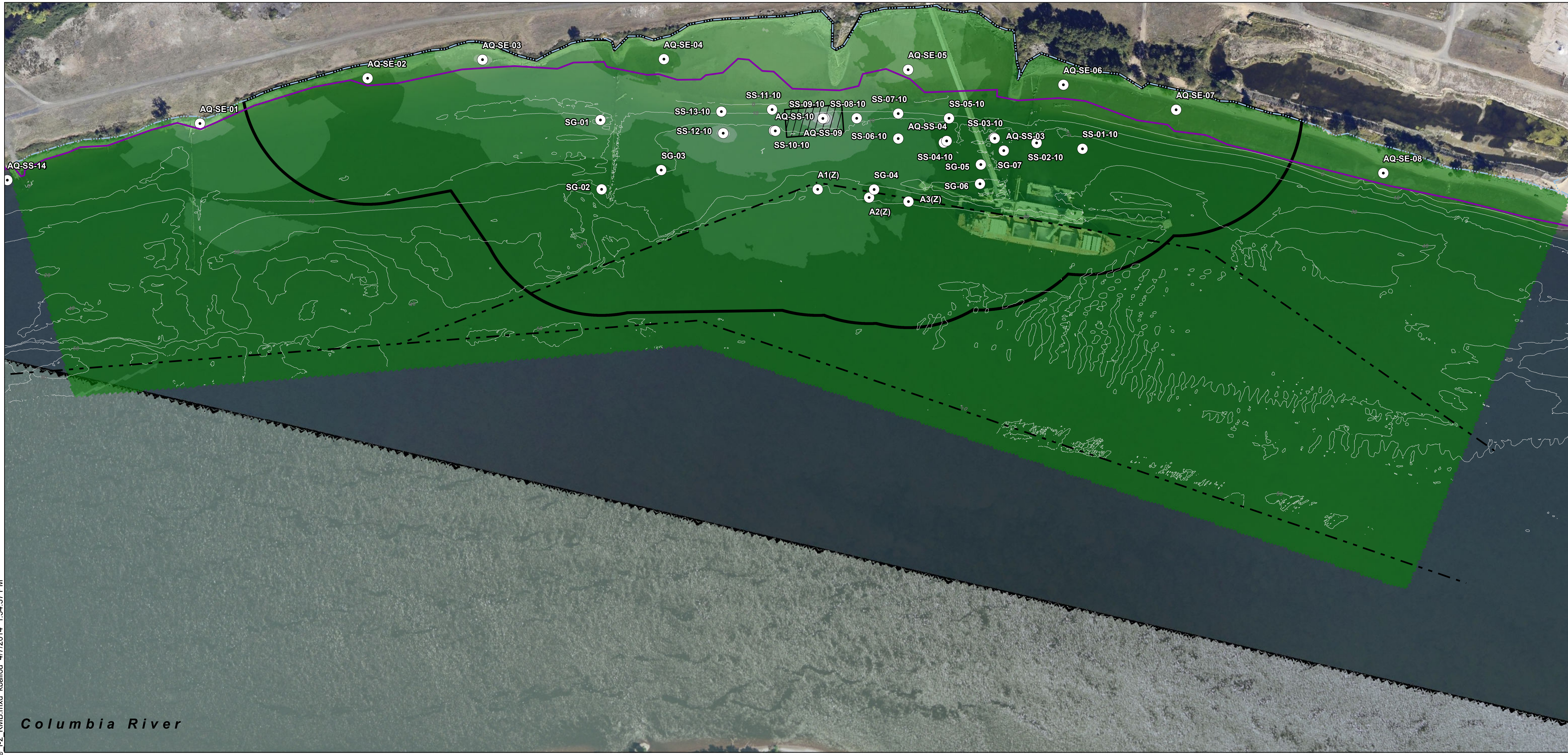
Notes:
All units are micrograms per kilogram (µg/kg).
1 = The non-detect qualifier was applied if all individual cPAH in the sample were non-detect.
2 = For samples with only total benzofluoranthenes reported, a TEF of 0.1 was used.
cm = centimeter
cPAH = carcinogenic polycyclic aromatic hydrocarbon
DMMP = Dredged Material Management Program
EIM = Environmental Information Management
EPA = U.S. Environmental Protection Agency
MTCA = Model Toxics Control Act
ND = non-detect
TEF = Toxicity Equivalency Factor
TEQ = Toxicity Equivalent Concentration

Table I-2-9
Summary of Statistics for Regional Datasets Total cPAH TEQs Calculated with MTCA TEFs

Regional Dataset	Statistics for Datasets Including Non-Detects										
	Summary Statistics				Upper Threshold Statistics			Central Tendency Statistics		MTCA Statistics	
	Minimum	Maximum	Median	Mean	95th percentile	95-UPL	Statistic	95-UCL	Statistic	4x50th percentile	90th percentile
U=1/2											
Columbia River Upstream Data (see Table 2)	0.422	88.16	4.68[a,b]	14.06[a,b]	--	45.39[a]	95%KM UPL(t)	19.2[a]	95% KM (BCA) UCL	18.7[a,b]	37.83[a,b]
U=0											
Columbia River Upstream Data (see Table 2)	0.01	88.16	3.32[a,b]	13.42[a,b]	--	44.75[a]	95%KM UPL(t)	16.91[a]	95% KM (BCA) UCL	13.28[a,b]	37.53[a,b]

Notes:
All units are micrograms per kilogram (µg/kg).
a = Statistics calculated with ProUCL 4.1.
b = Raw summary statistics.
BCA = bias corrected accelerated
cPAH = carcinogenic polycyclic aromatic hydrocarbon
KM = Kaplan-Meier
MTCA = Model Toxics Control Act
TEF = Toxicity Equivalency Factor
TEQ = Toxicity Equivalent Concentration
UCL = upper confidence limit
UPL = upper prediction limit

FIGURES



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NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

⊙ Sample Location

Benzo(a)anthracene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

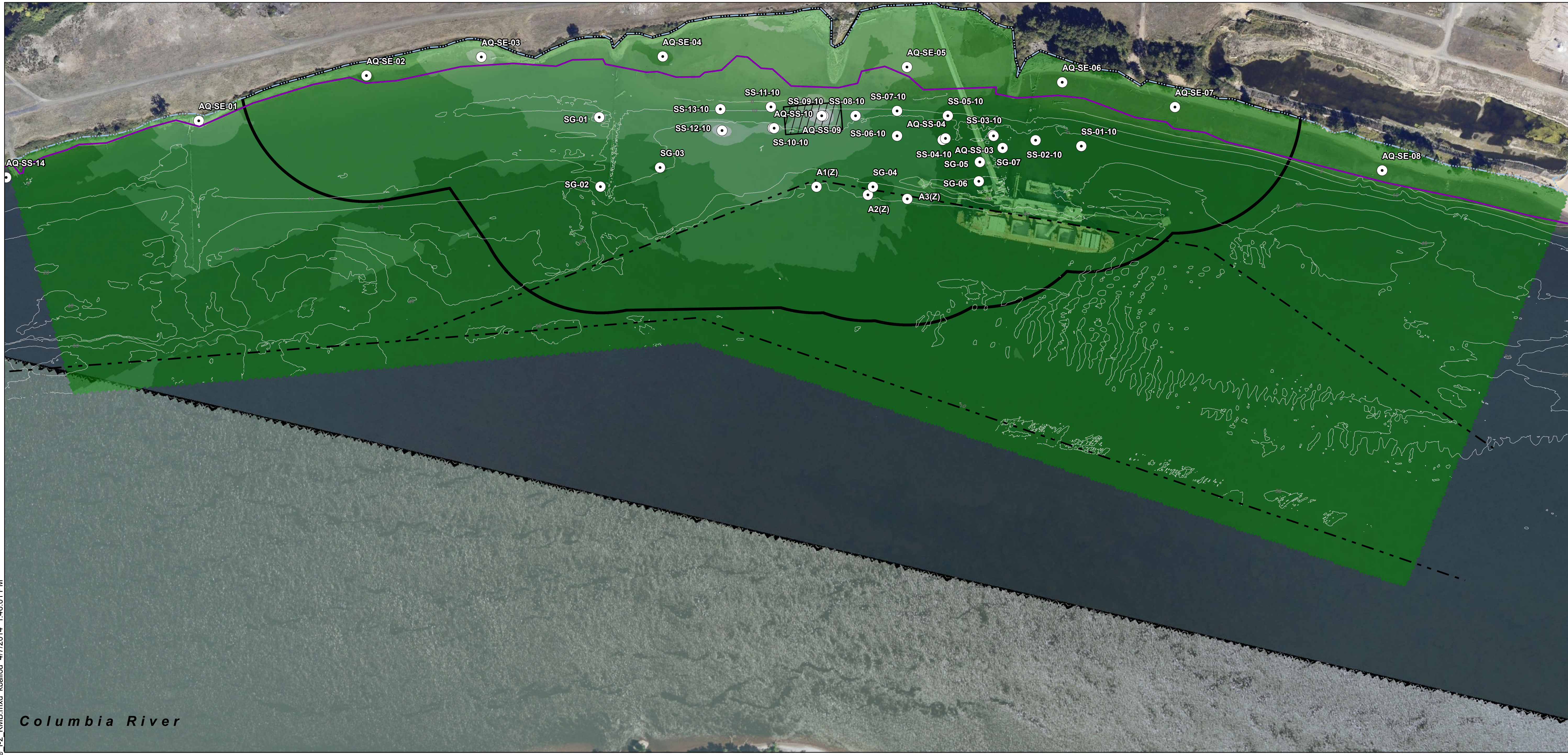
Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

Ecology Specified Boundary for Data Set and SWAC Estimation
Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

ANCHOR QEA

Figure I-2-1
Inverse Distance Weighted Interpolation: Benzo(a)anthracene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview



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NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

Sample Location

Benzo(a)pyrene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

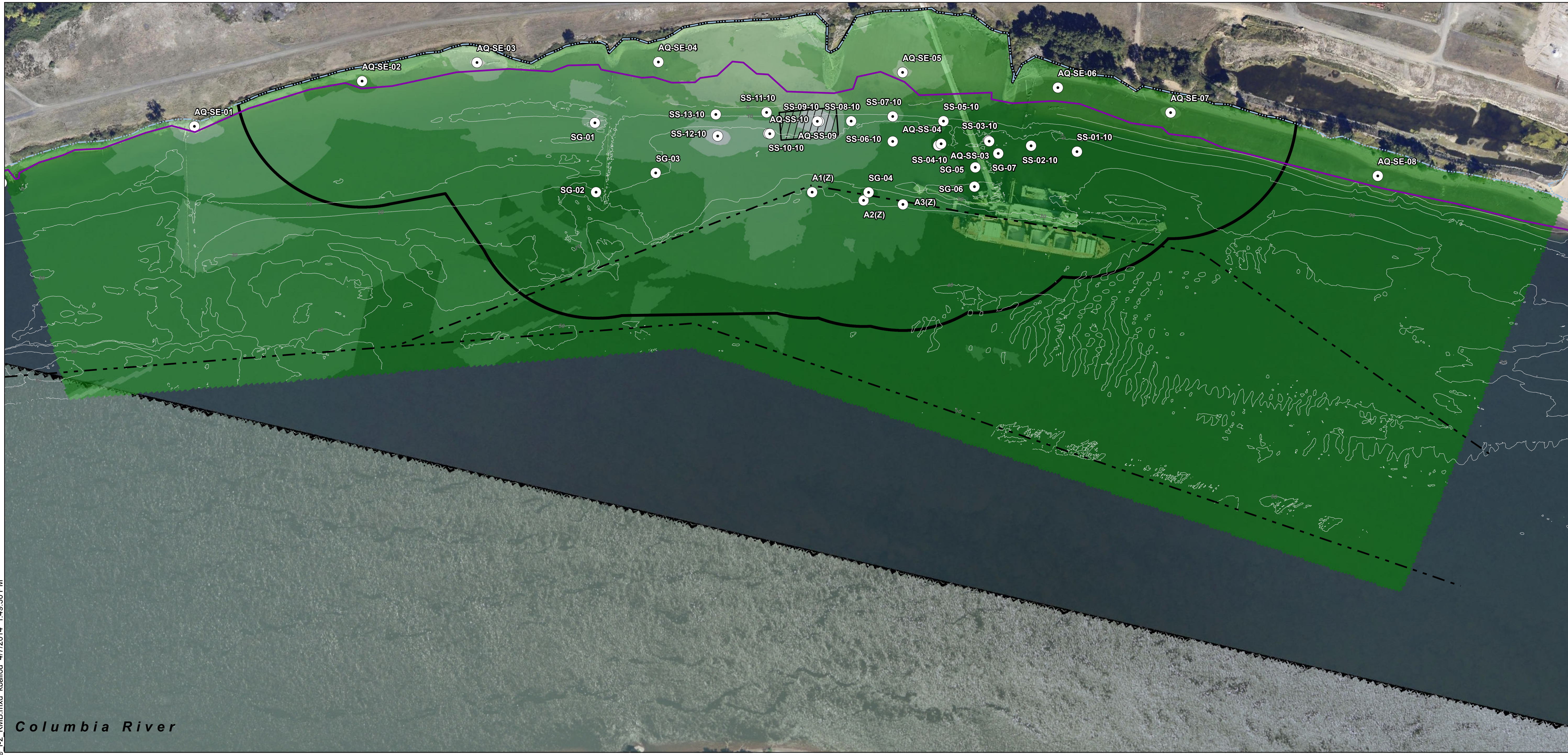
Ecology Specified Boundary for Data Set and SWAC Estimation

Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

ANCHOR QEA

Figure I-2-2
Inverse Distance Weighted Interpolation: Benzo(a)pyrene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview



NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

Sample Location

Benzo(b)fluoranthene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

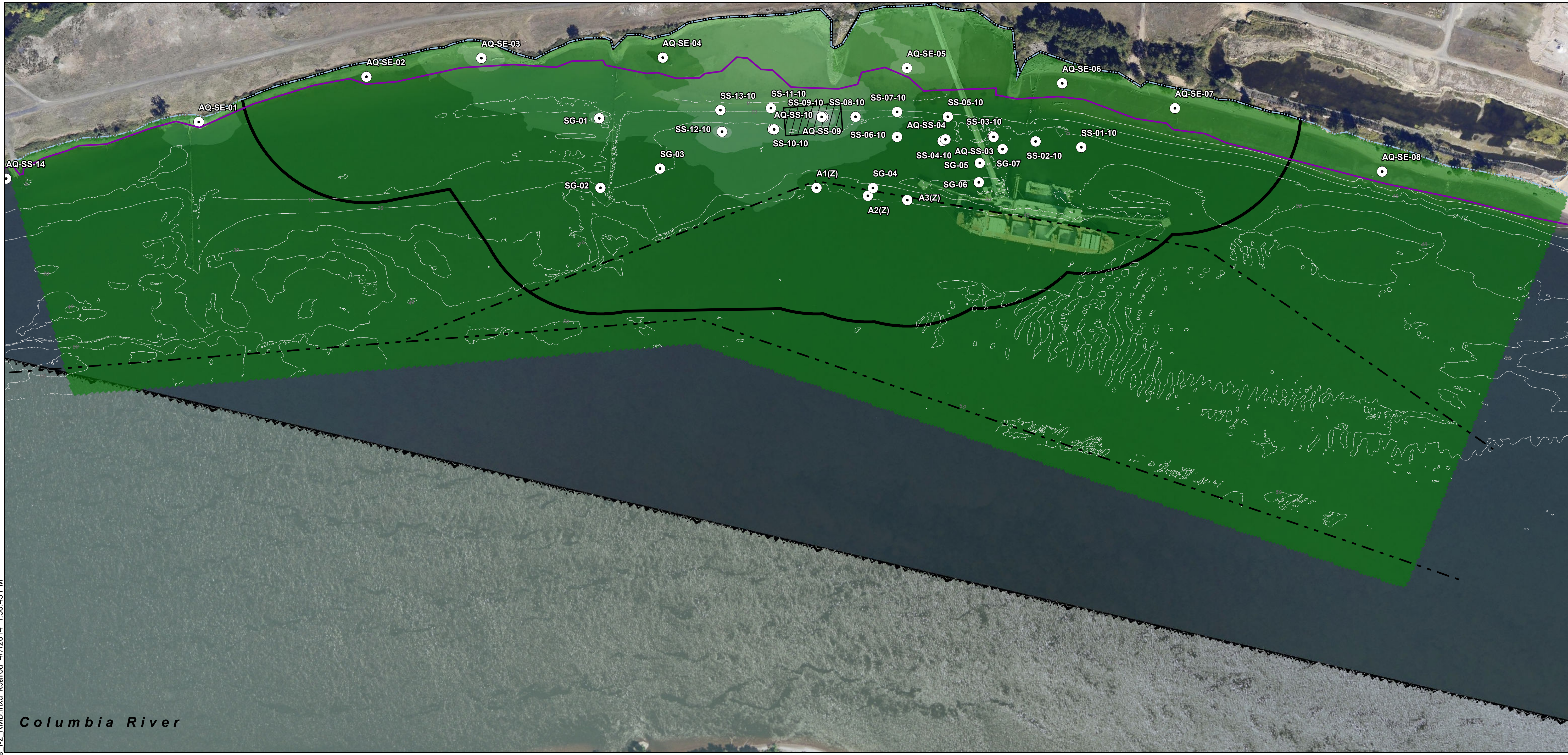
Ecology Specified Boundary for Data Set and SWAC Estimation

Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

ANCHOR QEA

Figure I-2-3
Inverse Distance Weighted Interpolation: Benzo(b)fluoranthene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview



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NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

Sample Location

Benzo(k)fluoranthene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

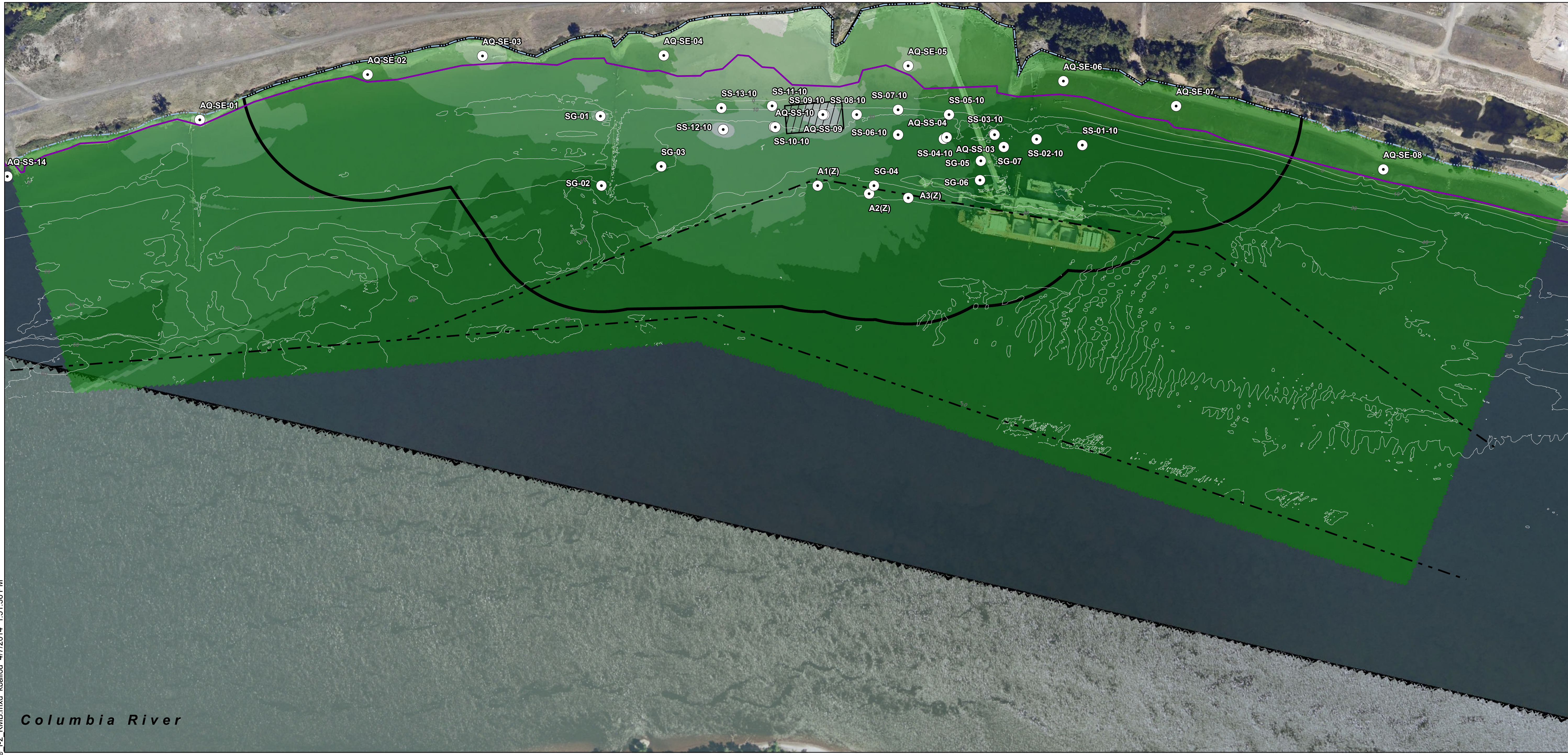
Ecology Specified Boundary for Data Set and SWAC Estimation

Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

ANCHOR QEA

Figure I-2-4
Inverse Distance Weighted Interpolation: Benzo(k)fluoranthene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview



NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

Sample Location

Chrysene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

Ecology Specified Boundary for Data Set and SWAC Estimation

Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

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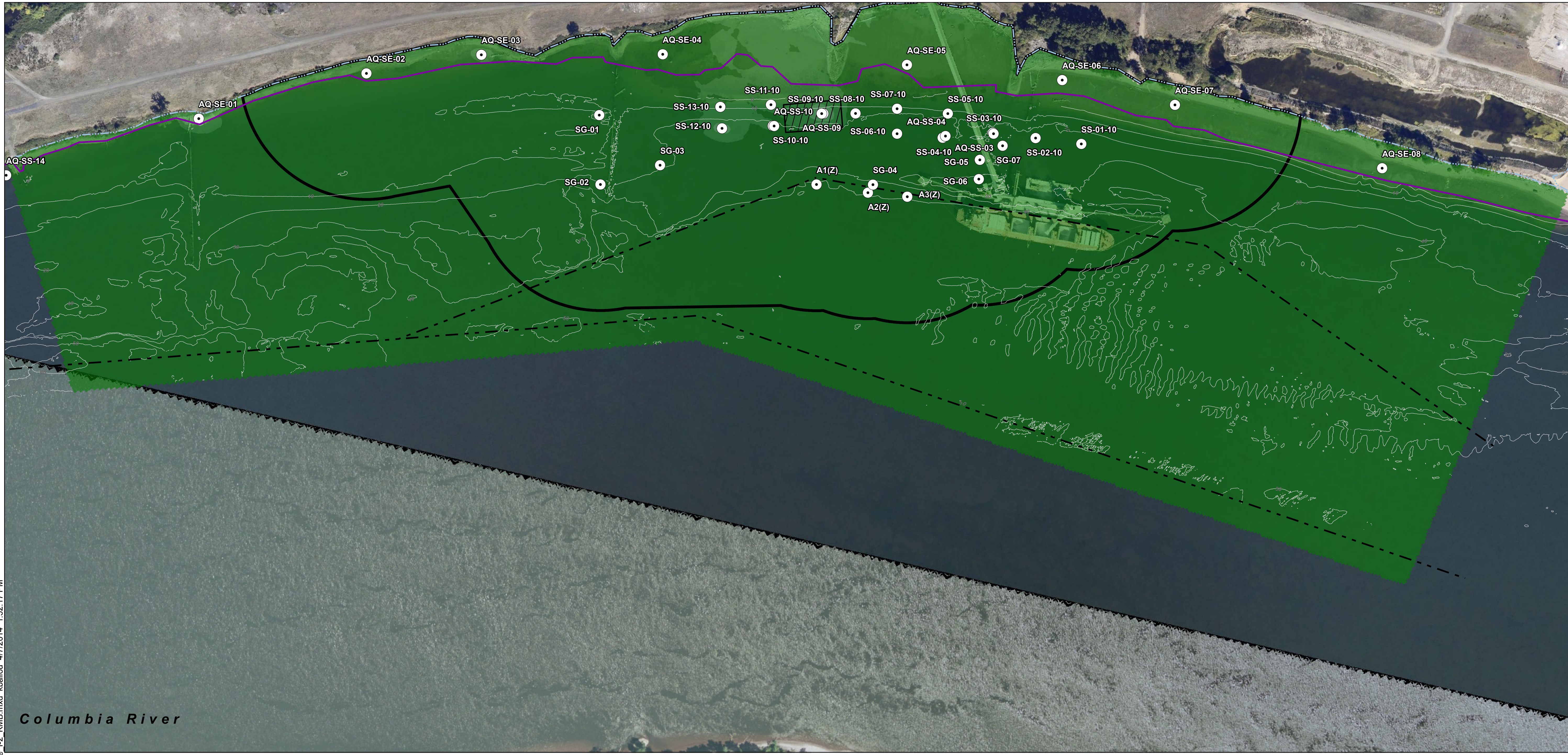
ANCHOR QEA

Figure I-2-5
Inverse Distance Weighted Interpolation: Chrysene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview



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NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

Sample Location

Dibenzo(a,h)anthracene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

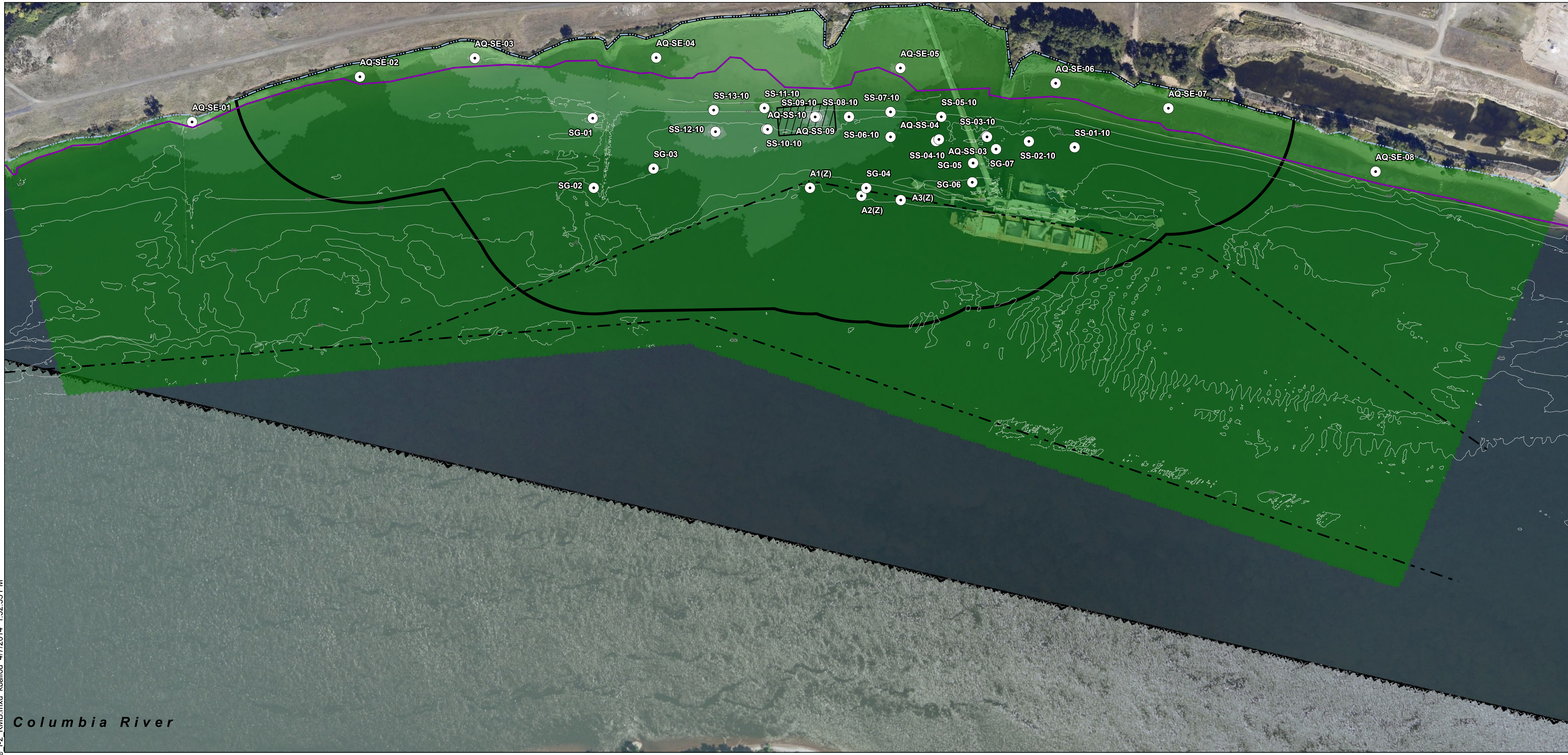
Ecology Specified Boundary for Data Set and SWAC Estimation

Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

ANCHOR QEA

Figure I-2-6
Inverse Distance Weighted Interpolation: Dibenzo(a,h)anthracene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview



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NOTES:
1. Interpolated concentrations computed using inverse distance weighting (IDW).
2. Non-detects are set to ½ MDL and the interpolated surface is restricted to the rectangular extent of the dataset.
3. Elevation 0.00 feet CRD is accepted as Extreme Low Water (ELW) and the line between Tide Lands and Bed Lands.
4. Duplicate samples averaged with the parent sample.
5. Vertical Datum: NAVD88, Feet.
6. Aerial images from CVI (August 2010) and Aerometric (June 2013).

Sample Location

Indeno(1,2,3-c,d)pyrene (µg/kg dry weight)
- < 10
- 10 - 20
- 20 - 50
- 50 - 100
- > 100

Approximate Ordinary High Water Line
Bathymetric Contour CRD (feet)
Navigation Channel
Property Boundary

Ecology Specified Boundary for Data Set and SWAC Estimation
Area of Benthic Exceedance Adjacent to Outfall 002A

Feet
0 200 400 600 800

ANCHOR QEA

Figure I-2-7
Inverse Distance Weighted Interpolation: Indeno(1,2,3-c,d)pyrene
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview

Source:
http://science.marshall.edu/joy/PDF/Invert%20Zool/Corbicula%20fluminea.pdf

ANCHOR QEA

Figure I-2-8
Corbicula Siphons In Situ
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview

Col. R. Channel Deepening July 1997

Determination Regarding the Suitability of Proposed Dredged Material from the Weyerhaeuser Property, Longview, Washington, For Flow-Lane Disposal in the Columbia River, or for Beneficial Reuse

Lower Columbia Backwater Recon. Survey

Mt Coffin Ship Channel

Old Mouth of the Cowlitz River Federal Project Sediment Quality Evaluation Report

Portland Shipyard Sed. Inv.

Sed. Char. of Sponsor's Berths

Turning Basin Dredged Material Characterization Weyerhaeuser Property Longview, Washington

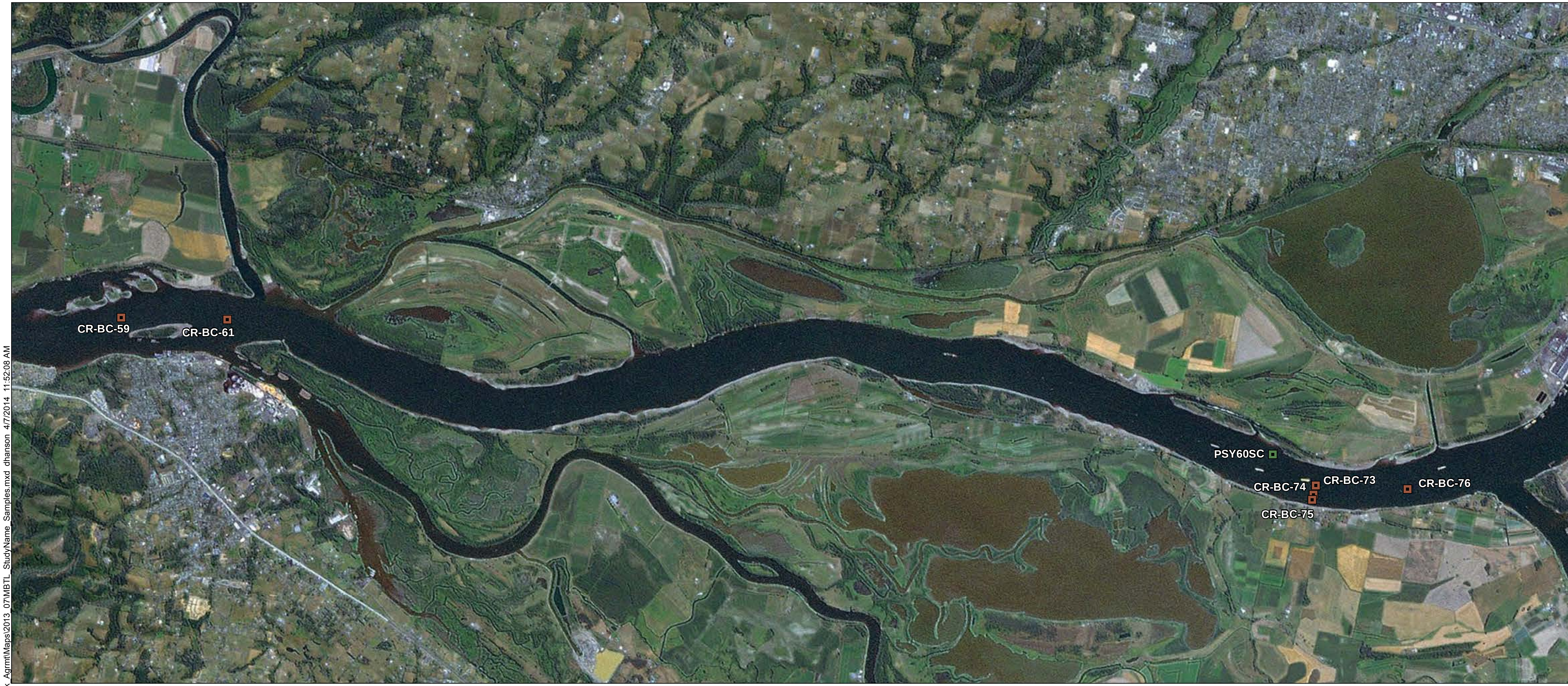
NOTE:
""_U" was added to the Mt. Coffin Ship Channel study Sample IDs to differentiate between the Turning Basin Dredged Material Characterization study samples.

Feet
0 2,900 5,800 8,700 11,600

Q:\Jobs\110730-01.05_Millennium_Bulk_Term_Holdback_Agrmt\Maps\2013_07\MBTL_StudyName_Samples.mxd dhanson 4/7/2014 11:52:04 AM

ANCHOR QEA

Figure I-2-9a
Lower Columbia River Upstream Surface Sediment Samples
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview



- Col. R. Channel Deepening July 1997
- Determination Regarding the Suitability of Proposed Dredged Material from the Weyerhaeuser Property, Longview, Washington, For Flow-Lane Disposal in the Columbia River, or for Beneficial Reuse
- Lower Columbia Backwater Recon. Survey
- Mt Coffin Ship Channel
- Old Mouth of the Cowlitz River Federal Project Sediment Quality Evaluation Report
- Portland Shipyard Sed. Inv.
- Sed. Char. of Sponsor's Berths
- Turning Basin Dredged Material Characterization Weyerhaeuser Property Longview, Washington

NOTE:
""_U" was added to the Mt. Coffin Ship Channel study Sample IDs to differentiate between the Turning Basin Dredged Material Characterization study samples.

Feet
0 2,900 5,800 8,700 11,600

ANCHOR QEA

Figure I-2-9b
Lower Columbia River Upstream Surface Sediment Samples
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview

ATTACHMENT 1
SEDIMENT SURFACE WEIGHTED AVERAGE CONCENTRATIONS OF CARCINOGENIC PAH COMPOUNDS

TABLE OF CONTENTS

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LIST OF ACRONYMS AND ABBREVIATIONS

cPAH	carcinogenic polycyclic aromatic hydrocarbon
Ecology	Washington State Department of Ecology
FS	Feasibility Study
IDW	Inverse Distance Weighting
MDL	method detection limit
QEA	Quantitative Environmental Analysis
Reynolds Facility	former Reynolds Metals Reduction Plant
RI	Remedial Investigation
RMSE	root mean square error
SWAC	surface weighted average concentration
TEQ	Toxicity Equivalent Concentration

This document summarizes the data and specific methods used to develop surface weighted average concentrations (SWACs) for Columbia River sediments in the Remedial Investigation/Feasibility Study (RI/FS) Study Area adjacent to the former Reynolds Metals Reduction Plant (Reynolds Facility). This analysis was performed for each of the seven carcinogenic polycyclic aromatic hydrocarbon (cPAH) compounds to support the human health risk screening of these sediments. This appendix and the methods described herein were developed in coordination with the Washington State Department of Ecology (Ecology).

1 DATASETS USED

Table 1 lists available sampling data from recent studies with acceptable quality assurance/quality control parameters. Reported concentrations of cPAH compounds are listed in the Table 1. As directed by Ecology, a subset of these available surface data was used in the development of a current SWAC for sediments adjacent to the Reynolds Facility. Datasets included the following:

- National Pollutant Discharge Elimination System monitoring data (2012; 0- to 10-centimeter samples only)
- RI/FS nearshore sediment sampling data (2012)
- RI/FS offshore sediment sampling data (2012) Chinook Ventures, Inc., surface sediment characterization data (2010)

As directed by Ecology, data from extreme upstream and downstream portions of the RI/FS Study Area were excluded from the analysis, and no data from adjacent study areas (e.g., Weyerhaeuser sediment characterization studies) were used.

2 DATA PRE-PROCESSING AND TREATMENT OF NON-DETECTS

Results of data pre-processing steps are provided in Table 1 for each cPAH compound and for total cPAH Toxicity Equivalent Concentration (TEQ). The following procedures were used in data pre-processing:

- **Averaging of Duplicates.** Where multiple values were available for a test sample due to availability of field duplicates or the reanalysis of archived samples, the average value for that sample station was used in the interpolations.
- **Non-detects Plotted at Detection Limit.** For mapping of individual cPAH compounds and for calculating of averages, non-detect values were plotted at half the indicated method detection limit (MDL).
- **Calculation of Total cPAH TEQ.** For calculation of total cPAH values as benzo(a)pyrene TEQ values, total cPAH TEQ calculations were performed individually at each test location.
  - **cPAH TEQ Calculations.** TEQ calculations were performed using the California Environmental Protection Agency Toxicity Equivalency Factor values approved for use under the Model Toxics Control Act and Sediment Management Standards regulations.
  - **Treatment of Non-detects During Totaling.** Where individual compounds were not detected, they were assumed to be present at half of the reported MDL for these total cPAH TEQ calculations.
  - **Averaging.** If duplicate test results were available at a given station, the individual cPAH TEQ values for each test result were calculated, and then the average of these values was used for mapping. The resulting TEQ values are provided in Table 1.

Table 1 shows the initial cPAH data ("raw data"), and the "processed data," including treatment of non-detected values, the calculated cPAH TEQ totals, and also the results of averaging calculations used for duplicate test results. Truncated location identifiers carried forward in Table 2 are listed, as well.

3 SOFTWARE USED FOR INVERSE DISTANCE WEIGHTING DEVELOPMENT

The data contouring and associated geostatistical data analysis was performed using ArcMap (ESRI 2013) and Geostatistical Analyst (ESRI 2013). All data analysis protocols used during development of the Inverse Distance Weighting (IDW) surface and the SWAC values were consistent with ESRI-defined procedures.

4 DATA TRANSFORMATIONS

Figure 1a illustrates the distribution of the total cPAH TEQ concentration data. As is common with environmental datasets, the data do not follow a normal (i.e., bell-curve) distribution. In situations where data are not normally distributed, they must be transformed using either logarithmic or power transformations in order to avoid errors in the IDW surface development process. Transformation steps used in the analysis were performed as directed by Ecology.

Figure 1b illustrates the distribution of the same dataset when transformed using a power-based data transformation (specifically the Box-Cox transformation). As shown in Figure 1b, the transformed data follow the traditional bell-curve pattern, as required to minimize potential errors in the IDW surface development.

The Box-Cox transformation (see Equation 1) changes the original variable (X) into the transformed variable (Y; QEA 2007).

$$Y = \frac{x^{\lambda}-1}{\lambda} \; for \, \lambda \neq 0 \tag{1}$$

The transformation requires selection of the value of lambda (λ). This value was selected independently for each analyte in order to optimize the normality of the transformed dataset. This is done to minimize the skew of the dataset distribution (peak of the curve to either side of center), kurtosis (reducing impact from spikes in the dataset), and reducing the difference between the mean and median values (indicator of symmetrical distribution). Lambda (λ) values for individual analytes are provided in Chart 1, and transformed data are shown in Table 2:

Chart 1
Lambda Values for cPAH Analytes

Analyte	Lambda (λ)
Benzo(a)anthracene	-0.3
Benzo(a)pyrene	-0.25
Benzo(b)fluoranthene	-0.21
Benzo(k)fluoranthene	-0.3
Chrysene	-0.24
Dibenzo(a,h)anthracene	-0.36
Indeno(1,2,3-cd)pyrene	-0.28
Total cPAH TEQ	-0.28

Notes:
cPAH = carcinogenic polycyclic aromatic hydrocarbon
TEQ = Toxicity Equivalent Concentration

5 FIXED NEIGHBORHOOD ANALYSIS

The IDW surfaces were developed using a fixed neighborhood analysis. In developing this surface, the data are sampled repeatedly by the IDW program, developing estimated contaminant concentrations for each point on a grid throughout the area of interest. This data sampling is initially conducted using data points located within a fixed neighborhood around the grid point in question. That initial neighborhood can be circular or elliptical depending on the data patterns and site characteristics. The initial search area can be either expanded or contracted appropriately if initial sampling of the fixed neighborhood results in either too many or too few data points (see Section 6 for discussion of maximum and minimum neighbor analysis).

Given observed patterns in the data, the fixed neighbor analysis used an ellipse rather than a circular search pattern. The use of a non-circular search pattern is frequently required in river systems where the data show directionality (i.e., data from upstream and downstream pairs are more related than data pairs located in cross-current directions).

The optimized size and orientation of the ellipse were determined using semi-variogram functions in Geostatistical Analyst. The optimized search ellipse characteristics were determined as follows:

- Major axis= 1,000 feet
- Minor axis= 600 feet
- Angle = 130 degrees

Figure 2 illustrates the elliptical search pattern and its orientation relative to the river channel.

6 INVERSE DISTANCE WEIGHTING PARAMETER OPTIMIZATION

IDW development was conducted using optimized values for each of three parameters, including: 1) the power parameter; 2) the maximum and minimum number of neighbors; and 3) the sector approach used for IDW development. Each of these parameters was selected using a root mean square error (RMSE) analysis. The parameter settings selected after optimization in the RMSE analysis are as follows:

- **Power Parameter.** The power parameter determines the influence of a data point on the estimated IDW grid concentration relative to its distance away exponentially. The larger the value, the less influence the data point has on the estimated concentration. Power parameters that yield reasonable results tend to be between 0.5 and 3 (ESRI 2013). The power selected for the dataset was 1, which is within this typical range.
- **Maximum and Minimum Neighbors.** The number of points selected for the IDW calculation (neighbors) can be greater or less than those initially included within the fixed neighborhood search pattern. The final data selection is established by selecting a maximum and minimum number of neighbors for that analysis. The maximum and minimum neighbors selected in this dataset were 5 and 2, respectively. These are consistent with IDW methods performed for other environmental datasets (AECOM 2012).
- **Sector Search Methods.** Geostatistical Analyst includes three sector search options for conducting the IDW data search protocols. These search options affect the manner in which the maximum and minimum neighbor search is conducted. The method breaks the elliptical search pattern into one, four, or eight sectors prior to conducting data evaluation. When the neighborhood is divided into sectors, the specified maximum and minimum number of neighbors is applied to each sector (ESRI 2013). The eight-sector search pattern was selected based on the best RMSE output (compared to the one-sector and four-sector options). An example of an eight-sector search pattern is illustrated in the ellipse shown in Figure 2.

7 FINAL CONTOUR DEVELOPMENT

Contouring of the IDW surface was developed using ArcMap. This involved the following three steps.

- **Grid Development.** First the grid of concentration estimates was developed using the transformed data and each of the above-described IDW parameter settings.
- **Reverse Transformation.** The resultant grid (of transformed data) was run through a reverse transformation to generate corresponding grid points with concentration estimates in standard concentration units (i.e., micrograms per kilogram). The reverse transformation was conducted for each point in the grid using Equation 2. This reverse transformation preserves the contour relationships between the grid points developed using the IDW protocol but reflects them in the appropriate concentration units.

$$X = (\lambda Y + 1)^{\frac{1}{\lambda}} \quad (2)$$

- **Final Map Development.** The IDW surface was then contoured to produce a map in standard concentration units.

These IDW outputs result in the SWAC outputs for the Columbia River sediments within the RI/FS Study Area that are shown in Chart 2:

Chart 2
Estimated Surface Weighted Average Concentrations of cPAH Compounds Adjacent to the Reynolds Facility

Analyte	SWAC (µg/kg)
Benzo(a)anthracene[1]	14.02*
Benzo(a)pyrene[1]	16.05*
Benzo(b)fluoranthene[1]	22.5*
Benzo(k)fluoranthene[1]	9.99*
Chrysene[1]	23.71*
Dibenzo(a,h)anthracene[1]	5.27*
Indeno(1,2,3-c,d)pyrene[1]	11.42*

Notes:
1 = Non-detected compounds were assumed present at a value equal to the detection limit during development of the IDW. Duplicate results were averaged prior to use in IDW development.
* = Value has been updated since distribution of draft Appendix I-2.
µg/kg = microgram per kilogram
cPAH = carcinogenic polycyclic aromatic hydrocarbon
IDW = Inverse Distance Weighting
SWAC = surface weighted average concentration

8 REFERENCES

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TABLES

Table 1
Summary of Available cPAH Sediment Sampling Data and Data Pre-Processing for IDW Development

Study	Full Sample ID	Duplicates (Y/N)	Truncated Station ID	Benzo(a)anthracene		Benzo(a)pyrene		Benzo(b)fluoranthene		Benzo(k)fluoranthene		Chrysene		Dibenz(a,h)anthracene		Indeno(1,2,3-cd)pyrene		Total cPAH	
				Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values
Chinook	DU15-B-100903 *	Composite	--	9.28	9.28	14.4	14.4	15.6	15.6	6.07	6.07	10.9	10.9	3.37U	1.685	7.11	7.11	18.48	18.48
Chinook	DU1-A-100903 *	Individ. Core	A1(Z)	9.28	9.28	14.4	14.4	15.6	15.6	6.07	6.07	10.9	10.9	3.37U	1.685	7.11	7.11	18.48	18.48
Chinook	DU2-A-100902 *	Individ. Core	A2(Z)	9.28	9.28	14.4	14.4	15.6	15.6	6.07	6.07	10.9	10.9	3.37U	1.685	7.11	7.11	18.48	18.48
Chinook	DU3-A-100902 *	Individ. Core	A3(Z)	9.28	9.28	14.4	14.4	15.6	15.6	6.07	6.07	10.9	10.9	3.37U	1.685	7.11	7.11	18.48	18.48
RI/FS	AQ-SE-01-10 *	No	AQ-SE-01	43.6	43.6	61.3	61.3	97.5	97.5	25.9J	25.9	58.6	58.6	37.1U	18.55	38	38	84.24	84.2
RI/FS	AQ-SE-02-10	No	AQ-SE-02	6.13	6.13	8.63	8.63	17.3	17.3	3.96J	3.96	15.3	15.3	4.36U	2.18	7.73	7.73	12.51	12.51
RI/FS	AQ-SE-03-10	No	AQ-SE-03	106J	106	136J	136	180J	180	59.9J	59.9	134J	134	18.6J	18.6	87.1J	87.1	182.5	182.5
RI/FS	AQ-SE-04-10	No	AQ-SE-04	10.1	10.1	10.1	10.1	17.7	17.7	5.84	5.84	41.9	41.9	4.76U	2.38	7.23	7.23	14.84	14.84
RI/FS	AQ-SE-05-10	No	AQ-SE-05	84.9	84.9	71.6	71.6	261	261	71.6	71.6	294	294	9.64	9.64	38.4	38.4	121.09	121.09
RI/FS	AQ-SE-06-10	No	AQ-SE-06	2.96J	2.96	5.48J	5.48	7.92	7.92	3.88J	3.88	5.89	5.89	4.43U	2.215	4.43U	2.215	7.46	7.46
RI/FS	AQ-SE-07-10	Yes	AQ-SE-07	12.4	7.725	15.4	10.89	19.9	13.345	7.24	6.965	13.8	8.39	4.52U	4.49	7.82	5.055	20.5	14.34
RI/FS	AQ-SE-07FD / AQ-SE-57-10	Yes (Dup)	--	3.05J	--	6.38J	--	6.79	--	6.69U	--	2.98J	--	4.46U	--	2.29J	--	8.18	--
RI/FS	AQ-SE-08-10 *	No	AQ-SE-08	3.47J	3.47	5.3	5.3	7.16	7.16	4.48U	2.24	5.14	5.14	4.48U	2.24	2.76J	2.76	7.14	7.14
RI/FS	AQ-SS-03-10	Yes	AQ-SS-03	5.82U	2.91	5.82U	2.91	5.82U	2.91	5.82U	2.91	5.82U	2.91	5.82U	2.91	5.82U	2.91	5.82	2.91
RI/FS	AQ-SS-04-10	No	AQ-SS-04	3.89J	3.89	5.1	5.1	6.13	6.13	4.49U	2.245	4.06J	4.06	4.49U	2.245	2.33J	2.33	6.82	6.82
RI/FS	AQ-SS-09-10	No	AQ-SS-09	16000J	16000	24100J	24100	33400J	33400	11000J	11000	25800J	25800	2960J	2960	16200J	16200	32,314	32314
RI/FS	AQ-SS-10-10	No	AQ-SS-10	8.12	8.12	13.4	13.4	14.7	14.7	4.46J	4.46	8.5	8.5	4.95U	2.475	7.59	7.59	17.22	17.22
RI/FS	AQ-SS-14-10	No	AQ-SS-14	3.64J	3.64	4.66	4.66	7.92	7.92	4.11U	2.055	9.75	9.75	4.11U	2.055	2.59J	2.59	6.58	6.58
Weyerhaeuser	DMMU-10-C10 *	No	DMMU-10-C10	1.9U	0.95	1.9U	0.95	1.6U	0.8	1.6U	0.8	1.7U	0.85	1.7U	0.85	1.7U	0.85	1.6U	1.6
Weyerhaeuser	DMMU-6-C6 *	No	DMMU-6-C6	23	37	37	23	31.5	31.5	31.5	31.5	49	49	8.7	8.7	21	21	36.5	36.5
Weyerhaeuser	DMMU-8-C8 *	No	DMMU-8-C8	1.7U	0.85	1.7U	0.85	1.4U	0.7	1.4U	0.7	1.5U	0.75	1.5U	0.75	1.5U	0.75	1.4U	1.4
Weyerhaeuser	DMMU-9-C9 *	No	DMMU-9-C9	1.7U	0.85	1.7U	0.85	1.4U	0.7	1.4U	0.7	1.5U	0.75	1.5U	0.75	1.5U	0.75	1.4U	1.4
Chinook	SG-01-100830	Yes	SG-01	81.2	96.1	98.7J	113.35	110	130	41.5	45.95	89.9	108.45	17.6	20.3	81.3	92.65	132.76	152.95
Chinook	SG-51-100830	Yes (Dup of SG-01)	--	111	--	128J	--	150J	--	50.4	--	127	--	23	--	104	--	173.1	--
Chinook	SG-02-100830	No	SG-02	1.4J	1.4	2.54UJ	1.27	1.62J	1.62	2.54U	1.27	1.45J	1.45	1.69U	0.845	0.983J	0.983	1.90	1.896
Chinook	SG-03-100830	No	SG-03	5.04	5.04	5.38J	5.38	6.12	6.12	2.02J	2.02	4.57	4.57	1.27J	1.27	6.3	6.3	7.50	7.5
Chinook	SG-04-100830	No	SG-04	4.81	4.81	2.09J	2.09	3.04	3.04	2.62U	1.31	6.72	6.72	1.74U	0.87	1.35J	1.35	3.30	3.3
Chinook	SG-05-100830	No	SG-05	13.9	13.9	13.1J	13.1	13.1	13.1	3.8J	3.8	14.6	14.6	4.22J	4.22	6.66	6.66	17.41	17.41
Chinook	SG-06-100830	No	SG-06	6.18	6.18	4.54J	4.54	7.45	7.45	2.48J	2.48	6.96	6.96	0.984J	0.984	3.21	3.21	6.64	6.64
Chinook	SG-07-100830	No	SG-07	2.8U	1.4	4.21UJ	2.105	4.21U	2.105	4.21U	2.105	2.8U	1.4	28U	14	28U	14	4.21	2.105
NPDES	MBTL12-SS-01-10	No	SS-01-10	16.8U	8.4	16.8U	8.4	16.8U	8.4	16.8U	8.4	16.8U	8.4	16.8U	8.4	16.8U	8.4	16.8	8.4
NPDES	MBTL12-SS-02-10	No	SS-02-10	16.6U	8.3	16.6U	8.3	16.6U	8.3	16.6U	8.3	16.6U	8.3	16.6U	8.3	16.6U	8.3	16.6	8.3
NPDES	MBTL12-SS-03-10	No	SS-03-10	17.2U	8.6	17.2U	8.6	17.2U	8.6	17.2U	8.6	17.2U	8.6	17.2U	8.6	17.2U	8.6	17.2	8.6
NPDES	MBTL12-SS-04-10	Yes	SS-04-10	15.4U	16.75	15.4U	12.69	15.4U	6.8625	15.4U	6.8625	15.4U	16.4	15.4U	14.65	15.4U	14.65	15.40	15.58
NPDES	MBTL12-SS-04-10FD/SS-54-10	Yes (Dup)	--	18.1	--	9.98J	--	12.05J	--	12.05J	--	17.4	--	13.9U	--	13.9U	--	15.76	--
NPDES	MBTL12-SS-05-10	No	SS-05-10	12.4J	12.4	14.2U	7.1	8.1J	8.1	8.1J	8.1	24.7	24.7	14.2U	7.1	14.2U	7.1	11.63	11.6
NPDES	MBTL12-SS-06-10	No	SS-06-10	16.3U	8.15	16.3U	8.15	16.3U	8.15	16.3U	8.15	16.3U	8.15	16.3U	8.15	16.3U	8.15	16.3	8.15
NPDES	MBTL12-SS-07-10	No	SS-07-10	30.2	30.2	23.1	23.1	35.1	35.1	35.1	35.1	114	114	14.3U	7.15	20.4	20.4	37.0	37
NPDES	MBTL12-SS-08-10	No	SS-08-10	26.4	26.4	17.9	17.9	42.3	42.3	42.3	42.3	57.9	57.9	13.5U	6.75	13.5U	6.75	30.9	30.9
NPDES	MBTL12-SS-09-10	Yes	SS-09-10	66,800	59600	89300	127650	71,500	67000	71,500	67000	83,800	74500	12,300	11300	59,800	54800	118,328	154365

Table 1
Summary of Available cPAH Sediment Sampling Data and Data Pre-Processing for IDW Development

Study	Full Sample ID	Duplicates (Y/N)	Truncated Station ID	Benzo(a)anthracene		Benzo(a)pyrene		Benzo(b)fluoranthene		Benzo(k)fluoranthene		Chrysene		Dibenz(a,h)anthracene		Indeno(1,2,3-cd)pyrene		Total cPAH	
				Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values	Raw Values	Processed Values
NPDES	MBTL12-SS-09-10CONF	Yes (Dup)	--	52400	--	166000	--	62500	--	62500	--	65200	--	10300	--	49800	--	190,402	--
NPDES	MBTL12-SS-10-10	Yes	SS-10-10	15.8	1287.9	13.7	2481.85	25.6	1815.3	25.6	1815.3	35	2032.5	13.3U	337.65	13.1J	1701.55	22.7	3197.6
NPDES	MBTL12-SS-10-10CONF	Yes (Dup)	--	2560	--	4950	--	3605	--	3605	--	4030	--	662	--	3390	--	6,372.5	--
NPDES	MBTL12-SS-11-10	Yes	SS-11-10	12.7J	12.35	11.2J	11.8	13.8	17.6	13.8	17.6	29	31.95	13.3U	11.35	9.05J	9.575	17.09	18.4
NPDES	MBTL12-SS-11-10CONF	Yes (Dup)	--	12	--	12.4	--	21.4	--	21.4	--	34.9	--	9.40U	--	10.1	--	19.71	--
NPDES	MBTL12-SS-12-10	Yes	SS-12-10	6520	3885	11900	7025	8550	5102.5	8550	5102.5	7560	4555	1470	868.5	8190	4830	15,304	9049.4
NPDES	MBTL12-SS-12-10CONF	Yes (Dup)	--	1250	--	2150	--	1655	--	1655	--	1550	--	267	--	1470	--	2,795	--
NPDES	MBTL12-SS-13-10	Yes	SS-13-10	18.2	16.15	17.6	18.8	16.9	18.35	16.9	18.35	28.6	25.6	13.7U	11.495	13.1J	14.05	25.08	26.33
NPDES	MBTL12-SS-13-10CONF	Yes (Dup)	--	14.1	--	20	--	19.8	--	19.8	--	22.6	--	9.29U	--	15	--	27.56	--

Notes:

* = As directed by the Washington State Department of Ecology, these data were not included in the IDW interpolation or SWAC estimates.

cPAH = carcinogenic polycyclic aromatic hydrocarbon

IDW = Inverse Distance Weighting

NPDES = National Pollutant Discharge Elimination System

RI/FS = Remedial Investigation/Feasibility Study

SWAC = surface weighted average concentration

Table 2
Summary of Transformed cPAH Concentration Data Used for SWAC Estimation

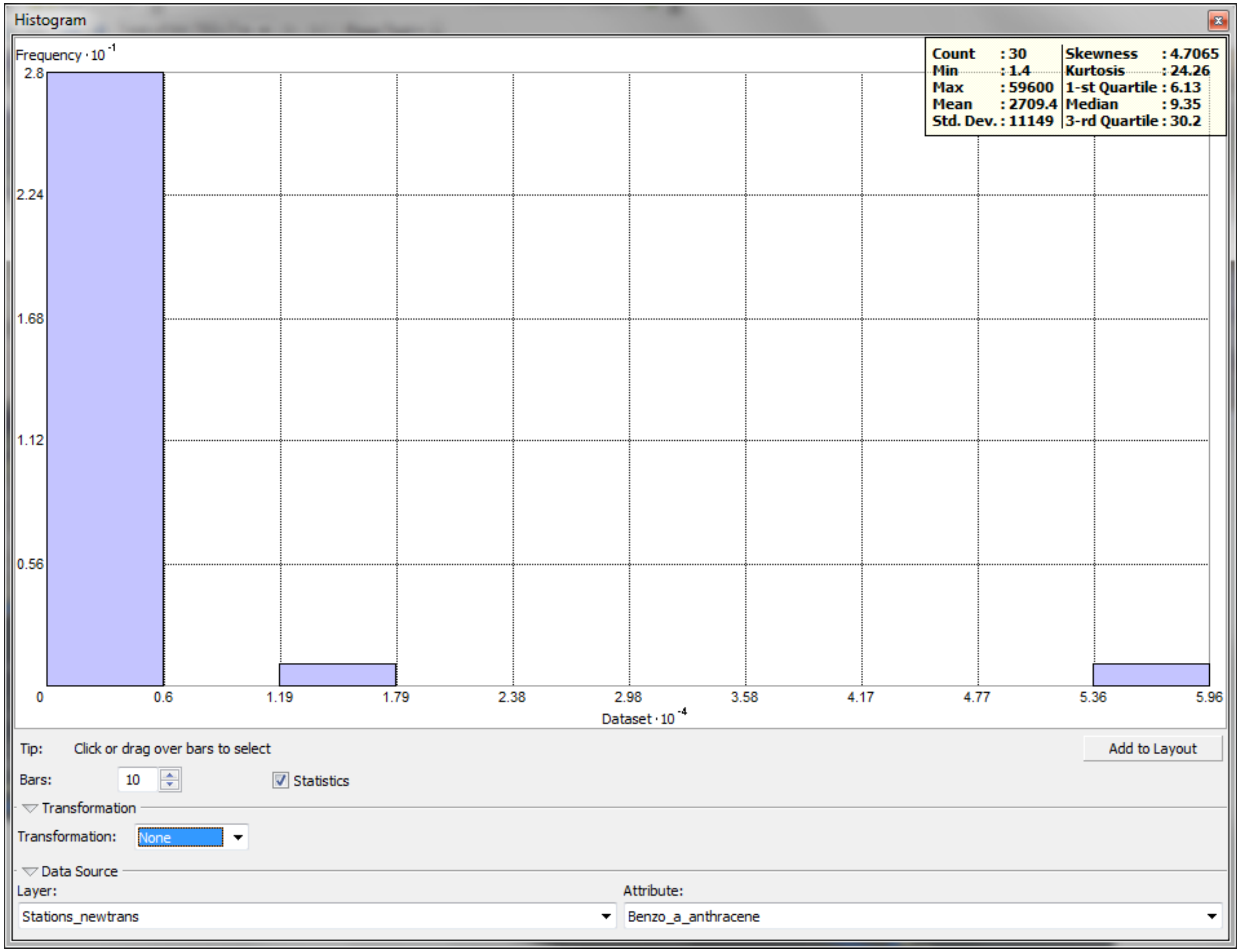
Location_ID	Benzo(a)anthracene		Benzo(a)pyrene		Benzo(b)fluoranthene		Benzo(k)fluoranthene		Chrysene		Dibenzo(a,h)anthracene		Indeno(1,2,3-cd)pyrene		Total cPAH TEQ	
	Initial Data (X)	Transformed Data (Y) (Lambda = -0.3)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.25)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.21)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.3)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.23)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.36)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.28)	Initial Data (X)	Transformed Data (Y) (Lambda = -0.28)
A1(Z)*	9.28	--	14.40	--	15.60	--	6.07	--	10.90	--	1.69	--	7.11	--	18.48	--
A2(Z)*	9.28	--	14.40	--	15.60	--	6.07	--	10.90	--	1.69	--	7.11	--	18.48	--
A3(Z)*	9.28	--	14.40	--	15.60	--	6.07	--	10.90	--	1.69	--	7.11	--	18.48	--
AQ-SE-01*	43.60	--	61.30	--	97.50	--	25.90	--	58.60	--	18.55	--	38.00	--	84.20	--
AQ-SE-02	6.13	1.40	8.63	1.67	17.30	2.14	3.96	1.13	15.30	2.03	2.18	0.68	7.73	1.56	12.51	1.81
AQ-SE-03	106.00	2.51	136.00	2.83	180.00	3.16	59.90	2.36	134.00	2.94	18.60	1.81	87.10	2.55	182.50	2.74
AQ-SE-04	10.10	1.67	10.10	1.76	17.70	2.16	5.84	1.37	41.90	2.51	2.38	0.74	7.23	1.52	14.84	1.89
AQ-SE-05	84.90	2.45	71.60	2.62	261.00	3.28	71.60	2.41	294.00	3.17	9.64	1.55	38.40	2.29	121.09	2.64
AQ-SE-06	2.96	0.93	5.48	1.39	7.92	1.68	3.88	1.11	5.89	1.46	2.22	0.69	2.22	0.71	7.46	1.54
AQ-SE-07	7.73	1.53	10.89	1.80	13.35	2.00	6.97	1.47	8.39	1.68	4.49	1.16	5.06	1.30	14.34	1.88
AQ-SE-08*	3.47	--	5.30	--	7.16	--	2.24	--	5.14	--	2.24	--	2.76	--	7.14	--
AQ-SS-03	2.91	0.91	2.91	0.94	2.91	0.96	2.91	0.91	2.91	0.95	2.91	0.89	2.91	0.92	2.91	0.92
AQ-SS-04	3.89	1.12	5.10	1.34	6.13	1.51	2.25	0.72	4.06	1.20	2.25	0.70	2.33	0.75	6.82	1.49
AQ-SS-09	16000.00	3.15	24100.00	3.68	33400.00	4.23	11000.00	3.13	25800.00	3.93	2960.00	2.62	16200.00	3.33	32314.00	3.38
AQ-SS-10	8.12	1.56	13.40	1.91	14.70	2.05	4.46	1.20	8.50	1.69	2.48	0.77	7.59	1.55	17.22	1.96
AQ-SS-14*	3.64	--	4.66	--	7.92	--	2.06	--	9.75	--	2.06	--	2.59	--	6.58	--
DMMU-10-C10*	0.95	--	0.95	--	0.80	--	0.80	--	0.85	--	0.85	--	0.85	--	1.60	--
DMMU-6-C6*	37.00	--	23.00	--	31.50	--	31.50	--	49.00	--	8.70	--	21.00	--	36.50	--
DMMU-8-C8*	0.85	--	0.85	--	0.70	--	0.70	--	0.75	--	0.75	--	0.75	--	1.40	--
DMMU-9-C9*	0.85	--	0.85	--	0.70	--	0.70	--	0.75	--	0.75	--	0.75	--	1.40	--
SG-01	96.10	2.49	113.35	2.77	130.00	3.05	45.95	2.28	108.45	2.87	20.30	1.84	92.65	2.57	152.95	2.70
SG-02	1.40	0.32	1.27	0.23	1.62	0.46	1.27	0.23	1.45	0.36	0.85	-0.17	0.98	-0.02	1.90	0.59
SG-03	5.04	1.28	5.38	1.37	6.12	1.51	2.02	0.63	4.57	1.28	1.27	0.23	6.30	1.44	7.50	1.54
SG-04	4.81	1.25	2.09	0.67	3.04	0.99	1.31	0.26	6.72	1.54	0.87	-0.14	1.35	0.29	3.30	1.01
SG-05	13.90	1.82	13.10	1.90	13.10	1.99	3.80	1.10	14.60	2.00	4.22	1.12	6.66	1.47	17.41	1.97
SG-06	6.18	1.40	4.54	1.26	7.45	1.64	2.48	0.80	6.96	1.57	0.98	-0.02	3.21	0.99	6.64	1.47
SG-07	1.40	0.32	2.11	0.68	2.11	0.69	2.11	0.67	1.40	0.32	14.00	1.70	14.00	1.87	2.11	0.67
SS-01-10	8.40	1.57	8.40	1.65	8.40	1.72	8.40	1.57	8.40	1.68	8.40	1.49	8.40	1.60	8.40	1.60
SS-02-10	8.30	1.57	8.30	1.64	8.30	1.71	8.30	1.57	8.30	1.68	8.30	1.48	8.30	1.60	8.30	1.60
SS-03-10	8.60	1.59	8.60	1.66	8.60	1.73	8.60	1.59	8.60	1.70	8.60	1.50	8.60	1.62	8.60	1.62
SS-04-10	16.75	1.90	12.69	1.88	6.86	1.58	6.86	1.46	16.40	2.06	14.65	1.72	14.65	1.89	15.58	1.92
SS-05-10	12.40	1.77	7.10	1.55	8.10	1.69	8.10	1.55	24.70	2.27	7.10	1.41	7.10	1.51	11.60	1.77
SS-06-10	8.15	1.56	8.15	1.63	8.15	1.70	8.15	1.56	8.15	1.66	8.15	1.47	8.15	1.59	8.15	1.59
SS-07-10	30.20	2.13	23.10	2.18	35.10	2.51	35.10	2.19	114.00	2.89	7.15	1.41	20.40	2.04	37.00	2.27
SS-08-10	26.40	2.08	17.90	2.06	42.30	2.59	42.30	2.25	57.90	2.64	6.75	1.38	6.75	1.48	30.90	2.20
SS-09-10	59600.00	3.21	127650.00	3.79	67000.00	4.30	67000.00	3.21	74500.00	4.02	11300.00	2.68	54800.00	3.40	154365.00	3.45
SS-10-10	1287.90	2.94	2481.85	3.43	1815.30	3.78	1815.30	2.98	2032.50	3.59	337.65	2.44	1701.55	3.13	3197.60	3.20
SS-11-10	12.35	1.77	11.80	1.84	17.60	2.15	17.60	1.92	31.95	2.39	11.35	1.62	9.58	1.67	18.40	1.99
SS-12-10	3885.00	3.05	7025.00	3.56	5102.50	3.97	5102.50	3.08	4555.00	3.72	868.50	2.53	4830.00	3.24	9049.40	3.29
SS-13-10	16.15	1.89	18.80	2.08	18.35	2.18	18.35	1.74	25.60	2.29	11.50	1.62	14.05	1.87	26.33	2.14

Notes:

* = As directed by the Washington State Department of Ecology, these data were not included in the IDW interpolation or SWAC estimates.

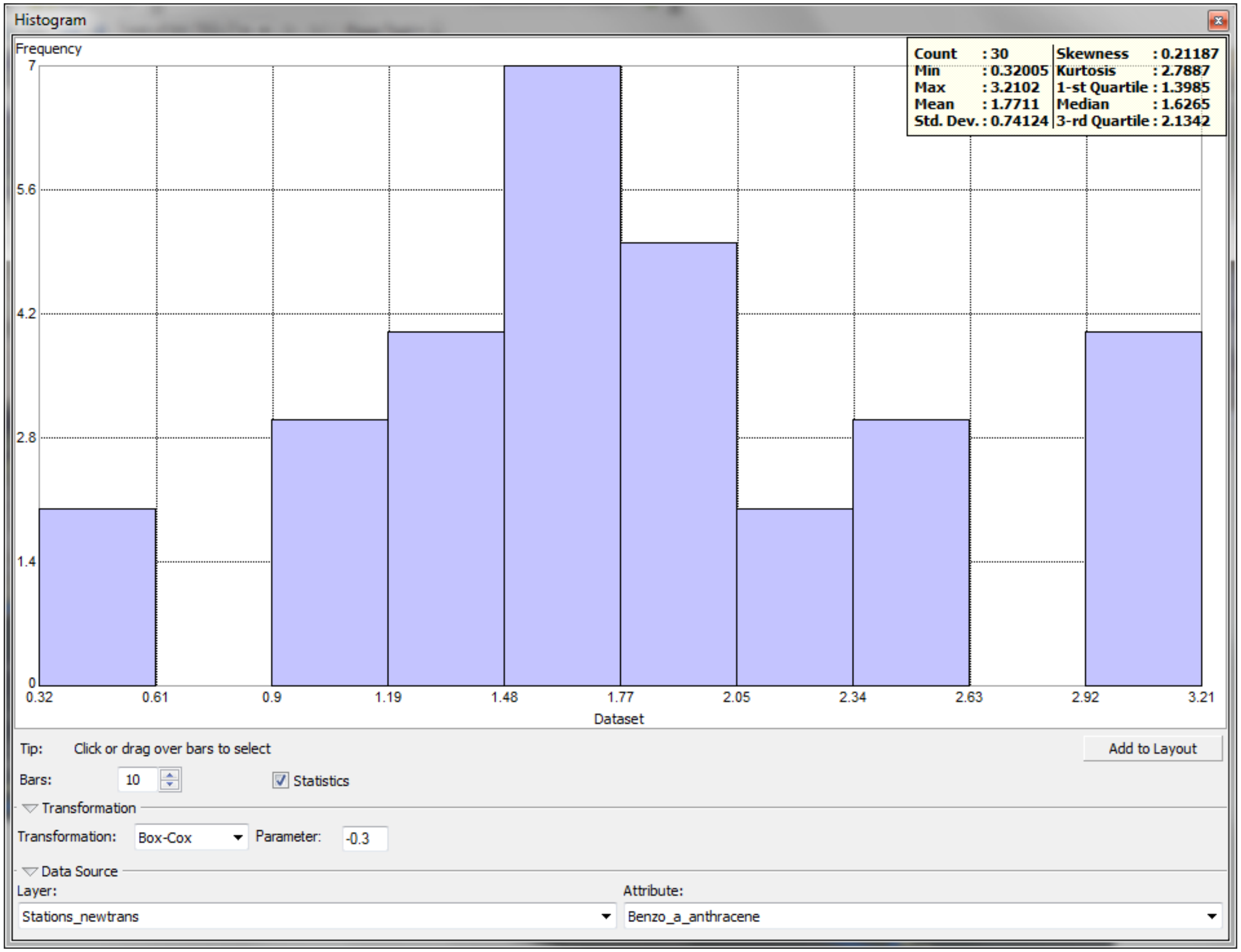
cPAH = carcinogenic polycyclic aromatic hydrocarbon IDW = Inverse Distance Weighting SWAC = surface weighted average concentration TEQ = Toxicity Equivalent Concentration

FIGURES



Notes:
Transformation = None
X-axis = Concentration (mg/kg) * 10^5
Y-axis = Count * 10

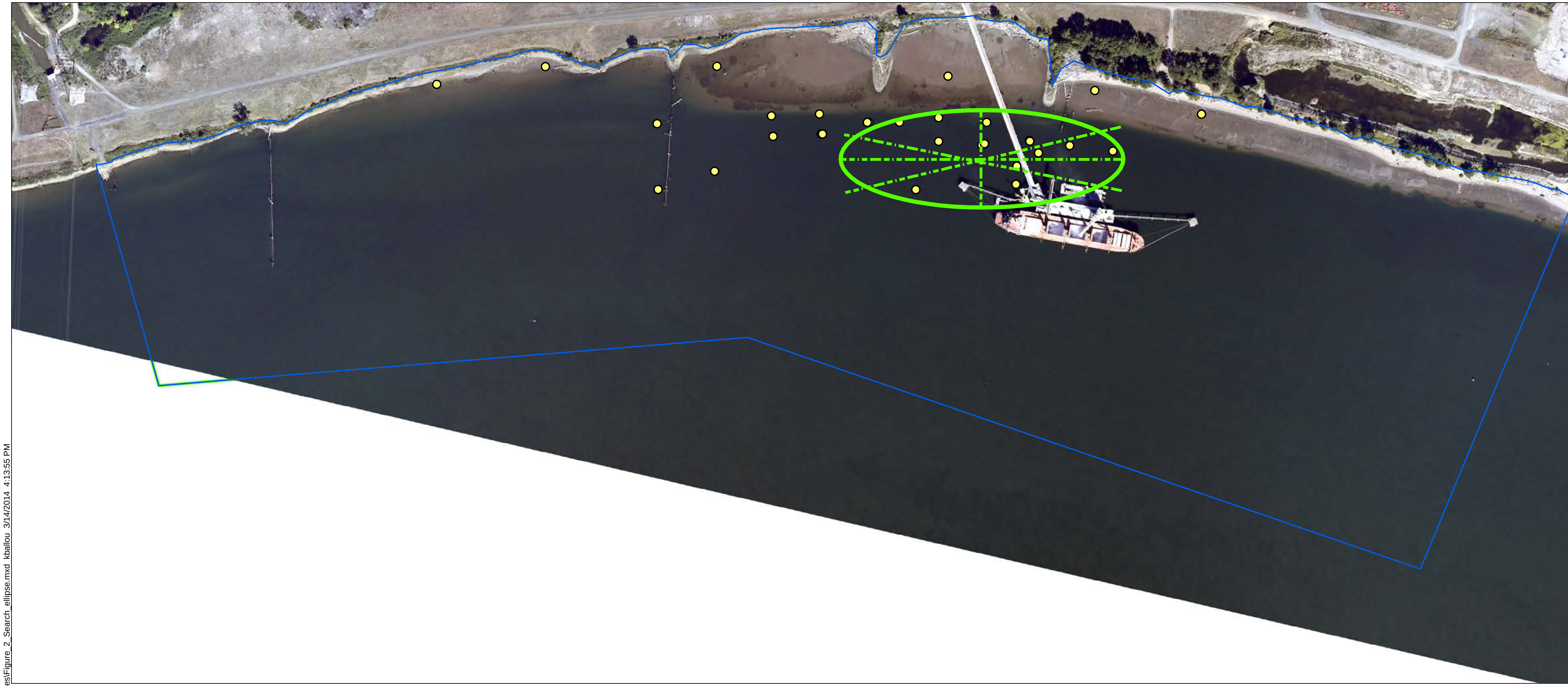
Figure 1a
Distribution of Total cPAH TEQ Concentration Data
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview



Notes:
Transformation = Box-Cox with λ of -0.3
X-axis = Transformed Concentration
Y-axis = Count * 10

ANCHOR QEA

Figure 1b
Distribution of Total cPAH TEQ Concentration Data Using Box-Cox Transformation
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview



SOURCE: Map prepared from multibeam bathymetric survey performed by TerraSond,ltd. from March 3 to 9,2013.
HORIZONTAL DATUM: Washington State Plane South,NAD83(91),US Survey Feet.
VERTICAL DATUM: Columbia River Datum (CRD) based on published tidal datums for NOAA Tide Station 944-0422 (1983-2001epoch).

Legend

- Sample Location
- Search Ellipse
- Internal Sector Boundaries
- Site Boundary

Feet
0 250 500 750 1,000

ANCHOR QEA

Figure-2
Inverse Distance Weighted Interpolation Example Search Ellipse
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant - Longview

APPENDIX J
EVALUATION OF ALTERNATIVES AND COSTS FOR ADDITIONAL MANAGEMENT OF SEDIMENTS LOCATED NEAR OUTFALL 002A

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LIST OF ACRONYMS AND ABBREVIATIONS

AC	activated carbon
CAD	confined aquatic disposal
CDF	confined disposal facility
cm	centimeter
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSL	cleanup screening level
cy	cubic yards
DMMP	Dredged Material Management Program
Ecology	Washington State Department of Ecology
ENR	enhanced natural recovery
EPA	U.S. Environmental Protection Agency
IC	institutional control
MNR	Monitored Natural Recovery
MTCA	Model Toxics Control Act
NPDES	National Pollution Discharge Elimination System
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
Reynolds Facility	former Reynolds Metals Reduction Plant
RI/FS	Remedial Investigation/Feasibility Study
SCO	sediment cleanup objective
SMS	Sediment Management Standards
USACE	U.S. Army Corps of Engineers
WAC	Washington Administrative Code

1 INTRODUCTION

This appendix summarizes the development and comparison of remedial alternatives to manage sediment in the area located near Outfall 002A (see Figure J-1) as part of the Remedial Investigation/Feasibility Study (RI/FS) for the former Reynolds Metals Reduction Plant (Reynolds Facility) in Longview, Washington. This appendix addresses the following FS elements for remediation of contaminated sediments:

- Brief description of chemical and physical characteristics
- Cleanup standards and remediation area
- Screening of remedial technologies
- Description of remedial alternatives
- Comparison of remedial alternatives
- Selection of a preferred alternative

This appendix has been prepared at the request of Washington State Department of Ecology (Ecology). Sediments in this area are located within the designated mixing zone associated with that outfall and have been previously characterized as part of RI/FS and National Pollution Discharge Elimination System (NPDES) sediment testing activities.

The results of testing do not exceed the SMS regulatory requirements for sediment site designation under the cluster rule (Washington Administrative Code [WAC] 173-204-510(2)(b)). However, as directed by Ecology, the sediment in the immediate vicinity of sample Station SS-09 and Outfall 002A has been carried forward into the FS evaluation of alternatives presented herein.

2 SEDIMENT AREA DESCRIPTION

The location and description of the Reynolds Facility are provided in Section 1 of the RI/FS.

The physical characteristics of the sediment area were observed during a dive survey performed in 2014 (see Figure J-1). Surface sediment consists of a thin layer of brown flocculent material, underlaid by silty sand. In the shallower half of the sediment area (i.e., toward the shoreline), silty sands are underlaid by a poorly-graded sand unit or by more silty sands. In the deeper half of the sediment area (i.e., toward the channel), silty sands are underlaid by a hard clay unit at 1 foot to 1.5 feet below mudline. The hydrodynamics of the river system result in periodic scour or deposition events. Transiting vessels are common in the adjacent navigation channel and berthing area; however, scour from propeller wash is not significant in the proximity of Outfall 002A.

As part of the RI/FS, samples of sediment were analyzed from nearshore and offshore areas within the Columbia River. The RI/FS testing program was coordinated with routine sediment monitoring performed as part of the NPDES monitoring requirements, supplemented by previous testing data (see Section 2 of the *Remedial Investigation and Feasibility Study*). Both RI/FS and NPDES testing data are summarized in Section 5.5 of the *Remedial Investigation and Feasibility Study*, and results of chemical analyses are presented in Tables 5-21 and 5-22 and Figure 5-15 of the report.

The results of sediment chemical testing were screened against SMS criteria for freshwater sediments, as defined in Ecology's update of the SMS rule (February 2013). Two out of 28 locations were found to exceed screening levels when considering chemical concentrations and bioassay tests (SS-09 and SS-17; see Figure J-2). Two other locations exceeded chemical screening levels for polycyclic aromatic hydrocarbons (PAHs) but passed bioassay tests (SS-10 and SS-12). Sediment monitoring data have demonstrated substantial reductions in organic constituent concentrations in the recent sediments (0 to 2 centimeter [cm] samples) near the outfall in comparison to deeper samples (0 to 10 cm samples), confirming the success of source control measures and the ongoing progress of natural recovery. The depth of contaminated sediment was found to be less than 24 cm based on a subsurface sample collected at SS-09.

In addition to chemical testing, a diver survey was conducted to visually delineate sheen observed at core Station SS-09 (see Figure J-1). The diver survey consisted of four transects parallel to the shoreline spaced approximately 40 feet apart. Each transect was 250 feet long and contained six push core sampling locations. The resulting grid encompassed Outfall 002A, as well as Stations SS-09 and SS-17, as shown on Figure J-2. Diver push cores were advanced to 18 inches or refusal and were logged by Anchor QEA staff, and sheen tests were conducted at several intervals in the push cores. The results indicate that the area with sheen is smaller than the preliminary remediation area shown on Figures J-1 and J-2.

Sediments in the impacted area are located within the designated mixing zone associated with Outfall 002A. Source control measures have been completed, including cleaning the facility drain lines of accumulated solids, removal of solids from the stormwater retention basin, and ongoing optimization of filter plant operations. The cleaning of the combined stormwater and wastewater system occurred in 2010, and cleanout of solids from the stormwater retention basin occurred in 2012.

3 CLEANUP STANDARDS AND AREA OF IMPACTED SEDIMENT

Under SMS, cleanup standards are developed based on protection of human health, higher trophic level species, and the benthic community.

Appendix I-1 performs the human health risk screening of sediment data for the site, finding that average concentrations in the study area are below the applicable risk-based threshold concentrations for bioaccumulative chemicals (e.g., carcinogenic polycyclic aromatic hydrocarbon [cPAHs] and polychlorinated biphenyls [PCBs]). Therefore, sediments are protective of human health at baseline conditions, and cleanup standards were not developed for protection of human health. Similarly, cleanup standards were not developed for higher trophic level species because sediments are below applicable risk-based threshold concentrations at baseline conditions.

Cleanup standards were developed for the benthic community based on the chemical and biological (i.e., bioassay) criteria in WAC 173-204-563. WAC 173-204-563 provides two levels for potential use as cleanup standards for each contaminant: the sediment cleanup objective (SCO) and the cleanup screening level (CSL). The SCO is set at a concentration at which no adverse effects have been shown to occur, including no acute or chronic adverse effects on biological resources. The CSL is a minor adverse effects level, which is the minimum level to be achieved in SMS cleanup actions. The more stringent SCO criteria were selected as cleanup levels for the site. The cleanup levels are applied to the biologically active zone, which is the upper 10 cm of sediment.

In addition to these analyses, further characterization to delineate the extent of sediments with sheen was performed using a dive survey. The area of impacted sediment, shown on Figure J-1, was developed by considering both chemical criteria and bioassays. Two locations exceeded cleanup standards; two other locations exceeded chemical criteria, but biological testing indicated no impact to the benthic community. The area of impacted sediment was determined by interpolating between sediment sampling locations and considering constructability.

In addition to these analyses, further characterization to delineate the extent with sheen was performed using a dive survey. The results indicate that the area of impacted sediment includes the area with sheen (see Figure J-1).

The total area of impacted sediment is approximately 0.7 acre, and the volume of impacted sediment is approximately 2,400 cubic yards (cy).

4 SCREENING AND SELECTION OF REMEDIAL TECHNOLOGIES

The following remedial technologies were considered for use to remediate sediments exceeding cleanup standards:

- Source control
- Ex situ treatment
- In situ treatment
- Removal (dredging) and:
  - Beneficial reuse of sediments
  - Disposal in an upland landfill
  - Disposal within an in-water facility (e.g., confined aquatic disposal [CAD]/confined disposal facility [CDF])
- Engineered capping
- Enhanced natural recovery
- Monitored natural recovery
- Institutional controls (ICs) and monitoring

The list includes the well-established remedial technologies for contaminated sediment. These technologies are described in the following sections, with the rationale for retaining or eliminating each in the development of remedial alternatives. Table J-1 summarizes the technology screening.

4.1 Source Control

Control of ongoing sources is essential for the long-term success of remedial technology. As noted, sediment exceeding cleanup standards are located in the mixing zone of Outfall 002A, for which source control actions were performed in 2010 and 2012. Surface sediment concentrations in the 0- to 2-cm interval are significantly less than concentrations in the 0- to 10-cm interval, indicating that freshly deposited sediment is below cleanup standards and that source control efforts have been successful. The source control efforts to date are considered to be part of the all remedial alternatives. Source control is retained as part of all remedial alternatives.

4.2 Ex Situ Treatment

Ex situ treatment refers to the process of transforming, destroying, or detoxifying contaminants in dredged sediments. While ex situ treatment of sediments are subject of considerable interest nationwide, these technologies generally have limited feasibility at full-scale for application to contaminated sediments. Use of ex situ treatment technologies can be challenging because treatment needs to accommodate beneficial reuse of the material and upland and in-water disposal remedies are usually much less expensive.

Potential ex situ treatment options include acid extraction, phytoremediation, soil/sediment washing, thermal desorption, light weight aggregate production, plasma vitrification, and solidification. None of these options are sufficiently implementable or cost effective to retain for the remedial alternatives.

4.3 In Situ Treatment

In situ treatment entails the direct application or placement of amendments into the sediment and/or mixing reagents with sediment cap substrate to reduce the bioavailability of certain contaminants. Typical application involves the placement of activated carbon (AC) or other types of reagents that bind certain organic and/or metal contaminants. Of the amendments available, AC has undergone more testing and evaluation than organoclays, particularly with respect to sediment remediation, because the sorption capacities for PAHs, dioxin/furans, and other chemicals in AC are at least an order of magnitude higher than other sorbents.

While application of in situ treatment has been demonstrated to be effective and implementable at other sediment sites, the remedial technology has not been employed as often as traditional remedial technologies, such as dredging, capping, enhanced natural recovery (ENR), and monitored natural recovery (MNR). Furthermore, in situ treatment relies on complex chemical and physical interactions and may require bench-scale studies prior to implementation. For these reasons, in situ treatment is not retained for further consideration for remediating the relatively small area of impacted sediment near Outfall 002A.

4.4 Removal

Removal is a common and frequently implemented technology for remediation of contaminated sediment, either while it is submerged (dredging) or after water has been diverted or drained (excavation). After removal, the sediments must be managed, a process that can include dewatering, treatment, and/or disposal. As described previously, the physical and chemical properties of sediments may allow them to be beneficially reused.

Dredging is routinely used for both maintenance of navigation channels and removal of contaminated sediments. While the objective of navigational dredging is to remove sediment as efficiently and economically as possible to maintain waterways for recreational, national defense, and commercial purposes, environmental dredging is intended to remove sediment contaminated above certain action levels while minimizing the spread of contaminants to the surrounding environment during dredging.

Removal consists of two major process options—dredging and excavation. Dredging is defined as the removal of sediment in the presence of overlying water (subtidal and intertidal) utilizing mechanical or hydraulic removal techniques and operating from a barge or other floating device. Excavation is defined as the dry or shallow-water removal of sediment using typical earth moving equipment, such as excavators and backhoes operating from exposed land or wharves. Depending on the location of the sediments being removed, there may be some overlap in the equipment used for dredging and excavation.

There are two major types of dredges—mechanical and hydraulic. While mechanical dredges function by digging into the sediments with a bucket (similar to a land-based process), hydraulic dredges function by loosening sediments with a mechanical device by vacuuming the sediments along with large quantities of entrained water and transporting the resulting dredge slurry in a pipeline to an area where the solids and liquids can be separated for subsequent management. Selection of dredging equipment and methods used for a site depend on several factors, including physical characteristics of the sediments to be dredged, the quantity and dredge depth of material, distance to the disposal area, the physical environment of the dredging area, contaminant concentrations in the sediment, method of disposal, production rates required for removal, equipment availability, amount and type of debris present, ability to manage produced waters, and cost (EPA 2005). For this appendix, it is assumed that sediments would be dredged and excavated with traditional mechanical methods; however, hydraulic dredging could be effective in conjunction with on-site upland disposal, as determined during remedial design.

Prior to re-handling, transport, and disposal, the dredged sediment may require dewatering to reduce the sediment water content. Dewatering technologies may be used to reduce the amount of water in dredged sediment and to prepare the sediment for on-site consolidation or upland transport and off-site disposal. This FS assumes that sediment would be dewatered by gravity through natural drainage of sediment porewater to reduce the dredged sediment water content. Water generated during dewatering is typically discharged to receiving waters directly after a level of filtration. Passive dewatering typically requires little or no treatability testing, although characteristics of the sediment, such as grain size, plasticity, settling characteristics, and contaminant content, are typically considered to determine specific dewatering methods, to determine the size of the dewatering area, and to estimate the time frame required for implementation.

Experience at other sediment cleanup projects shows that resuspension of contaminated sediment and release of contaminants occurs during dredging and that contaminated dredging residuals will remain following operations. Even after decades of sediment remediation project experience, there are still substantial uncertainties in understanding of the cause-effect relationships relating dredging processes to risk reduction (EPA 2005; Bridges et al. 2008; Bridges et al. 2010). This evaluation assumes that dredging residuals would be managed by placement of a layer of material similar to ENR, which would provide a clean sediment surface following construction and restore the area to grade.

4.5 Beneficial Reuse of Dredged Sediments

Dredged sediments could be beneficially reused in coordination with the upland cleanup of the Reynolds Facility. In particular, dredged sediment could be utilized during the closure of the existing landfill and fill deposit located in the southwest corner of the upland property. Dredged material would be placed within an engineered berm that would serve as horizontal containment during placement. Placed dredged sediment would provide fill material for grading the surface of the landfill in preparation for capping. Dredged material would be covered by an upland cap (low permeability soil cap) to ensure protection of human health. The upland remedy would include monitoring and maintenance to ensure that dredged sediment does not become a source of contamination to groundwater, surface water, surface soils, or downgradient sediment.

Compared to disposal in a commercial, off-site landfill, beneficial reuse has significantly lower costs and off-site impacts (e.g., transportation and landfill impacts). Beneficial reuse has implementability challenges, such as coordination with upland construction activities and long-term monitoring of contained sediment. Beneficial reuse is retained for development of the remedial alternatives.

4.6 Disposal of Dredged Sediments in an Upland Landfill

Dredged material could be placed in an upland disposal facility at a permitted municipal or private landfill (e.g., construction debris landfill or Subtitle D landfill). Sediments excavated using water-based equipment could be delivered to a landfill by barge, truck, and/or rail depending on the landfill selected. In this evaluation, two landfill options are retained, disposal in an on-site upland landfill as part of beneficial reuse and disposal in an off-site landfill. Both options for upland landfill disposal are readily implementable. Off-site landfill disposal is associated with high costs, due to high transportation costs and tipping fees.

4.7 Disposal of Dredged Sediments in an In-Water Facility

Other common methods of disposing of dredged sediments include construction of a nearshore CDF or open-water CAD. A CDF facility, or a nearshore fill, is an engineered containment structure that allows for dewatering and permanent storage of dredged sediments. CDFs feature both solids separation and landfill characteristics (EPA 1994), and containment of contaminated sediments in these facilities is generally viewed as a cost-effective remedial option at Superfund sites (EPA 1996). Interest in CDFs for disposal of contaminated dredged sediment has led both U.S. Army Corps of Engineers (USACE) and U.S. Environmental Protection Agency (EPA) to develop detailed guidance documents for their construction and management (USACE 1987, 2000; EPA 1996; Averett et al 1988; Brannon et al 1990). CDF facilities involve creation of a sediment containment area that has a final filled surface located above tidal elevations. CDFs are commonly known as nearshore fills because they involve filling of aquatic areas and conversion of those areas to upland use. At this time, there are no known CDF options near the study area without significantly reducing the aquatic area, and therefore, the CDF option has not been carried forward in this evaluation.

CAD facilities are similar to CDFs because they are constructed in in-water areas and are used to contain sediment dredged from other areas. However, the top surface of the CAD facility must be constructed so that its final elevation retains overlying aquatic uses and must be positioned below the authorized channel depth to allow for maintenance dredging. In some cases, the CAD surface is designed with a surface that provides enhanced habitat conditions. As discussed in RI/FS Section 2.4.5, sediments in the berthing area of the site were approved for open-water disposal by Dredged Material Management Program (DMMP) in 2010. However, the sediments near Outfall 002A are not expected to meet DMMP criteria for open-water disposal, and therefore, CAD is not retained as a remedial alternative.

4.8 Engineered Capping

Capping is a well-developed and documented in situ remedial technology for sediment that contains and isolates contaminants from the overlying water column and prevents direct contact with aquatic biota. A cap should be designed with the objective of reducing risk through the following three main mechanisms (EPA 2005): 1) physical isolation of the contaminated sediment sufficient to reduce exposure due to direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface; 2) stabilization of contaminated sediment and erosion protection of the sediment and cap, sufficient to reduce resuspension and transport of contaminants into the water column; and 3) chemical isolation that prevents contaminated sediment to be solubilized and transported through the cap and into the water column.

In situ caps are generally constructed using granular material, such as clean sediment, sand, or gravel. Erosion resistance of a sediment cap could be improved, as necessary, by armoring stone (specifying minimum grain size on the surface of the cap) or by a layer of engineered concrete (e.g., grout mat). Chemical isolation could be improved, as necessary, with material specifications of the isolation layer, such as the addition of contaminant sorbing or blocking materials (reactive caps). The additives are selected based on their ability to adsorb or react with contaminants migrating through the cap thickness; examples of reactive amendment materials that have been applied in caps are AC, bentonite, apatite, AquaBlok™, and petroleum coke.

Capping could be designed to effectively isolate impacted sediment near Outfall 002A from the biological active zone. However, implementability challenges include design for physical stability and chemical flux through porewater advection. As directed by Ecology, capping is not retained for use on the small area of impacted sediment near Outfall 002A.

4.9 Enhanced Natural Recovery

ENR involves active measures, such as the placement of a thin layer of suitable sand or sediment, to accelerate the natural recovery process. ENR is often applied in areas with moderate chemical concentrations where natural recovery processes appear to be occurring, yet the rate of sedimentation or other natural processes is insufficient to reduce concentrations within an acceptable time frame (EPA 2005). The acceleration of natural recovery most often occurs due to burial and/or incorporation and mixing of the clean material into the contaminated surface sediments through bioturbation and physical mixing processes. ENR is usually applied in areas that are stable and not subject to scour; however, engineered aggregate mixes or engineered synthetic products may be used to ensure stability (Palermo et al. 1998). Placement of ENR materials is different than capping because it is not designed to provide long-term isolation of contaminants. As with MNR, ENR includes both monitoring and contingency plan components to verify that recovery is occurring as expected and to respond accordingly. ENR has been highly effective in managing residual sediment remaining following dredging, referred to as residuals management cover, as discussed in conjunction with dredging in Section 4.4.

4.10 Monitored Natural Recovery

The MNR remedy relies on natural recovery processes to reduce risks to acceptable levels following source control, while monitoring recovery over time to measure remedy success (Magar et al. 2009). Monitoring is a fundamental component of the MNR remedy and consists of data collection (physical, chemical, and biological testing) to assess the remedy performance and effectiveness. In the event that MNR does not meet or progress sufficiently toward achieving cleanup levels, contingency actions (such as source control, ENR, capping, or dredging) may be used. An adaptive management framework is essential in establishing decision rules with target endpoints and time frames for the performance of MNR in the long-term (Magar et al. 2009). MNR can be implemented as a sole remedy but is more frequently combined with other active remedial measures and ICs (EPA 2005).

Based on the evidence of natural recovery in the study area, MNR is a retained remedial technology. In particular, the comparison of the sediment samples in the upper 0- to 2-cm interval compared to the upper 0- to 10-cm interval indicates that newly deposited sediment is below cleanup standards and that natural recovery will occur as a result of additional sedimentation.

4.11 Institutional Controls and Monitoring

ICs are non-engineered measures and mechanisms for ensuring the long-term performance and protectiveness of cleanup actions. Sediments in the impacted area are located within the designated mixing zone associated with Outfall 002A and will be subject to regulation under NPDES for any remedial action. Regulation will require routine monitoring, maintenance, and additional source control, as necessary (e.g., if permit requirements are not met). These actions, in addition to recent source control actions under the NPDES permit, are part of all remedial alternatives.

For sediment remediation projects, permitting review procedures constitute ICs. For aquatic construction projects (e.g., dredging in a berth area), environmental reviews are conducted by permitting agencies, including USACE, Ecology, and other resource agencies. These include a review of area files relating to sediment conditions and a review of requirements to address materials management and water quality.

Additional ICs may be implemented, as appropriate, depending on the preferred remedial alternative ultimately selected by Ecology. Such additional controls could include use authorizations of aquatic lands, and/or notification and documentation of the site remedial action in County property records, USACE and regulatory agency permit records, and/or records maintained by the State of Washington. For example, ICs would be necessary for MNR and ENR to ensure that future activities would be performed so as to not increase site risk.

ICs can be effective, implementable, and cost beneficial when the remedial action for which the ICs are implemented is consistent with land and navigation uses.

5 REMEDIAL ALTERNATIVES

From the retained technologies, four engineering alternatives were assembled for evaluation in comparison to the Base Case (i.e., continued management of the area under the NPDES program). Detailed cost estimates were then developed for each of the four remedial alternatives and for the Base Case. These cost estimates are contained in Attachment 1. Costs are estimated in 2014-year costs without escalation and without present value discounting. Contingencies have been included consistent with RI/FS procedures. The following subsections provide a summary of the Base Case and four remedial alternatives.

5.1 Base Case

Source control actions have already been implemented, including cleanout of facility drain lines and removal of accumulated solids from the retention pond. Additional costs, beyond those included in Attachment 1 for the Base Case, have been incurred by Millennium Bulk Terminals – Longview, LLC, for filter plant optimization. Under the Base Case, ongoing natural attenuation processes, which have been shown to be effectively reducing contaminant concentrations in sediments, will continue. Ongoing NPDES monitoring associated with the outfall mixing zone will provide confirmation of the performance of natural recovery processes.

5.2 Alternative 1 – Source Control and Monitored Natural Recovery

As with the Base Case, Alternative 1 includes the benefits of completed and ongoing source control actions. These actions have been shown to be effective, and sediments at the outfall are recovering naturally, as shown in the results of sediment testing. Under this alternative, the monitoring under the NPDES program will be coordinated with the Model Toxics Control Act (MTCA) remedy implementation and monitoring program to ensure full recovery is achieved within a 10-year restoration time frame. Monitoring is assumed to occur at years 5 and 10 following the commencement of remediation.

5.3 Alternative 2 – Source Control and Enhanced Natural Recovery

Under Alternative 2, source control and natural recovery will continue, but these processes will be enhanced through the placement of clean river sand throughout the area identified on Figure J-1. Sand is assumed to be placed at an average depth of 12 inches (6 inches of placement plus 6 inches of overplacement). The restoration time frame for this alternative is estimated to be approximately 3 years, including recovery of the sediment benthic community following clean sand placement. Monitoring is assumed to occur at years 5 and 10 following construction.

5.4 Alternative 3 – Source Control, Dredging, and On-Site Beneficial Reuse and Disposal

Alternative 3 utilizes dredging of the sediments located within the area shown on Figure J-1. Dredged sediments would be removed from the river, transferred to the upland property, and beneficially reused as part of the remediation of an existing landfill and fill deposit located in the southwest corner of the upland property. Clean river sand would be backfilled within the dredging footprint to maintain existing bathymetric contours and manage dredging residuals. Approximately 3,600 cy of sediment would be dredged (2,400 cy plus 1,200 cy of overdredging), and 4,200 cy would be backfilled (3,600 cy plus 600 cy of overplacement). Because the alternative includes complete removal of contaminated sediment, no additional monitoring events would be required in the water under this alternative. However, monitoring under the requirements of the NPDES permit for Outfall 002A would continue. The estimated restoration time frame under this alternative is approximately 3 years, including recovery of the sediment benthic community, following dredging and clean sand placement. ICs and monitoring are provided for the landfill as part of the upland cleanup action.

5.5 Alternative 4 – Source Control, Dredging, and Off-Site Commercial Landfill Disposal

This alternative is similar to Alternative 3, except the sediments will not be beneficially reused as part of the upland landfill cleanup. Instead, the sediments will be managed by off-site disposal at a commercial landfill facility. Approximately 3,600 cy of sediment would be dredged (2,400 cy plus 1,200 cy of overdredging), and 4,200 cy would be backfilled (3,600 cy plus 60o cy of overplacement). Because the alternative includes complete removal of contaminated sediment, no additional monitoring events would be required in the water under this alternative. However, monitoring under the requirements of the NPDES permit for Outfall-002A would continue. The costs of this alternative are substantially higher than those in Alternative 3 due to the incremental costs of landfill disposal. ICs and monitoring will be provided for the landfill by the commercial landfill operator. The estimated restoration time frame under this alternative is approximately 3 years, which is the same as Alternative 3.

6 COMPARISON OF REMEDIAL ALTERNATIVES

The Base Case and the four developed alternatives were evaluated using the criteria established under the MTCA and SMS regulations for selection of a remedial alternative.

6.1 Minimum Requirements

Cleanup actions performed under the SMS must comply with 11 minimum requirements under WAC 173-204-570(3). Alternatives that do not comply with these criteria would typically not be considered suitable cleanup actions under the SMS. Each of the four evaluated remedial alternatives meets SMS minimum requirements, as discussed in the following sections.

6.2 Compliance with Cleanup Standards

Under SMS, compliance with cleanup standards represents the measure of whether and when an alternative has reduced risk sufficiently to protect human health and the environment. The cleanup standards were developed to protect human health, the health of the benthic community, and the health of higher trophic level species under WAC 173-204-560 through 563. Therefore, compliance with cleanup standards is used to evaluate the minimum requirements of "protection of human health and the environment" (WAC 173-204-570(3)(a)), "compliance with cleanup standards" (WAC 173-204-570(3)(c)), and to "provide for a reasonable restoration time frame" (WAC 173-204-570(3)(d)).

The description of the remedial alternatives provides the estimated time to achieve cleanup standards for the remedial alternatives. Natural recovery trends indicate that all alternatives are expected to meet cleanup standards from approximately 3 to 10 years following construction. Consistent with WAC 173-204-570(5)(a), all alternatives are considered to have a reasonable restoration time frame and meet these three minimum requirements.

6.3 Other Minimum Requirements

The achievement of other minimum requirements is discussed in the following list:

- Available evidence suggests that sources are controlled for the purpose of achieving cleanup standards for the remedial alternatives (WAC 173-204-570(3)(f)).

- Alternatives comply with applicable laws (WAC 173-204-570(3)(f)).
- A sediment recovery zone is not expected to be necessary for the remedial alternatives ((WAC 173-204-570(3)(g)) because cleanup standards are achieved within 10 years following construction.
- None of the remedial alternatives exclusively rely on MNR or ICs (WAC 173-204-570(3)(h)). The Base Case and Alternative 1 both use natural recovery processes to achieve cleanup standards; however, both alternatives rely primarily on source control and monitoring that are part of NPDES permit activities.
- Under any alternative, the RI/FS and Cleanup Action Plan will undergo appropriate public review and comment by affected landowners and the general public (WAC 173-204-570(3)(i)), and a periodic review will be performed under WAC 173-204-570(3)(k).
- All alternatives include adequate monitoring to ensure effectiveness of the cleanup action WAC 173-204-570(3)(j).

The minimum requirement of "using permanent solutions to the maximum extent practicable" (WAC 173-204-570(3)(d)) is evaluated in the disproportionate cost analysis (DCA) discussed in the next section.

6.4 Minimum Requirements

A disproportionate cost analysis was performed according to MTCA and SMS requirements. This analysis is summarized in Table J-2. A weighted evaluation of MTCA benefits was performed consistent with Ecology-defined procedures for each alternative using the following evaluation criteria and weightings:

- Protectiveness (30 percent weighting)
- Permanence (25 percent weighting)
- Long-term effectiveness (20 percent weighting)
- Short-term risk management (15 percent weighting)
- Technical and administrative implementability (10 percent weighting)

Consideration of public concerns was not included in the evaluation at this time because this requires prior completion of a public comment process. The long-term effectiveness criterion was evaluated using the procedures contained in the updated SMS rule (WAC 173-204-570(4)(b)). The benefit scores were developed in conjunction with Ecology.

For the disproportionate cost analysis, a composite benefits ranking was developed by first assigning a score between 1 and 10 for each criterion, as shown in Table J-2. These scores were qualitatively assigned based on the information presented in the table. A score of 10 represents the highest possible weighted benefits ranking, and a score of 1 represents the lowest possible weighted benefits. The final weighted score for each alternative was then developed using the indicated weightings. The total weighted benefit scores for the four alternatives and the Base Case ranged between 5.6 and 8.4.

For protectiveness, the alternatives were scored based on how well they are expected to achieve cleanup standards, which were developed to protect human health from seafood consumption, clamming and beach play, the health of the benthic community, and the health of higher trophic order species. Table J-2 shows that relative scores for the alternatives, with the dredging alternatives (Alternatives 3 and 4) scoring higher than the natural recovery and ENR alternatives (the Base Case and Alternatives 1 and 2).

For permanence, the alternatives were scored based on how well they permanently reduce site-related risk. Table J-2 shows that relative scores for the alternatives, with the dredging alternatives (Alternatives 3 and 4) scoring higher than the natural recovery and ENR alternatives (the Base Case and Alternatives 1 and 2).

Long-term protectiveness was scored based on the hierarchy of cleanup components listed in Table J-1. This hierarchy indicates that source control (all alternatives) and beneficial reuse (Alternative 3) should score the highest, with dredging (Alternatives 3 and 4) scoring higher than ENR (Alternative 2) and MNR (Alternative 1).

Management of short-term risk was scored based on the risks to human health and the environment during construction and implementation. For this criterion, the alternatives that have fewer impacts during construction by relying more on natural processes (the Base

Case and Alternatives 1 and 2) score higher than the alternatives that rely more on construction-intensive dredging (Alternatives 3 and 4).

Technical and administrative implementability consider the technical and administrative challenges for each alternative. For this criterion, the alternatives that have fewer technical challenges by relying more on natural processes (the Base Case and Alternatives 1 and 2) score higher than the alternatives that rely more on technically dredging, dewatering, transportation, and disposal (Alternatives 3 and 4).

In the DCA, the total benefit points are compared to costs to assess the comparative costs and benefits for the alternatives. The costs of the alternatives are listed in Table J-2, with costs ranging from $0.7 million for the Base Case alternative, to $2.4 million for Alternative 4.

As shown in Table J-2, the incremental benefits rankings were then developed for each alternative in comparison to the preceding alternative (Alternative 1 was compared to the Base Case). Similarly, the incremental costs were then developed for each alternative in comparison to those of the preceding alternative. Incremental benefits and costs are presented as percentages in Table J-2. An increase in a benefit score from 5.0 to 7.5 would represent a 50 percent increase in weighted benefit ranking. An increase in cost from $500,000 to $750,000 between two alternatives would similarly represent an increase in cost of 50 percent. Finally, the ratio of incremental benefits to incremental costs was identified for each alternative by dividing these two percentage values. A ratio value equal to or greater than 1:1 represents a proportionate relationship between MTCA incremental benefits and incremental costs.

Figure J-3 summarizes the results of the disproportionate cost analysis. MTCA states that "costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower alternative exceed the incremental degree of benefits achieved by the alternative over that of the lower cost alternative" (WAC 173-340-360(3)(e)(i)). MTCA also states that "where two or more alternatives are equal in benefits, the department shall select the less costly alternative" (WAC 173-340-360(3)(e)(ii)(C)). From this basis, Alternative 4 is disproportionately costly to Alternative 3 because it costs more without additional benefit.

7 PREFERRED ALTERNATIVE

The preferred alternative was selected by Ecology considering the disproportionate cost analysis and focusing on permanence. Because Alternative 3 has higher benefits than the other alternatives and because it ranks high for permanence, it was selected.

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TABLES

Table J-1
Summary of Environmental Technologies and Alternatives for Sediments Located Near Outfall 002A[1]

Remedial Technology[2]	SMS Technology Ranking for Long-Term Effectiveness[3]	Base Case	Alternative 1	Alternative 2	Alternative 3	Alternative 4
		Source Control[1,5]	Source Control, Monitored Natural Recovery	Source Control, Enhanced Natural Recovery	Source Control, Dredging with On-site Beneficial Reuse and Landfill Disposal	Source Control, Dredging with Off-site Disposal
Source control with other cleanup technologies	1	X	X	X	X	X
Beneficial reuse of the sediments	2				X	
Immobilization, destruction, or detoxification	3					
Dredging and landfill disposal	4				X	X
Dredging and in-water disposal (e.g., CAD/CDF)	5					
Engineered capping	6					
Dredging and open-water disposal (as approved)	7					
Enhanced natural recovery	8			X		
Monitored natural recovery	9	X	X	X		
Institutional controls and monitoring	10	X	X	X	X	
Estimated Cost of Remedial Alternative (millions)[2]		0.725	0.76	1.2	1.8	2.4
Incremental Costs Relative to Previous Alternative (percent)[4]		--	6%	62%	43%	36%

Table J-1
Summary of Environmental Technologies and Alternatives for Sediments Located Near Outfall 002A[1]

Notes:

1 = Bioassay performance standards were exceeded in surface sediments (0 to 10 cm) from one sample (SS-09) located adjacent to Outfall 002A (see Figure J-1). NPDES monitoring of recent (0- to 2-cm) and deeper (0- to 10-cm) sediments has shown that sediments are recovering naturally and that source control measures already implemented have been effective. This area is subject to ongoing monitoring under the NPDES program. Sediments at the outfall do not exceed the SMS "cluster" rule, as defined in WAC 173-204-510(2)(b).

2 = Refer to Attachment 1 for the description and estimated costs for each alternative.

3 = Remedial technologies are numbered in order of decreasing ranking for long-term effectiveness, as defined under SMS regulations in WAC 173-204-570(4)(b).

4 = The incremental costs of each alternative relative to the preceding alternative is expressed as a percentage of the costs of the preceding alternative. Costs of Alternative 1 are compared to those of the Base Case.

5 = Completed source control actions include cleaning of facility drain lines, removal of accumulated stormwater solids, and optimization of the water treatment systems.

CAD = confined aquatic disposal

CDF = confined disposal facility

cm = centimeter

NPDES = National Pollution Discharge Elimination System

SMS = Sediment Management Standards

WAC = Washington Administrative Code

Table J-2

Summary of Environmental Benefits of Evaluated Remedial Alternatives[1,2, 4]

Remedial Alternative[1]	Protectiveness (30%)[2]	Permanence (25%)[2]	Long-Term Effectiveness (20%)[2]	Short-Term Risk Management (15%)[2]	Technical and Administrative Implementability (10%) [2]	Environmental Benefit Score[2,3]	Incremental Benefits Over Preceding Alternative (%)	Probable Cost[4]	Incremental Costs Over Preceding Alternative (%)	Ratio of Incremental Benefits / Costs
	Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.	*The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.*	*Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The hierarchy defined in SMS regulations was used to evaluate relative long-term effectiveness rankings (see Table J-1).*	*The risk to human health and the environment associated with the alternative during construction and implementation and the effectiveness of measures that will be taken to manage such risks.*	*Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.*					
Base Case	Source control actions have already been implemented. Under the base case, ongoing natural attenuation processes, which have been shown to be effective at reducing contaminant concentrations in sediments, are expected to continue. Ongoing NPDES monitoring associated with the outfall mixing zone will provide confirmation of the performance of natural recovery processes. The Base Case scores relatively low compared to the other alternatives because two exceedances of cleanup standards remain for approximately 10 years.	Ongoing natural recovery processes have been shown to be effective, confirming both the recovery potential for the river sediments and the success of completed source control efforts. Benthic monitoring using sediment bioassays is expected as part of ongoing NPDES requirements, and sediments are expected to achieve SMS performance standards at location SS-09 within a 10-year restoration time frame through clean sediment deposition and mixing. The Base Case scores relatively low compared to the other alternatives because subsurface contamination remains on site.	The Base Case includes source control and monitoring. Source control actions have already been implemented, and monitoring has shown that these measures have been effective. This alternative relies on ongoing natural attenuation processes, which have been shown to reduce concentrations of organic constituents in sediments. Ongoing NPDES monitoring associated with the established mixing zone would provide confirmation of the performance of natural recovery processes. The Base Case scores moderately because the alternative relies primarily on source control but also relies on natural recovery processes.	The Base Case does not disturb site sediments or require additional construction activities. Accordingly, this alternative poses the least short-term risks; therefore, the alternative scores high compared to the other alternatives.	The Base Case is readily implementable and does not require additional permits. Monitoring will be implemented under the NPDES program. The alternative scores high compared to the other alternatives.	5.6	NA	$0.72M	NA	NA
	4	4	5	9	10					

Table J-2

Summary of Environmental Benefits of Evaluated Remedial Alternatives[1,2,4]

Remedial Alternative[1]	Protectiveness (30%)[2]	Permanence (25%)[2]	Long-Term Effectiveness (20%)[2]	Short-Term Risk Management (15%)[2]	Technical and Administrative Implementability (10%)[2]	Environmental Benefit Score[2,3]	Incremental Benefits Over Preceding Alternative (%)	Probable Cost[4]	Incremental Costs Over Preceding Alternative (%)	Ratio of Incremental Benefits / Costs
	Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.	*The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.*	*Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The hierarchy defined in SMS regulations was used to evaluate relative long-term effectiveness rankings (see Table J-1).*	*The risk to human health and the environment associated with the alternative during construction and implementation and the effectiveness of measures that will be taken to manage such risks.*	*Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.*					
Alternative 1	As with the Base Case, Alternative 1 includes the benefits of completed source control actions. These actions have been shown to be effective, and sediments at the outfall are recovering naturally, as shown in the results of sediment testing. For this alternative, the monitoring under the NPDES program will be coordinated with the MTCA remedy implementation and monitoring program to ensure that full recovery is achieved within a 10-year restoration time frame. Alternative 1 scores relatively low compared to the other alternatives because two exceedances of cleanup standards remain for approximately 10 years.	As with the Base Case, natural recovery processes have been shown to be effective, confirming both the recovery potential for the river sediments and the success of completed source control efforts. Benthic monitoring activities will be coordinated between the MTCA and NPDES program requirements, and sediments are expected to achieve SMS performance standards at location SS-09 within a 10-year restoration time frame through clean sediment deposition and mixing. Alternative 1 scores relatively low compared to the other alternatives because subsurface contamination remains on site.	As with the Base Case, source control actions have been implemented and have been shown to be effective. Alternative 1 includes additional coordination between the MTCA cleanup program and the NPDES program. Ongoing natural attenuation processes will be monitored to ensure that full recovery is achieved within a 10-year restoration time frame. Coordination of monitoring efforts would be enhanced over the Base Case. Alternative 1 scores moderately because the alternative relies primarily on source control but also relies on natural recovery processes.	As with the Base Case, Alternative 1 does not disturb site sediments or require additional construction activities. Accordingly this alternative poses the least short-term risks; therefore, the alternative scores high for this criterion compared to the other alternatives.	Alternative 1 is readily implementable and does not require additional permits. Monitoring under the NPDES program will be coordinated with the MTCA cleanup action. Therefore, the alternative scores high compared to the other alternatives.	6.1	10%	$0.76M	6%	1.8
	5	5	5	9	10					

Table J-2

Summary of Environmental Benefits of Evaluated Remedial Alternatives[1,2, 4]

Remedial Alternative[1]	Protectiveness (30%)[2]	Permanence (25%)[2]	Long-Term Effectiveness (20%)[2]	Short-Term Risk Management (15%)[2]	Technical and Administrative Implementability (10%) [2]	Environmental Benefit Score[2,3]	Incremental Benefits Over Preceding Alternative (%)	Probable Cost[4]	Incremental Costs Over Preceding Alternative (%)	Ratio of Incremental Benefits / Costs
	Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.	*The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.*	*Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The hierarchy defined in SMS regulations was used to evaluate relative long-term effectiveness rankings (see Table J-1).*	*The risk to human health and the environment associated with the alternative during construction and implementation and the effectiveness of measures that will be taken to manage such risks.*	*Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.*					
Alternative 2	This alternative increases protectiveness over Alternative 1 by actively enhancing rates of sediment natural recovery with placement of clean river sand within the area shown on Figure J-1. The estimated restoration time frame under this alternative is approximately 3 years. Alternative 2 scores moderately compared to the other alternatives because of some reliance on natural recovery processes.	Source control efforts have been implemented and have been shown to be successful. Under Alternative 2, sediment natural recovery processes will be enhanced through the placement of clean river sand. The restoration time frame for this alternative is estimated to be approximately 3 years. Alternative 2 scores moderately compared to the other alternatives because subsurface contamination remains on site under placed river sand.	As with Alternative 1, source control actions have been implemented, and sediments are subject to ongoing natural recovery. Coordinated monitoring will be provided under the MTCA and NPDES programs to ensure full recovery is achieved. This alternative further enhances remedy long-term effectiveness by placing clean river sand within the area shown on Figure J-1. Alternative 2 scores moderately high because the alternative relies on source control and enhanced natural recovery processes.	This alternative has slightly elevated risks associated with the hauling and placement of river sand, including potential water quality impacts associated with sand placement. Risks would be managed through the implementation of best management practices and monitoring. The project is of short duration in comparison to other more intensive remediation approaches and, therefore, scores high compared to the other alternatives.	Alternative 2 requires development of project permits to place river sand. This increases the complexity of remedy implementation over Alternative 1. However, experienced contractors are locally available, and the work is of short duration, resulting in a better implementability ranking than Alternatives 3 or 4.	6.8	11%	$1.2M	62%	0.2
	6	6	7	8	9					

Table J-2

Summary of Environmental Benefits of Evaluated Remedial Alternatives[1,2,4]

Remedial Alternative[1]	Protectiveness (30%)[2]	Permanence (25%)[2]	Long-Term Effectiveness (20%)[2]	Short-Term Risk Management (15%)[2]	Technical and Administrative Implementability (10%)[2]	Environmental Benefit Score[2,3]	Incremental Benefits Over Preceding Alternative (%)	Probable Cost[4]	Incremental Costs Over Preceding Alternative (%)	Ratio of Incremental Benefits / Costs
	Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.	*The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.*	*Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The hierarchy defined in SMS regulations was used to evaluate relative long-term effectiveness rankings (see Table J-1).*	*The risk to human health and the environment associated with the alternative during construction and implementation and the effectiveness of measures that will be taken to manage such risks.*	*Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.*					
Alternative 3	This alternative utilizes dredging of the sediments located within the area shown on Figure J-1. Sediments would be removed from the river, transferred to the upland property, and beneficially reused as part of the remediation of an existing upland landfill and fill deposit located in the southwest corner of the site. Clean river sand would be backfilled within the dredging footprint to maintain existing bathymetric contours and manage dredging residuals. This alternative does not require further sediment monitoring following implementation to document effectiveness. The estimated restoration time frame under this alternative is approximately 3 years. Institutional controls and monitoring are provided for the landfill as part of the upland cleanup action. Alternative 3 scores high compared to the other alternatives because dredging would fully remove contaminated sediment. However, sediments would require time to recover from disturbance and dredging residuals.	Alternative 3 includes removal of sediments by dredging, followed by backfill of the dredging area with clean river sand. The benthic community is expected to recolonize the dredging footprint and achieve a restoration time frame within 3 years of construction. Dredged sediments will be beneficially reused as part of the upland cleanup action to remediate a former landfill and fill deposit in the southwest corner of the upland property. Beneficial reuse and upland disposal results in a higher degree of remedy permanence over Alternatives 1 and 2. Long-term sediment monitoring is not required under this alternative. Alternative 3 scores high compared to the other alternatives because dredging would fully remove contaminated sediment from the aquatic environment; however, contaminated sediment would be placed in the upland site.	As with Alternatives 1 and 2, source control actions have been implemented, and sediments are subject to ongoing natural recovery. However, this alternative additionally includes remedial dredging within the area shown on Figure J-1. The removed sediments will be transferred to the upland property and beneficially reused as part of the cleanup of an existing landfill and fill deposit. Landfill capping and monitoring will be provided as part of the upland MTCA cleanup action. The sediment dredging area will be backfilled with clean river sand to restore bathymetric contours and manage dredging residuals. Alternative 3 scores high because the alternative relies on source control and removal with beneficial reuse.	This alternative has slightly elevated risks associated with the dredging and rehandling of impacted sediment and with the hauling and placement of river sand. These risks include potential water quality impacts associated with dredging, material rehandling, and clean sand placement. Risks would be managed through the implementation of best management practices and monitoring. The project requires a longer period to implement than Alternatives 1 and 2 and, therefore, scores relatively low.	Alternative 3 requires development of project permits to address dredging, upland beneficial reuse, and backfill of the dredging area with clean river sand. This increases the complexity of remedy implementation over Alternatives 1 and 2. Experienced contractors are locally available. Construction activities are expected to require 2 to 3 weeks to implement (excluding upland landfill capping activities). Coordination with off-site landfill operators and off-loading locations is not required under this alternative, resulting in an implementability ranking intermediate between Alternatives 2 and 4.	8.4	23%	$1.8M	43%	0.5
	9	8	9	7	8					

Table J-2

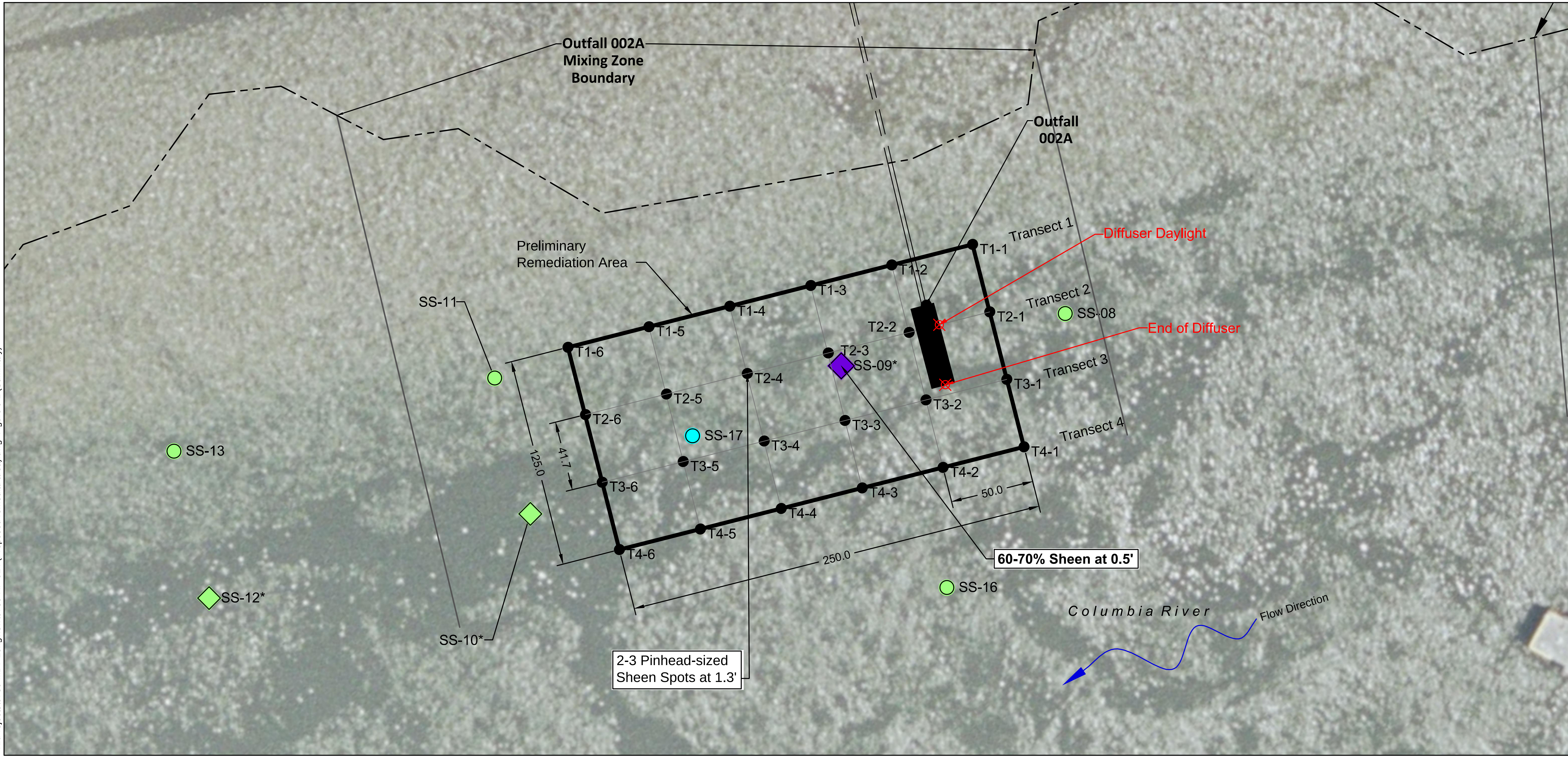
Summary of Environmental Benefits of Evaluated Remedial Alternatives[1,2,4]

Remedial Alternative[1]	Protectiveness (30%)[2]	Permanence (25%)[2]	Long-Term Effectiveness (20%)[2]	Short-Term Risk Management (15%)[2]	Technical and Administrative Implementability (10%)[2]	Environmental Benefit Score[2,3]	Incremental Benefits Over Preceding Alternative (%)	Probable Cost[4]	Incremental Costs Over Preceding Alternative (%)	Ratio of Incremental Benefits / Costs
	Overall protectiveness of human health and the environment, including the degree to which existing risks are reduced, time required to reduce risk at the facility and attain cleanup standards, on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality.	*The degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying the hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment process, and the characteristics and quantity of treatment residuals generated.*	*Long-term effectiveness includes the degree of certainty that the alternative will be successful, the reliability of the alternative during the period of time hazardous substances are expected to remain on-site at concentrations that exceed cleanup levels, the magnitude of residual risk with the alternative in place, and the effectiveness of controls required to manage treatment residues or remaining wastes. The hierarchy defined in SMS regulations was used to evaluate relative long-term effectiveness rankings (see Table J-1).*	*The risk to human health and the environment associated with the alternative during construction and implementation and the effectiveness of measures that will be taken to manage such risks.*	*Ability to be implemented including consideration of whether the alternative is technically possible, availability of necessary off-site facilities, services and materials, administrative and regulatory requirements, scheduling, size, complexity, monitoring requirements, access for construction operations and monitoring, and integration with existing facility operations and other current or potential remedial actions.*					
Alternative 4	This alternative is similar to Alternative 3, except that the sediments will not be beneficially reused as part of the upland landfill cleanup. Instead, the sediments will be managed by off-site disposal in a commercial landfill facility. Institutional controls and monitoring are provided for the landfill by the commercial landfill operator. The estimated restoration time frame under this alternative is approximately 3 years. Alternative 4 scores high compared to the other alternatives because dredging would fully remove contaminated sediment. However, sediments would require time to recover from disturbance and dredging residuals.	Alternative 4 uses removal of sediments by dredging, followed by backfill of the dredging area with clean river sand. The benthic community is expected to recolonize the dredging footprint and achieve a restoration time frame within 3 years of construction. Dredged sediments will be managed by off-site disposal at a commercial landfill facility. Long-term sediment monitoring is not required under this alternative. Alternative 4 scores high compared to the other alternatives because dredging would fully remove contaminated sediment from the aquatic environment.	As with Alternatives 1, 2, and 3, source control actions have been implemented, and sediments are subject to ongoing natural recovery. This alternative additionally includes remedial dredging within the area shown on Figure J-1. The removed sediments will be transported for disposal at an off-site commercial landfill facility. Landfill capping and monitoring will be provided by the commercial landfill operator. The sediment dredging area will be backfilled with clean river sand to restore bathymetric contours and manage dredging residuals. Alternative 4 scores high because the alternative relies on source control and removal to an upland landfill.	This alternative elevates risks associated with the dredging and long-range transport and rehandling of impacted sediment and with the hauling and placement of river sand. These risks include potential water quality impacts associated with dredging, material rehandling, material transportation, and clean sand placement. Risks would be managed through the implementation of best management practices and monitoring. The project includes much longer haul distances than Alternative 3 and, therefore, scores the lowest of the alternatives.	This alternative requires development of project permits for dredging and river sand placement. Additional coordination is required with off-site offloading and transport/disposal facilities. However, experienced contractors and commercial landfill operators are available within the region. Alternative 4 scores lower than the other remedial alternatives for this criterion.	8.2	-2%	$2.4M	36%	0.0
	9	9	9	5	7					

Notes:

1 = Consideration of public concerns is not addressed in this table because the public has not yet had an opportunity to provide comments.
2 = Each of the DCA criteria listed were weighted, so the overall DCA score would be influenced most by criteria directly relating to protectiveness and effectiveness.
A score of 10 represents an alternative that satisfies all of the criteria to the highest degree.
3 = Although allowed, costs were not considered in the environmental benefit scoring.
4 = Alternative descriptions and probable costs (including applicable project contingencies) are provided in Attachment 1.
DCA = disproportionate cost analysis
M = million
MTCA = Model Toxics Control Act
NA = not applicable
NPDES = National Pollution Discharge Elimination System
SMS = Sediment Management Standards

FIGURES



SOURCE: Aerial image from Aerometric dated June 2013.

NOTES:

1. No sheen was observed unless otherwise noted.
2. Sediment Management Standards (SMS) Final Rule [WAC 173-204] Ecology, February 22, 2013

LEGEND:

- Approximate Ordinary High Water Line
- Property Line
- Approximate Outfall and Diffuser
- Preliminary Remediation Area
- ●TI-1 Push Core Location

Sample Name (RI/FS) — SS-10* ; Sample Name (Historical) — SG-04 ; Station Also Analyzed at an Additional Depth Interval ; Chemistry Only ; Historical Chemistry ; Bioassay Results

Sediment Quality

Historical Chemistry	RI/FS and NPDES Chemistry	Bioassay Results (RI/FS)	
△	○	◇	Meets Sediment Cleanup Objective [2]
△	○	◇	Exceeds Sediment Cleanup Objective [2]
▲	●	◆	Exceeds Cleanup Screening Level [2]

K:\Projects\0730-MBT-Longview\0730-RP-024 (Proposed remedial area).dwg Figure J-1 (Summary)

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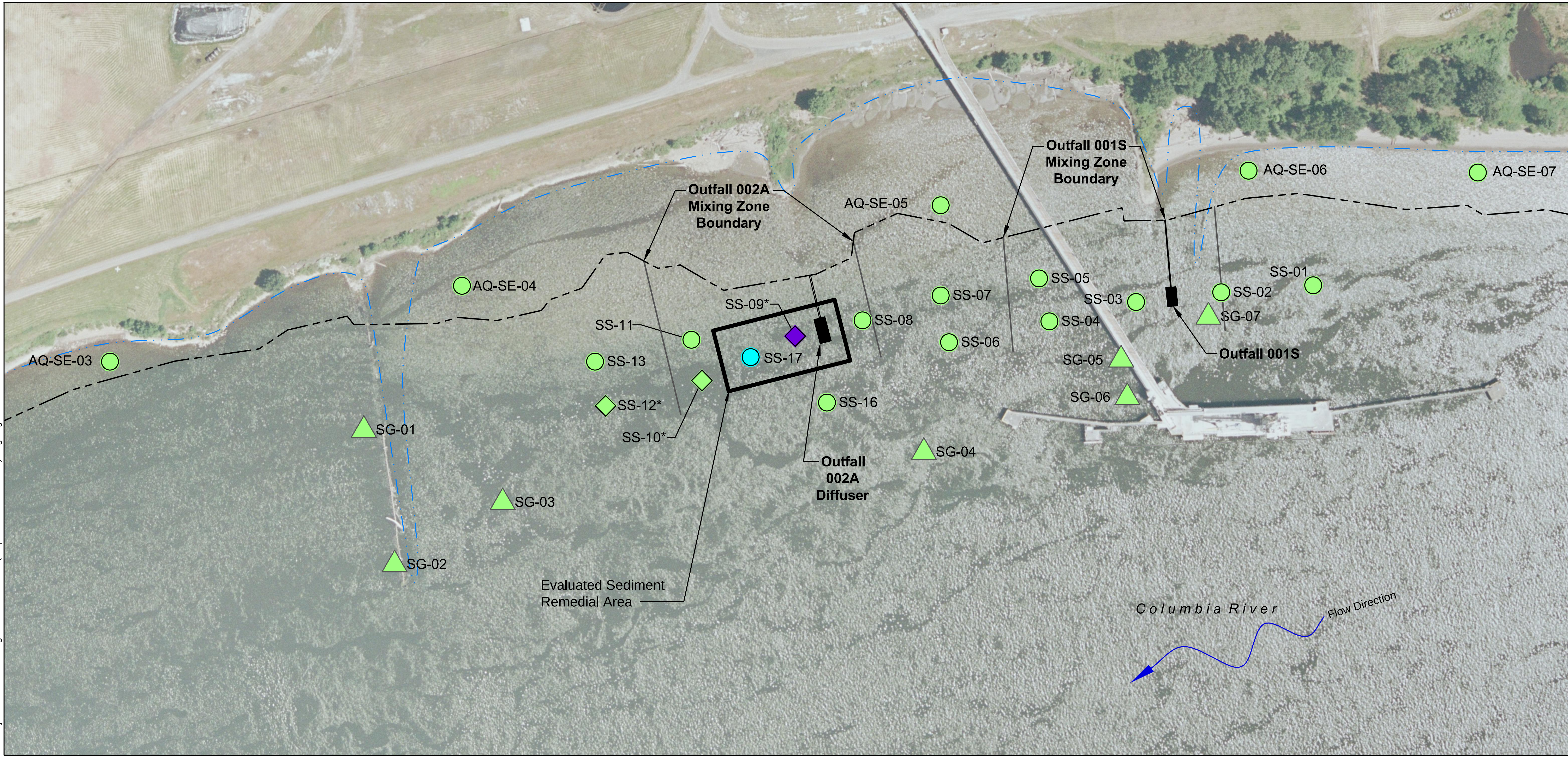
ANCHOR QEA

Figure J-1
Diver Survey Summary
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview



SOURCE: Aerial image from Aerometric dated June 2013.

NOTES:

1. Results shown are the maximum result from both the NPDES and RI/FS samples at the 0-10 cm interval.
2. Sediment Management Standards (SMS) Final Rule [WAC 173-204] Ecology, February 22, 2013.
3. Sediments within the vicinity of Outfall 002A do not exceed the SMS cluster rule criteria as defined in WAC 173-204-510(2)(b).
4. Results of sampling demonstrate that source control measures have been effective and sediments are naturally recovering.

LEGEND:

- Approximate Ordinary High Water Line
- Property Line
- Approximate Outfall and Diffuser
- Preliminary Remediation Area

Sample Name (RI/FS) — SS-10*
Sample Name (Historical) — SG-04
Station Also Analyzed at an Additional Depth Interval
Chemistry Only
Historical Chemistry
Bioassay Results

Sediment Quality

Historical Chemistry	RI/FS and NPDES Chemistry	Bioassay Results (RI/FS)	
△	○	◇	Meets Sediment Cleanup Objective [2]
△	○	◇	Exceeds Sediment Cleanup Objective [2]
▲	●	◆	Exceeds Cleanup Screening Level [2]

0 200
Scale in Feet

K:\Projects\0730-MBT-Longview\0730-RP-023 (Proposed remedial area).dwg Figure J-2
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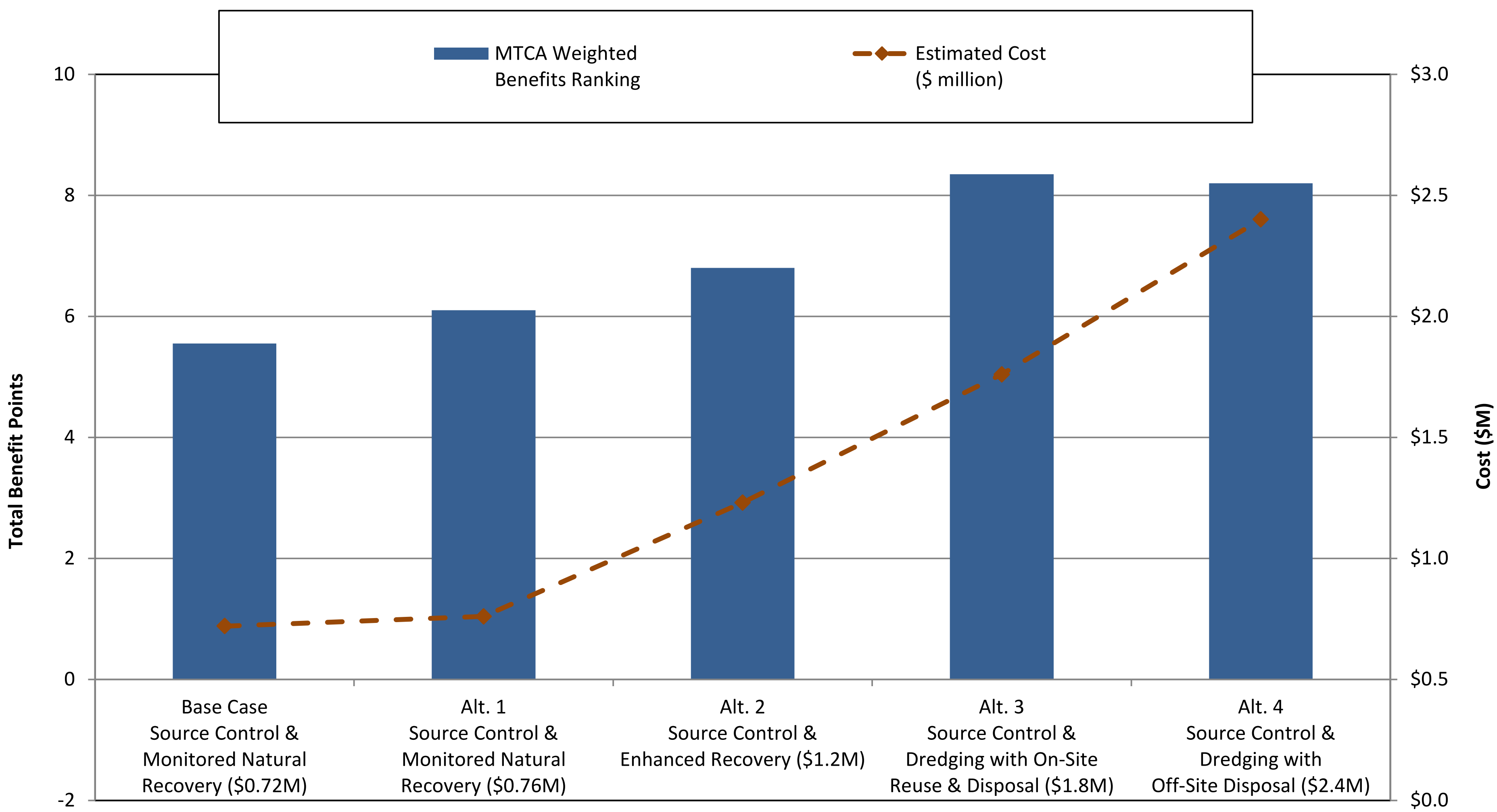
Figure J-2
Evaluated Sediment Remediation Area
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview

ANCHOR QEA



ANCHOR QEA

Figure J-3
Results of the Disproportionate Cost Analysis
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview

ATTACHMENT 1
DESCRIPTIONS AND COST ESTIMATES FOR EVALUATED ALTERNATIVES

Preliminary Sediment Remediation Cost Opinion
Base Case – Source Control and Monitoring

Item	Description	Quantity	Unit	Unit Cost	Amount
	Completed Actions				
1	Completed Source Control Actions	1	LS	$723,000	$723,000
	Total Cost				**$723,000**

Assumptions:
1 = Costs for source control include costs for cleaning out facility drain lines and removing accumulated solids from the lines and retention pond. Additional costs incurred by Millennium Bulk Terminals – Longview, LLC, to optimize the filter plant operations are not included in this cost figure.

2 = Sediment monitoring is expected to continue under the National Pollution Discharge Elimination System program.

Notes:

LS = lump sum

Preliminary Sediment Remediation Cost Opinion
Alternative 1 – Source Control and Monitored Natural Recovery

Item	Description	Quantity	Unit	Unit Cost	Amount
	Completed Actions				
1	Completed Source Control Actions	1	LS	$723,000	$723,000
	Incremental Monitoring and Coordination				
2	Sampling Event Coordination and Reporting	2	EA	$12,500	$25,000
	Subtotal Additional Actions				$25,000
	Contingency	1	LS	50%	$13,000
	Subtotal Completed Actions				$723,000
	Total Cost				**$761,000**

Assumptions:

1 = Costs for source control include costs for cleaning out facility drain lines and removing accumulated solids from the lines and retention pond. Additional costs incurred by Millennium Bulk Terminals – Longview, LLC, to optimize the filter plant operations are not included in this cost figure.

2 = Sediment monitoring under the National Pollution Discharge Elimination System program to be coordinated with the Model Toxics Control Act cleanup action.

3 = Sediment testing assumed to be performed twice (approximately years 5 and 10, following cleanup decision).

Notes:

EA = each

LS = lump sum

Preliminary Sediment Remediation Cost Opinion
Alternative 2 – Source Control and Enhanced Natural Recovery

Item	Description	Quantity	Unit	Unit Cost	Amount
	Completed Actions				
1	Completed Source Control Actions	1	LS	$723,000	$723,000
	Permitting				
2	Project Permitting	1	LS	$80,000	$80,000
	Design				
3	Pre-design Work and Design Reports and PS&E	1	LS	$66,500	$66,500
	Mobilization/Demobilization				
4	Derrick Barge (place)	1	EA	$40,000	$40,000
5	Material Barge (3,500 ton)	1	EA	$4,500	$4,500
	Place Sand – ENR Material				
6	Sand Purchase and Deliver	1,620	TN	$18.00	$29,160
7	Sand Placement	1,200	CY	$15.00	$18,000
	placement (6 inches)	*600*	CY		
	over-placement (6 inches)	*600*	CY		
	Construction Support				
8	Placement Verification, CM, and Reporting	1	LS	$75,000	$75,000
	Incremental Monitoring and Coordination				
9	Sampling Event Coordination and Reporting	2	EA	$12,500	$25,000
	Subtotal Additional Actions				$338,000
	Contingency	1	LS	50%	$169,000
	Subtotal Completed Actions				$723,000
	Total Cost				**$1,230,000**

Assumptions:

1= Costs for source control include costs for cleaning out facility drain lines and removing accumulated solids from the lines and retention pond. Additional costs incurred by Millennium Bulk Terminals – Longview, LLC, to optimize the filter plant operations are not included in this cost figure.

2 = Sand placement area dimensions as shown on Figure J-1.

3 = 0.5-foot sand placement thickness and 0.5-foot over-placement allowance.

4= 1.35 ton/cubic yard for sand fill, dry (100 pounds/cubic foot).

5 = Sand assumed to represent river dredge material obtained from a Longview-area facility or project.

6 = Sediment testing assumed to be performed twice (approximately years 5 and 10, following construction).

Notes:

CM = construction management

CY = cubic yard

EA = each

ENR = Enhanced Natural Recovery

LS = lump sum

PS&E = plans, specifications, and estimates

TN = ton

Preliminary Sediment Remediation Cost Opinion
Alternative 3 – Source Control, Dredging, and On-site Reuse and Disposal

Item	Description	Quantity	Unit	Unit Cost	Amount
	Completed Actions				
1	Completed Source Control Actions	1	LS	$723,000	$723,000
	Permitting				
2	Project Permitting	1	LS	$80,000	$80,000
	Design				
3	Pre-design Work and Design Reports and PS&E	1	LS	$95,000	$95,000
	Mobilization/Demobilization				
4	Derrick Barge (dredge/place)	1	EA	$40,000	$40,000
5	Material Barge (sediment) (3,500 ton)	2	EA	$4,500	$9,000
6	Material Barge (sand) (3,500 ton)	1	EA	$4,500	$4,500
	Dredge and Disposal				
7	Sediment Dredging	3,600	CY	$24.00	$86,400
	dredge	*2,400*	CY		
	overdredge	*1,200*	CY		
8	Sediment Offloading	3,600	CY	$10.00	$36,000
9	Sediment Containment Embankment	1,400	CY	$12.00	$16,800
10	Water Management	1	EA	$10,000	$10,000
	Grade Restoration				
11	Sand Purchase and Delivery	5,670	TN	$18.00	$102,060
12	Sand Placement	4,200	CY	$15.00	$63,000
	placement	*3,600*	CY		
	over-placement	*600*	CY		
	Construction Support				
13	Verification, CM, and Reporting	1	LS	$150,000	$150,000
	Subtotal Additional Actions				$692,760
	Contingency	1	LS	50%	$346,000
	Subtotal Completed Actions				$723,000
	Total Cost				**$1,762,000**

Preliminary Sediment Remediation Cost Opinion
Alternative 3 – Source Control, Dredging, and On-site Reuse and Disposal

Assumptions:

1 = Costs for source control include costs for cleaning out facility drain lines and removing accumulated solids from the lines and retention pond. Additional costs incurred by Millennium Bulk Terminals – Longview, LLC, to optimize the filter plant operations are not included in this cost figure.

2 = Dredge and sand placement area dimensions as shown on Figure J-1.

3 = 2-foot dredge depth and 1-foot overdredge allowance (potential refinement during design/permitting).

4 = Sand placement thickness includes a 0.5-foot over-placement allowance.

5 = 1.35 ton/cubic yard for sand backfill, dry (100 pounds/cubic foot).

6 = Sand assumed to represent river dredge material obtained from a Longview-area facility or project.

7 = Sediment to be reused beneficially during remediation of Landfill #2.

8 = Water management assumed to include use of existing on-site treatment system.

Notes:

CM = construction management

CY = cubic yard

EA = each

LS = lump sum

PS&E = plans, specifications, and estimates

TN = ton

Preliminary Sediment Remediation Cost Opinion
Alternative 4 – Source Control, Dredging, and Off-site Commercial Landfill Disposal

Item	Description	Quantity	Unit	Unit Cost	Amount
	Completed Actions				
1	Completed Source Control Actions	1	LS	$723,000	$723,000
	Permitting				
2	Project Permitting	1	LS	$80,000	$80,000
	Design				
3	Pre-design Work and Design Reports and PS&E	1	LS	$95,000	$95,000
	Mobilization/Demobilization				
4	Derrick Barge (dredge/place)	1	EA	$40,000	$40,000
5	Material Barge (sediment) (3,500 ton)	2	EA	$4,500	$9,000
6	Material Barge (sand) (3,500 ton)	1	EA	$4,500	$4,500
	Dredge and Disposal				
7	Sediment Dredging	3,600	CY	$24.00	$86,400
	dredge	*2,400*	CY		
	overdredge	*1,200*	CY		
8	Water Management	1	EA	$10,000	$10,000
9	Sediment Offloading	3,600	CY	$5.00	$18,000
10	Sediment Transport, Dewatering, and Disposal	5,400	TN	$85.00	$459,000
	Grade Restoration				
11	Sand Purchase and Delivery	5,670	TN	$18.00	$102,060
12	Sand Placement	4,200	CY	$15.00	$63,000
	placement	*3,600*	CY		
	over-placement	*600*	CY		
	Construction Support				
13	Verification, CM, and Reporting	1	LS	$150,000	$150,000
	Subtotal Additional Actions				$1,116,960
	Contingency	1	LS	50%	$558,000
	Subtotal Completed Actions				$723,000
	Total Cost				**$2,398,000**

Preliminary Sediment Remediation Cost Opinion

Alternative 4 – Source Control, Dredging, and Off-site Commercial Landfill Disposal

Assumptions:

1 = Costs for source control include costs for cleaning out facility drain lines and removing accumulated solids from the lines and retention pond. Additional costs incurred by Millennium Bulk Terminals – Longview, LLC, to optimize the filter plant operations are not included in this cost figure.

2 = Dredge and sand placement area dimensions as shown on Figure J-1.

3 = 2-foot dredge depth and 1-foot overdredge allowance (potential refinement during design/permitting).

4 = Sand placement thickness includes a 0.5-foot over-placement allowance

5 = 1.5 ton/cubic yard for dredged sediment, wet (110 pounds/cubic foot).

6 = 1.35 ton/cubic yard for sand backfill, dry (100 pounds/cubic foot).

7 = Sand assumed to represent river dredge material obtained from a Longview-area facility or project.

8 = Sediment disposal assumed to include barge transportation and offloading, dewatering, transporting, and disposing using commercially available off-site landfill facilities.

Notes:

CM = construction management

CY = cubic yard

EA = each

LS = lump sum

PS&E = plans, specifications, and estimates

TN = ton

APPENDIX K
EVALUATIONS IN SUPPORT OF REMEDIAL TECHNOLOGY SCREENING

TABLE OF CONTENTS

List of Tables

List of Attachments

LIST OF ACRONYMS AND ABBREVIATIONS

FS	Feasibility Study
HELP	Hydrologic Evaluation of Landfill Performance
L	liter
mg	milligram
PRB	permeable reactive barrier
RI	Remedial Investigation
WAC	Washington Administrative Code

1 INTRODUCTION

This appendix to the Remedial Investigation/Feasibility Study (RI/FS) report for the former Reynolds Metals Reduction Plant documents supplemental engineering evaluations and literature reviews in support of the Section 9 remedial technology screening. It specifically focuses on the evaluation of amendment materials that could be included in the design of a permeable reactive barrier (PRB) and the infiltration modeling performed to evaluate the benefits of a range of physical barrier technologies. The technology screening summary presented in Section 9.5.4 was also based on supplemental evaluations; however, these assessments were performed in parallel to the hydrogeologic modeling and are discussed in Appendix H.

2 PERMEABLE REACTIVE BARRIER AMENDMENTS

In situ fluoride remediation with mineral amendments emplaced in a PRB or amended soil backfill is a component of several remedial alternatives considered at the site. This appendix provides technical background to support selection of mineral amendments for in situ fluoride treatment, including the following: 1) a summary of the relevant scientific literature; 2) further examination of select studies relevant to mineral amendment selection for the site; and 3) conceptual design considerations.

2.1 Literature Review

Principal literature review findings are as follows:

- Precipitation of the calcium fluoride (fluorite) is induced by adding soluble calcium (typically calcium chloride or calcium hydroxide). This process effectively removes high concentrations of fluoride from water. Addition of soluble calcium, followed by settling (or filtration), is commonly used to treat wastewaters with elevated fluoride concentrations. Concentrations can be reduced from several thousand milligrams per liter (mg/L) to less than 10 mg/L relatively rapidly. Optimal removal occurs under neutral to alkaline pH conditions. Removal efficiency can be limited by high concentrations of competing anions (e.g., several hundred mg/L of sulfate or phosphate). This amendment will be retained for further consideration.
- Uptake by apatite (rock phosphate, bone char, or bonemeal) can remove fluoride from water to final concentrations less than 1 mg/L; however, the low amendment capacity limits the usefulness of this amendment to moderately low initial fluoride concentrations. Optimal removal occurs under neutral pH conditions. Apatite is not commonly used for drinking water treatment, as it can impart an undesirable taste.
- Adsorption onto alumina and other metal oxides and hydroxides can effectively remove elevated fluoride concentrations to concentrations less than 1 mg/L. However, these treatments are only effective under acidic conditions, with optimal removal achieved in the pH range of 3 to 5 on alumina. This process is useful for wastewater treatment, where pH can be adjusted to optimize removal.
- Clay minerals, zeolites, and soils can also remove low levels of fluoride by adsorption. Numerous studies report on the potential of such amendments for groundwater and drinking water treatment, but there is limited documentation of their effectiveness.

Summaries of relevant studies are provided in Table K-1.

2.2 Permeable Reactive Barrier Amendment Selection

Based on the review of the scientific literature and site conditions, precipitation of fluorite by addition of sparingly soluble source of calcium to induce fluorite precipitation and uptake by apatite are the preferred methods for in situ fluoride removal. Metal oxides, such as alumina, are not considered suitable for in situ treatment at the site due to the requirement of acidic pH conditions.

2.2.1 Fluorite Precipitation

Fluorite precipitation is commonly used to remove excess fluoride from wastewater. This removal process may be accomplished by addition of soluble calcium. Calcium hydroxide, calcium oxide (quicklime), or calcium chloride are commonly used in treatment of wastewater streams with elevated fluoride concentrations. The theoretical removal is 1.0 pound fluoride ion removed per 1.06 pounds of calcium added, with final concentration less than 10 mg/L. The greatest removal efficiency is achieved when competing ions (e.g., sulfate) are not present, and the pH is within an optimal range. There are two pH optima for the process, occurring at pH 8 and above pH 12. Fluorite precipitation is relatively rapid; the water is typically reacted with the calcium mineral for 30 minutes to several hours. This initial reaction is then followed by either settling or filtration to remove fine particles of fluorite. For further information on the application of this treatment to fluoride in wastewater, see the review by Paulson (1977).

Use of calcite (i.e., calcium carbonate) as a source of calcium has several advantages for in situ remediation, as compared to the compounds commonly used in wastewater treatment (calcium oxide, calcium hydroxide, or calcium chloride). Calcite will increase the pH of treated groundwater but not to the highly alkaline conditions caused by calcium hydroxide treatment. Additionally, the readily soluble calcium salts would have a limited effective lifetime, whereas the more sparingly soluble calcite can provide treatment over a longer term. Finally, in the form of crushed limestone, calcite is widely available and is relatively low-cost material that can be easily incorporated into a PRB or mixed with soil backfill.

Calcite is, therefore, the preferred calcium mineral amendment to enhance fluorite precipitation.

The selection of calcite for in situ treatment of fluoride is also supported by the literature. Several studies have examined the application of calcite for removal of fluoride under dynamic flow conditions as opposed to the batch treatment typical of ex situ wastewater processes. For example, Reardon and Wang (2000) tested a laboratory-scale limestone (calcite rock) reactor, which effectively removed fluoride, reducing initial concentrations of 109 mg/L to 4 mg/L with a 2-hour residence time in the reactor and to 8 mg/L with a 35-minute residence time. Additionally, a series of laboratory-scale batch tests, as well as a field-scale pilot study, were conducted by Turner et al. (2006, 2008, 2010) in support of PRB design for treatment of spent potliner-impacted groundwater at a former smelter site in Australia. During this pilot test, a PRB with a narrow reactive layer (70 centimeters of crushed limestone) removed approximately 400 mg/L of fluoride, with a residence time of less than 1 day within the reactive layer. The PRB reduced the concentrations significantly, even with a low residence time, very high initial fluoride concentration, and non-optimal pH (Turner et al. 2006). Batch tests in support of the PRB development at the site determined that removal was inhibited by elevated phosphate (Turner et al. 2010). The authors also determined that effective removal of 1,000 mg/L of fluoride was possible at the site if the pH was maintained at 9.5 within the reactive layer (Turner et al. 2008).

The circum-neutral site groundwater adjacent to the potential PRB locations and the expected slight increase in alkalinity caused by calcite treatment suggest that pH in the PRB will be within the optimal range for fluorite precipitation. Crushed limestone is likely to be the primary PRB amendment selected for the site given the expected longevity within the PRB, demonstrated success in removal of fluoride from groundwater under similar site conditions, effective removal of elevated initial concentrations, and minimal water quality impacts.

2.2.2 Uptake by Apatite

An amendment with apatite (e.g., bone meal) will be considered a supplemental amendment if needed to achieve remedial goals. Adsorption onto apatite (as bone meal, rock phosphate, or fish bones) is well documented in the literature. Several studies suggest that this will be effective to remove residual concentrations within the PRB. For example, an initial fluoride concentration of 10 mg/L can be rapidly reduced (within 60 to 90 minutes) below 1 mg/L (Larsen and Pearce 2002; Bhargava and Killedar 1992). Bone meal price will be dependent on the commodities market. Bone meal is readily available as a granular material appropriate for emplacement within a PRB.

2.2.3 Adsorption by Clays and Oxides

Clays and metal oxides are not considered suitable as PRB amendments given the lack of characterization and requirement for acidic conditions, respectively. However, naturally occurring metal oxides and clays present in the aquifer provide an important control on fluoride concentrations in site groundwater and are likely to provide additional attenuation in the aquifer downgradient of the PRB.

2.3 Permeable Reactive Barrier Conceptual Design

The following is the expected process for in situ removal of fluoride from groundwater within a PRB:

- Groundwater with elevated fluoride and neutral pH enters the PRB.
- Limestone dissolves, releasing calcium and carbonate ions into the solution, increasing the pH to slightly alkaline values.
- With elevated calcium ion concentration and slightly alkaline pH, calcium fluoride (fluorite) becomes supersaturated and precipitates.
- Flow of groundwater within the PRB and downgradient aquifer materials allows time for removal of fine fluorite precipitates; this process is expected to bring fluoride concentrations to within a few mg/L of the remedial goal of 4 mg/L.
- Fluoride removal continues onto aquifer solids (and potentially the bone meal amendment within the PRB).

PRB design considerations are summarized in Table K-2.

3 PHYSICAL BARRIER PERFORMANCE EVALUATION

A quantitative analysis of the performance of three conceptual physical barriers was performed using the Hydrologic Evaluation of Landfill Performance (HELP) model. Developed by the U.S. Army Corps of Engineers' Waterways Experiment Station, the HELP computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through, and out of landfills (Schroeder et al. 1994). It accepts weather, soil, and design data and uses solution techniques to calculate items such as runoff volume (which is a function of material and slope), material permeability (*k*; saturated and unsaturated), and evaporation rate. Landfill systems with various types of designs may be modeled. The primary purpose of the model is to assist in the comparison of landfill design alternatives.

The HELP weather generator module was used to simulate the following two categories of rainfall events: 1) annual accumulations simulated over a theoretical 100-year period; and 2) during the 25-year, 24-hour design return period event. For both approaches, precipitation data from the nearest representative observation location (Longview, Washington) was input to the HELP model to develop a rainfall record. The standard simulation was then manually modified to include the 25-year, 24-hour precipitation event that is included in Washington Administrative Code (WAC) 173-303-665 as design criteria.[1] This type of event is predicted to occur on average once every 25 years; in any given year, the probability of occurrence is 4 percent. Details of the analyses, including input parameters and summary result graphics produced by the HELP model, are presented in Attachments 1 and 2.

The results of the modeling are discussed in Section 9.3 of the RI/FS report.

[1] The 25-year, 24-hour precipitation event was calculated from Precipitation Intensity Cells for Washington State, available from the Oregon Climate Service as Geographic Information System shapefiles (WSDOT 2013). Cells overlaying the project site were queried using ArcView.

4 REFERENCES

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TABLES

Table K-1
Fluoride Literature Review

Removal Process	Treatment Media	Treatment Target	Initial Fluoride Concentration	Efficiency/ Treatment	Treatment Capacity	Residence Time	pH	Comments	Citation
Fluorite Precipitation	Fluorite (CaF_2) precipitation by calcium minerals; quicklime (CaO), calcium hydroxide ($Ca(OH)_2$), or calcium chloride ($CaCl_2$) followed by alumina (Al_2O_3) adsorption for polishing	Fluoride containing waste water	<1,000	Removal to concentrations as low as 7.8 mg/L without polishing	106 lb calcium to precipitate 1 lb of fluoride ion	0.5 – 24 hours to precipitate fluorite or form fluoride complexes	8 – 9 optimal	Literature review of industrial treatment processes noted that the presence of competing anions may inhibit removal	Paulson 1977
	Precipitation of fluorite and adsorption by limestone (rock calcite ($CaCO_3$)); crushed quarry limestone	Synthetic SPL impacted groundwater	2.97 – 2,100	90 – 99% removal at neutral pH	NR	Equilibrium removal in 24 hours; continued to 140 hours	Neutral pH optimal	Laboratory batch study noted that removal was not significantly reduced by sulfate	Turner et al. 2005
	Precipitation of fluorite by crushed limestone (rock calcite)	SPL impacted groundwater	2,100	90 – 99% removal at neutral pH; approximately 50% at pH 11.5	NR	24-hour residence time within the reactive layer	Neutral pH optimal	Pilot PRB field study with carbon dioxide injection to offset alkalinity increase for optimal performance	Turner et al. 2006
	Precipitation of fluorite by calcite (1 mm calcite grains) with CO_2 injections to control pH	SPL impacted groundwater	100 – 2,300	>95% with CO_2, approximately 60% without	Multiple pore volumes treated	Column residence time 2 – 6 hours	Neutral pH maintained	Laboratory column study noted that carbon black coats calcite surfaces and delays initial fluoride removal	Turner et al. 2008
	Precipitation of fluorite by calcite (150 µm or 1.18 mm grains)	Synthetic SPL wastewater	Up to 2,000	NR	450 mg/g	1 day – 4 weeks	6 – 12	Laboratory batch study noted that removal is inhibited by phosphate	Turner et al. 2010
	Precipitation of fluorite by calcite; 14 – 2 mm grains limestone or marble and CO_2 added to feed water	Synthetic groundwater	5 – 109	Removal to 4 mg/L	Multiple pore volumes treated	Residence time 2.2 hours	With CO_2 conditioning, 5.37 – 8.63	Laboratory column study noted increasing pH during treatment, especially with high influent fluoride concentrations; authors suggest treatment would not be effective above 500 mg/L initial concentration	Reardon and Wang 2000
	Precipitation of fluorite by calcium chloride and treatment with flocculant	Synthetic fluoride wastewater	640	13.4 mg/L precipitation alone/ 6 mg/L final with flocculant added	NR	30-minute reaction period, followed by flocculant addition and filtration	6.5 – 8.5	Laboratory batch tests, a short reaction period with the calcium salt, addition of flocculant to remove fine crystals and improve removal by precipitation	Chang and Liu 2007
	Precipitation of fluorite by calcite (35 – 70 mesh grains)	Synthetic wastewater	25 – 3,000	With elevated calcium concentrations and neutral pH, removal to 6 mg/L	NR	NR	Neutral pH optimal	Laboratory column study noted that fluoride removal was inhibited by sulfate and phosphate in the test solutions	Yang et al. 1999
	Precipitation of fluorite by calcium hydroxide (reagent grade)	Synthetic wastewater	300 – 2,000	Up to 80% removal	NR	Equilibrium removal reached within 0.5 hours	NR	Laboratory fluidized bed reactor	Aldaco et al. 2005
	Adsorption and precipitation by quarry (rock) quicklime	Test solution	50	80% removal to 9.7 mg/L final	80.6 mg/g	Equilibrium removal reached within 1.25 hours	12.6 – 12.8	Laboratory batch study noted that fluoride removal was inhibited by phosphate, sulfate, and nitrate (in order of decreasing inhibition) in solutions	Islam and Patel 2007

Table K-1
Fluoride Literature Review

Removal Process	Treatment Media	Treatment Target	Initial Fluoride Concentration	Efficiency/ Treatment	Treatment Capacity	Residence Time	pH	Comments	Citation
Uptake by Apatite	Precipitation of apatite by analytical grade calcite and brushite with boiling	Drinking water	5 – 20	<1 mg/L final when 10 mg/L initial	NR	Boiled for 30 seconds, cooled for 1.5 or 18 hours	6.7 – 7.4	Laboratory test of home treatment; kit could only treat to <1 mg/L with low initial concentrations; 18 hours of settling for greatest removal	Larsen and Pearce 2002
	Adsorption by hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$), fluorite, and calcite (highly crystalline)	Drinking water	<1	90% removal by hydroxyapatite	NR	Equilibrium adsorption within 0.5 hour	Neutral	Laboratory batch study	Fan et al. 2003
	Adsorption by apatite ($Ca_{10}(PO_4)_6(OH,F,Cl)_2$); geogenic (rock phosphate), biogenic (bone meal), and synthetic apatite forms tested	Test solution	1 – 90	30 – 95% removal, greatest percent for low initial	2.2 – 2.3 mg/g	Equilibrium within 1.5 hours	2 – 11; 5 – 6 optimal	Laboratory batch study of adsorption capacity for synthetic nano-apatite > bone meal > rock phosphate (order of decreasing capacity)	Gao et al. 2009
	Adsorption by fish bone charcoal; fish bones (biogenic apatite), baked for 2 hours at 1,000 °C	Fluoride spiked tap water	1.36 – 22.4	Final <1 mg/L for initial <10 mg/L	150 mg/g	Equilibrium within 1 hour	7.9 – 8.1	Laboratory flow cell	Bhargava and Killedar 1992
	Adsorption by bone (biogenic apatite) charcoal; fija fluorite bone charcoal	Test solution	1 – 20	Final <1 mg/L with low initial concentration	2.5 – 6 mg/g	Equilibrium within 18 hours	Maintained at 7	Stirred laboratory batch reactor	Leyva-Ramos et al. 2010
	Adsorption by brushite; brushite generated in the laboratory by reacting calcium and phosphate salts	Buffered test solution	20 – 50	Approaches 100% removal, dependent on adsorbent dose	6.59 mg/g	Equilibrium absorption within 1 hour	6.8 – 6.9	Laboratory batch study noted that adsorption capacity is reduced by competition from nitrate, chloride and sulfate in solution and by elevated pH	Mourabet et al. 2011

Table K-1
Fluoride Literature Review

Removal Process	Treatment Media	Treatment Target	Initial Fluoride Concentration	Efficiency/ Treatment	Treatment Capacity	Residence Time	pH	Comments	Citation
Adsorption by Clays and Oxides	Adsorption by alumina (Al_2O_3); merck activated alumina (0063 mm grain)	Test solution	15 – 100	50 mg/L reduced to 10 mg/L	0.2 – 0.5 mmol/g	Equilibrium absorption within 5 hours	4 – 11; 4 – 6 optimal	Laboratory batch study noted that removal is inhibited by sulfate	Ku and Chiou 2001
	Adsorption by alumina; synthetic mesoporous alumina and calcium doped alumina prepared in the laboratory	Synthetic groundwater and test solutions	2 – 1,000	<1 mg/L final for low initial concentrations	450 mg/g for calcium doped; 300 mg/g for mesoporous	12 hour reaction period	6.5	Laboratory batch study noted competition from silica, nitrate, and phosphate in solution	Li et al. 2011
	Adsorption by alumina; commercial alumina from Tramfloc, Inc.	Test solutions	5 – 150	Approximately 75% with 150 mg/L initial concentration	0.25 – 2 mg/g	Equilibrium absorption within 15 hours	5 – 10.5; 5.5 – 7.5 optimal	Laboratory batch study noted competition from phosphate > bicarbonate > sulfate > chloride in solution (order of decreasing inhibition)	Tang et al. 2009
	Adsorption by mixed iron and aluminum hydroxides; laboratory synthesized amendments with varying iron/aluminum ratios	Groundwater from Orissa, India and test solutions	10 – 30	<1 mg/L for groundwater when pH adjusted to 4	16.51 – 34.25 mg/g	Equilibrium absorption within 1.5 hours	4	Stirred laboratory batch tests noted that adsorption is strongly inhibited by phosphate, sulfate, and arsenic	Sujana and Anand 2010
	Adsorption by hematite (iron oxide, 30 – 140 mesh grain size) treated with aluminum hydroxide ($Al(OH)_3$) in the laboratory	Drinking water and test solutions	3.2 or 10 – 30, respectively	NR	116.75 mg/g	Equilibrium absorption within 48 hours	2.34 – 6.26 optimal	Laboratory batch study noted competition from other ions	Teutli-Sequeira et al. 2011
	Adsorption by hydrous ferric oxide; synthesized by reacting ferric chloride with ammonia and hydrochloric acid in the laboratory	Test solutions	25 – 50	87 – 100% for 25 mg/L initial concentration	3.75 – 9.8 mg/g	Equilibrium absorption within 1 hour	2 – 9; 4 optimal	Laboratory batch study noted competition by arsenate, phosphate, and sulfate	Dey et al. 2004
	Adsorption/complexation by granular ferric hydroxide (FeOOH); commercial supplied by GFH Media and US Filter, Inc.	Test solutions	10 – 50 or 105	NR	9 mg/g	Equilibrium absorption within 8 hours	2 – 11; 3 – 6.5 optimal	Stirred laboratory batch tests noted that adsorption is inhibited by phosphate > carbonate > sulfate > chloride (order of decreasing inhibition)	Tang et al. 2009
	Adsorption by hydrous ferric oxide; commercial and laboratory synthesized	Test solution	28 μmol/L	NR	1.8 mmol/g	NR	4 – 9; 4 optimal	Laboratory batch study noted that phosphate inhibits adsorption	Streat et al. 2008
	Adsorption by iron oxide; laboratory synthesized goethite (FeO(OH))	Test solutions	10 – 150	0.5 mg/L mol final when 10 – 25 mg/L mol initial	59 mg/g	Equilibrium adsorption within 2 hours	2 – 11.6; 6 – 8 optimal	Laboratory batch study noted that chloride and sulfate in solution inhibit adsorption	Mohapatra et al. 2010
	Adsorption by aluminum manufacturing waste; consists of kaolin clay ($Al_2Si_2O_5(OH_4)$), quartz (SiO_2), sulfates, and oxides	Test solutions	10	85%	332.5 mg/g	Equilibrium adsorption within 1 hour	3 – 8	Laboratory batch study noted bicarbonate ion interferes in adsorption	Nigussie et al. 2007
	Adsorption by ligand exchange by commercial montmorillonite clay (grain size <10mm)	Test solutions	2 – 120	Maximum 65%, decreasing with increasing initial concentration	0.263 mg/g	Equilibrium adsorption within 3 hours	2 – 10; 6 optimal	Laboratory batch study	Tor 2006
	Adsorption by granular bentonite clay (mixed clay minerals); natural calcium bentonite (grain size <200 mesh) treated with acid and granulated in the laboratory	Test solutions	2.85 or 6.34	<0.5 mg/L mol	0.278 mg/g	Equilibrium adsorption within 0.7 hours	2.65 – 11.65; 4.95 optimal	Laboratory batch study	Ma et al. 2011
	Adsorption by aminoclays (clay minerals with methyl group substitutions); clays treated with aminopropyl in the laboratory	Synthetic waste solution	30 mg/L	Up to 75% removal	NR	24-hour reaction period	4.65	Laboratory batch study	Lee et al. 2011

Table K-1
Fluoride Literature Review

Removal Process	Treatment Media	Treatment Target	Initial Fluoride Concentration	Efficiency/ Treatment	Treatment Capacity	Residence Time	pH	Comments	Citation
Other	Uptake by calcium impregnated charcoal prepared by reacting with calcite or lime (CaO/CaOH)	Drinking water	10	<1 mg/L final	19.05 mg/g	24-hour reaction period	Neutral	Laboratory batch study noted slight interference from bicarbonate or chloride ions in solution	Tchomgui-Kamga et al. 2010
	Adsorption by Saponified (caustic digestion to fatty acid salts) orange waste treated with aluminum or other multivalent metals in the laboratory	Test solution	0.52 mmol/dm^3	NR	1.16 mol/kg	Equilibrium adsorption within 4 hours	1 – 12; 6 optimal	Stirred laboratory batch tests noted interference by sulfate and bicarbonate ions in fluoride adsorption	Paudyal et al. 2011
	Complexation by anhydrous aluminum chloride ($AlCl_3$)	Synthetic waste stream	1.1 – 2000	Below 15 mg/L mol final for some initial concentrations	NR	0.5-hour reaction period followed by filtration	3.7 – 6.81	Laboratory batch study	Saha 1993
	Adsorption by iron rich soil; laboratory heat treated to improve porosity	Test solutions	4.75 – 95	Treated 4 mg/L initial to <1 mg/L mol for 120 pore volumes	104 – 1,035 µg/g	48-hour reaction period	7.0 – 7.1	Laboratory batch and column studies noted minimal competition from chloride, sulfate, and bicarbonate	Wang and Reardon 2001
	Adsorption by iron impregnated ceramic; laboratory synthesized granular ceramics treated with iron sulfate or iron oxides	Test solutions	5 – 50	Greater than 90% removal with iron sulfate at neutral pH and initial 10 mg/L	1.7 – 2.2 mg/g	Equilibrium adsorption within 18 hours	2 – 12; 7 or 4 optimal respectively	Stirred laboratory batch tests	Chen et al. 2011
	Adsorption by iron rich laterite (highly weathered soils rich in iron and aluminum) ores; ore materials and mining overburden	Groundwater and test solution	10.25 or 10 – 50, respectively	Up to 90% removal for 50 mg/L initial concentrations	12 – 15 mg/g	Equilibrium adsorption within 4.5 hours	2.5 – 10; 5 – 6 optimal	Stirred laboratory batch tests noted that chloride and sulfate inhibit adsorption	Sujana et al. 2009
	Adsorption by iron modified zeolite (microporous aluminosiliate); laboratory treated with iron chloride to increase iron content	Test solutions	5 – 40	<1 mg/L final for initial concentrations <10 mg/L	2.31 mg/g	Equilibrium adsorption within 2 hours	3 – 11; 6.94 optimal	Stirred laboratory batch tests noted minimal competition from other ions when present at less than 300 mg/L	Sun et al. 2011
	Adsorption by granular Red Mud (byproduct of aluminum recovery from ore), granulated with fly ash (fine combustion residue)	Test solutions	5 – 150	NR	2.89 mg/g	Equilibrium adsorption within 6 hours	2.5 – 7; 4.7 optimal	Laboratory batch and column studies	Tor 2009
	Adsorption by hydrated cement; commercial Portland cement (primarily calcium silicate clinker), mixed with water, adsorpted tested over the first 72 hours of curing	Groundwater from India and test solutions	13.2 or 5 – 50, respectively	Initial concentration of 132 reduced to 195 mg/L final for groundwater	2.68 mg/g	24-hour reaction period	3 – 10	Stirred laboratory batch tests noted carbonate interference with adsorption, but chloride, sulfate, and nitrate inhibit adsorption	Kagne et al. 2008

Table K-1
Fluoride Literature Review

Removal Process	Treatment Media	Treatment Target	Initial Fluoride Concentration	Efficiency/ Treatment	Treatment Capacity	Residence Time	pH	Comments	Citation
Literature Reviews	Mineral adsorption (activated alumina, bone char, clays); membrane dialysis; ion exchange	Drinking water, groundwater, wastewater	Various	NR	Alumina 0.5 – 16.34 mg/g; bone 0.3 – 11.4 mg/g	NR	Various	Literature review: activated alumina adsorption capacity pH dependent; bone charcoal adsorption capacity dependent on char temperature	Onyango and Matsuda 2006
	Adsorption by alumina, clays, calcite and other minerals	Drinking water, groundwater, wastewater	Various; Low levels to 1,000+	NR	Varies	0.5 – 96 hours reaction periods; reaction period <4 hours for 50% of studies	Various	Literature review: summary table for a wide variety of adsorbents includes amendment capacity and concentration range tested for 102 studies	Bhatnagar et al. 2011
	Mineral adsorption (alumina and clays), membrane dialysis, and ion exchange; bentonite and kaolinite clays	Drinking water	Various <30	Varies	Varies	NR	Various	Literature review, indicates that initial concentrations greater than 30 mg/L pre-treated with fluorite precipitation	Mohapatra et al. 2009

Notes:
Initial concentration in mg/L unless otherwise stated.
Capacity reported as mass fluoride removed per mass adsorbent unless otherwise stated.
°C = degree Celsius
µg/g = microgram per gram
µm = micrometer
µmol/L = micromoles per liter
Al_2O_3 = alumina
$Ca_{10}(PO_4)_6(OH)_2$ = hydroxy-apatite
$Ca_{10}(PO_4)_6(OH,F,Cl)_2$ = substituted apatite
$CaCO_3$ = calcite, calcium carbonate, limestone
CaF_2 = fluorite
$CaHPO_42H_2O$ = brushite
$Ca(OH)_2$ = calcium hydroxide, slaked lime
CO_2 = carbon dioxide
F^- = fluoride ion
g = gram
lb = pound
mg/L = milligram per liter
mg/g = milligram per gram
mm = millimeter
mmol/g = millimole per gram
mol/kg = mole per gram
NR = not reported
SPL = spent potliner

Table K-1
Fluoride Literature Review (References)

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Table K-2
Design Table

Design Parameter and Implications		Treatment Considerations	Cost Considerations
Remedial Alternative Selected	Remedial options include varying PRB numbers/lengths and/or excavation and backfill with reactive amendments.	The total length of PRB emplaced would be 1,350 feet for Alternative 3 (PRBs in both the East and West Groundwater Areas), 350 feet for Alternative 4 (a single PRB in the West Groundwater Area), or 2,200 feet for Alternative 5 (PRB in the West Groundwater Area, discontinuous PRB along the eastern perimeter of the East Groundwater Area)	Alternative selection will significantly impact materials cost. The total mass of reactive amendment required will be comparable between PRBs and reactive backfill, as the order of magnitude volume difference will be offset by the lower amendment rate for backfill.
	Other remedial activities may impact fluoride flux or groundwater movement, for example emplacement of impermeable caps, or excavation of high concentration areas.	Alternatives that reduce groundwater flow or fluoride concentrations would reduce the total fluoride removal required.	Total fluoride removal capacity and source longevity would impact the mass of reactive material needed, which will influence materials cost.
PRB Volume	The total volume of the PRBs will be determined by the alternative selected (either 350 feet, 1,350 feet, or 2,200 feet of total length), depth of groundwater intercepted (20 to 23 feet), and PRB width (likely 3 feet).	The total volume of the PRB will determine the groundwater residence time within the reactive material. Literature indicates a residence times of 0.5 to 18 hours for precipitation by calcite or uptake by apatite. The residence time of groundwater in a PRB with dimensions (length by width by depth) of 350 feet by 3 feet by 20 feet would be on the order of days.	The residence time within a 3-foot-wide PRB is expected to be sufficient to allow fluoride removal within the PRB. While not anticipated, adjustments of the width of the PRB may be used to adjust residence time, which would increase material and construction costs.
Selected Location of PRB or Amended Backfill	Groundwater flux and depth to water table vary between the areas considered for PRBs or the Amended Backfill.	Groundwater flux will impact residence time within the reactive media and amendment longevity.	A greater flux may require increased amendment rates, increasing materials costs.
	Porosity, hydraulic conductivity, and infiltration of precipitation vary between the locations considered.	The hydraulic conductivity of the surrounding materials will determine the hydraulic conductivity necessary for the PRB to "draw" flow, and therefore, the grain size distribution required in the PRB material.	Additional gravel to enhance hydraulic conductivity should have minimal impact on cost unless a wider PRB is required to accommodate an increase in sand and gravel in the mixture.
	Fluoride concentrations in groundwater vary between the areas considered	Concentrations are generally less than 100 mg/L in the West Groundwater Area. Concentrations along the perimeter of the East Groundwater Area are less than 50 mg/L. Fluoride concentrations in excess of 1,000 mg/L would potentially be treated in small areas within the East Groundwater Area. Elevated concentrations are readily treated by precipitation of fluorite; however, moderate concentrations may require emphasizing apatite uptake rather than fluorite precipitation.	Apatite has a lower amendment capacity than calcite, and costs may increase if precipitation is not expected to be effective for removal.
	Groundwater pH is generally between pH 6 and 7; some areas considered for reactive backfill may be more alkaline.	The pH of groundwater entering reactive backfill or a PRB will determine the rate of calcite dissolution and, therefore, the concentration of the calcium ions necessary for fluorite precipitation. Uptake by apatite is also pH-dependent.	Elevated pH may limit the effectiveness of limestone and reduce the effectiveness of apatite uptake, potentially requiring greater amendment rates.

Table K-2
Design Table

Design Parameter and Implications		Treatment Considerations	Cost Considerations
Reactive Media Mixture	The reactive media mixture is limestone (reactive amendment composed of calcite) to increase the dissolved calcium concentration causing precipitation of calcium fluoride (fluorite).	Addition of limestone will cause precipitation of fluorite. Removal is effective at circumneutral pH, for moderate to high concentrations of fluoride, with removal to approximately 10 mg/L common.	The mass of limestone added as a reactive amendment will depend on longevity requirements, as consumption of the amendment will be controlled by dissolution rates.
	The reactive media mixture is bone meal (reactive amendment composed of biogenic apatite) for fluoride uptake.	The treatment consideration is an amendment for "polishing" moderate to low concentrations through apatite uptake of fluoride and removal to very low levels.	The mass of bone meal added as a reactive amendment will be dependent on the concentration after fluorite precipitation. Bone meal is significantly more expensive than limestone, and the level of polishing required may significantly impact material costs.
	The reactive media mixture is gravel or sand as a non-reactive matrix to enhance hydraulic conductivity.	Sand or gravel may be required to enhance hydraulic conductivity of the PRB. The PRB must have greater hydraulic conductivity than surrounding aquifer materials to ensure that groundwater will flow through the PRB.	Gravel addition may offset costs if concerns over residence time indicate the need for a wider reactive barrier, as the same mass of amendment can be present in the larger barrier.
PRB Construction Method	The method is continuous trenching with simultaneous excavation and amended media backfill if possible and construction with shoring and/or dewatering, if required.	The type of construction will be determined, in part, by the width of the PRBs.	Construction costs will vary with the type of construction and final PRB dimensions.

Notes:
CY = cubic yard
mg/L = milligram per liter
PRB = permeable reactive barrier

ATTACHMENT 1
HELP MODEL SUMMARY REPORT:
ANNUAL PRECIPITATION EVALUATION

Attachment 1
HELP Model Summary Report:
Annual Precipitation Evaluation

Project: Annual_Eval_Final_19Aug2013

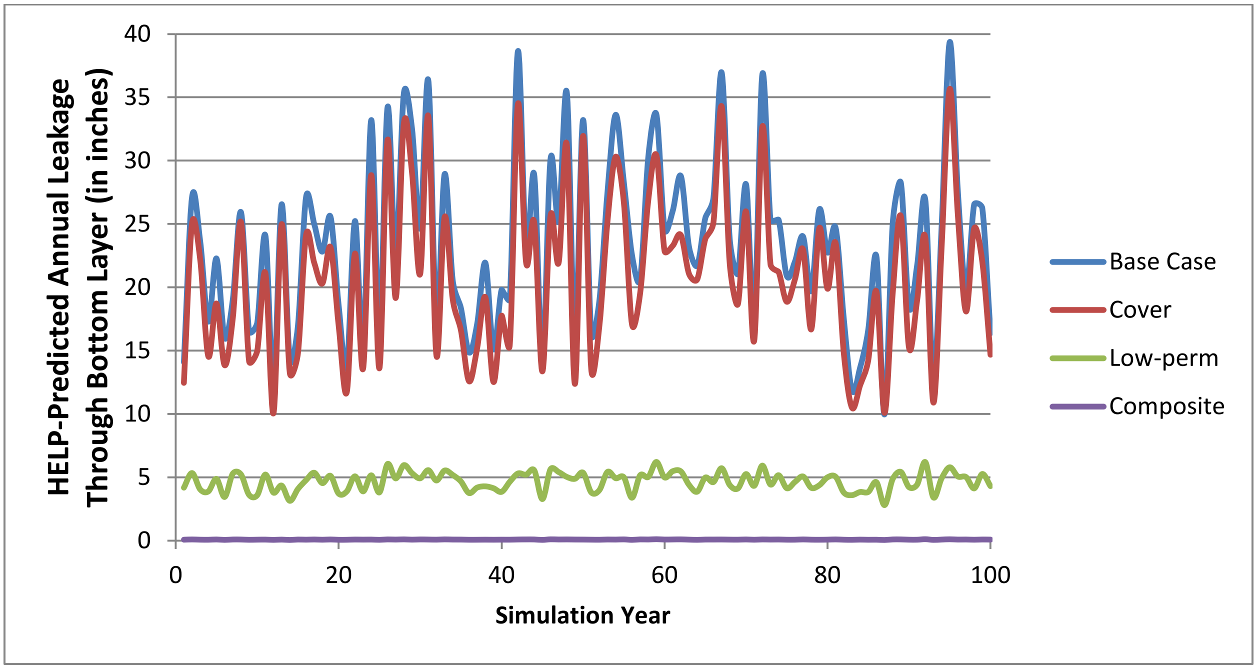
Preliminary physical barrier performance evaluation for
Former Reynolds Metals Reduction Plant FS Remedial Technology Screening

Model : HELP
An US EPA model for predicting landfill hydrologic processes and testing of effectiveness of landfill designs

Author : Rebecca Gardner, P.E.

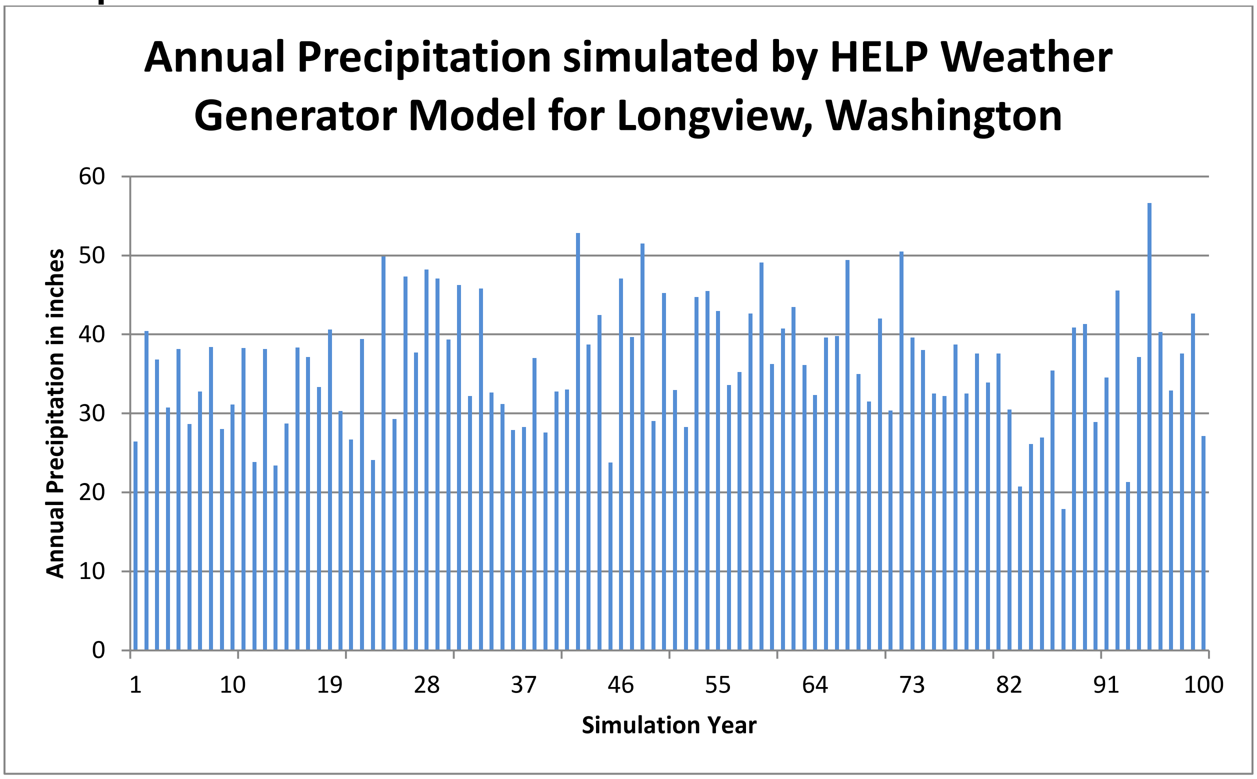
Location : Longview, WA

RESULTS SUMMARY



INPUT PARAMETERS

Precipitation



1 PROFILE. BASE CASE - EXISTING CONDITIONS

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Fair stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Loamy Sand1	0.0000	-2.0000	2.0000
Sand	-2.0000	-12.0000	10.0000

1.1 Layer. Loamy Sand1

Top Slope Length: 6000.0000
Bottom Slope Length: 6000.0000
Top Slope: 0.0000
Bottom Slope : 0.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.437	(vol/vol)
field capacity	0.105	(vol/vol)
wilting point	0.047	(vol/vol)
sat.hydr.conductivity	0.005	(cm/sec)
subsurface inflow	0	(mm/year)

1.2 Layer. Sand

Top Slope Length: 6000.0000
Bottom Slope Length: 6000.0000
Top Slope: 0.0000
Bottom Slope : 0.0000

[HELP] Lateral Drainage Layer Parameters

Parameter	Value	Units
total porosity	0.437	(vol/vol)
field capacity	0.062	(vol/vol)
wilting point	0.024	(vol/vol)
sat.hydr.conductivity	.01	(cm/sec)
subsurface inflow	0	(mm/year)

2 PROFILE. SAND_COVER

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Good stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Sandy Loam1	0.0000	-6.0000	6.0000
Fine Sand	-6.0000	-24.0000	18.0000

2.1 Layer. Sandy Loam1

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.4530	(vol/vol)
field capacity	0.1900	(vol/vol)
wilting point	0.0850	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0.0000	(cm/day)

2.2 Layer. Fine Sand

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Lateral Drainage Layer Parameters

Parameter	Value	Units
total porosity	0.457	(vol/vol)
field capacity	0.083	(vol/vol)
wilting point	0.033	(vol/vol)
sat.hydr.conductivity	0.0001	(cm/sec)
subsurface inflow	0	(mm/year)

3 PROFILE. LOW-PERMEABILITY_SOIL_CAP

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Good stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Sandy Loam1	0.0000	-6.0000	6.0000
Fine Sand	-6.0000	-12.0000	6.0000
Drainage Net (0.5cm)	-11.9995	-12.1964	0.1969
Sandy Clay, moderately compacted	-12.1959	-24.1959	12.0000

3.1 Layer. Sandy Loam1

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.4530	(vol/vol)
field capacity	0.1900	(vol/vol)
wilting point	0.0850	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0.0000	(cm/day)

3.2 Layer. Fine Sand

Top Slope Length: 0.0000
Bottom Slope Length: 1200.0000
Top Slope: 0.0000
Bottom Slope : 2.0000

[HELP] Lateral Drainage Layer Parameters

Parameter	Value	Units
total porosity	0.457	(vol/vol)
field capacity	0.083	(vol/vol)
wilting point	0.033	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0	(mm/year)

3.3 Layer. Drainage Net (0.5 cm)

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Geotextiles and Geonets Parameters

Parameter	Value	Units
total porosity	0.85	(vol/vol)
field capacity	0.01	(vol/vol)
wilting point	0.005	(vol/vol)
sat.hydr.conductivity	10	(cm/sec)
subsurface inflow	0	(mm/year)

3.4 Layer. Sandy Clay, moderately compacted

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Barrier Soil Liner Parameters

Parameter	Value	Units
total porosity	0.4	(vol/vol)
field capacity	0.366	(vol/vol)
wilting point	0.288	(vol/vol)
sat.hydr.conductivity	.000001	(cm/sec)
subsurface inflow	0	(mm/year)

4 PROFILE. COMPOSITE_CAP

Model Settings
[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Good stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Sandy Loam1	0.0000	-6.0000	6.0000
Sandy Clay, moderately compacted	-6.0000	-24.0000	18.0000
Drainage Net (0.5 cm)	-24.0000	-24.1969	0.1969
High Density Polyethylene (HDPE)	-24.1964	-24.2358	0.0394

4.1 Layer. Sandy Loam1

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.4530	(vol/vol)
field capacity	0.1900	(vol/vol)
wilting point	0.0850	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0.0000	(cm/day)

4.2 Layer. Sandy Clay, moderately compacted

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Barrier Soil Liner Parameters

Parameter	Value	Units
total porosity	0.4	(vol/vol)
field capacity	0.366	(vol/vol)
wilting point	0.288	(vol/vol)
sat.hydr.conductivity	.000001	(cm/sec)
subsurface inflow	0	(mm/year)

4.3 Layer. Drainage Net (0.5 cm)

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Geotextiles and Geonets Parameters

Parameter	Value	Units
total porosity	0.85	(vol/vol)
field capacity	0.01	(vol/vol)
wilting point	0.005	(vol/vol)
sat.hydr.conductivity	10	(cm/sec)
subsurface inflow	0	(mm/year)

4.4 Layer. High Density Polyethylene (HDPE)

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Geomembrane Liner Parameters

Parameter	Value	Units
sat.hydr.conductivity	2E-13	(cm/sec)
pinhole density	2	(#/ha)
installation defects	2	(#/ha)
placement quality	4	(-)
geotextile transmissivity	0	(cm2/sec)

ATTACHMENT 2
HELP MODEL SUMMARY REPORT: DESIGN-EVENT PRECIPITATION EVALUATION

Attachment 2
HELP Model Summary Report:
Design-event Precipitation Evaluation

Project: Design_Event_Final_19Aug2013

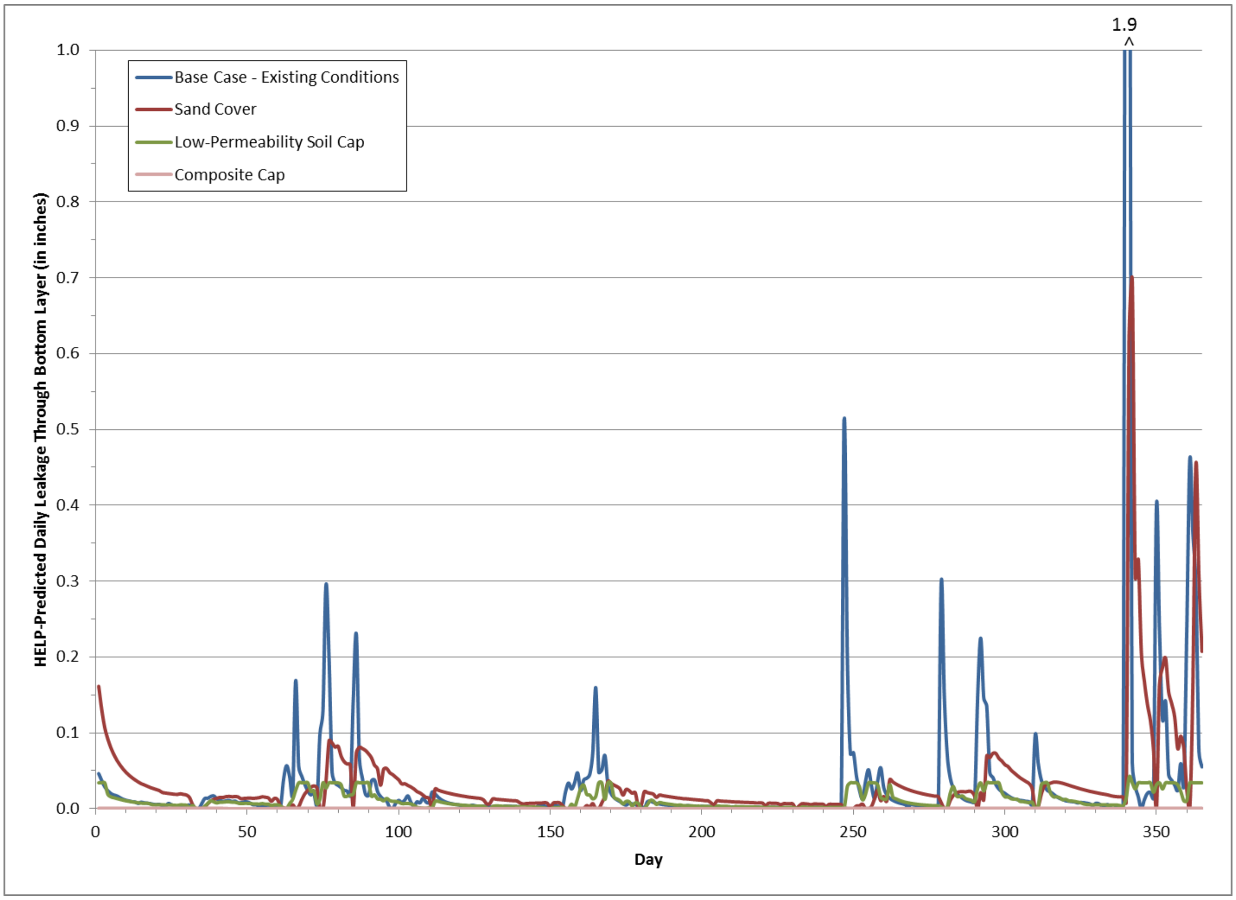
Preliminary physical barrier performance evaluation for
Former Reynolds Metals Reduction Plant FS Remedial Technology Screening

Model : HELP
An US EPA model for predicting landfill hydrologic processes and testing of effectiveness of landfill designs

Author : Rebecca Gardner, P.E.

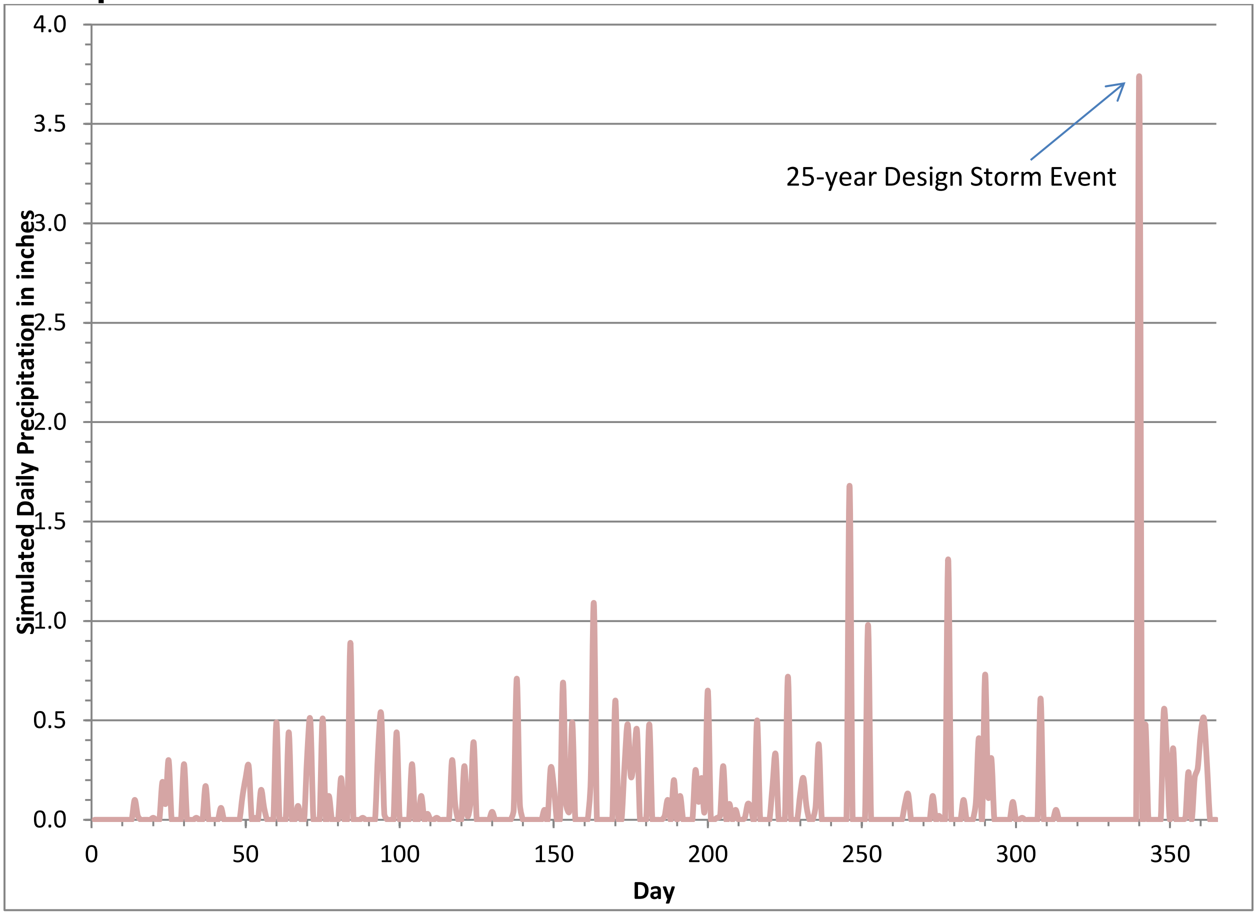
Location : Longview, WA

RESULTS SUMMARY



INPUT PARAMETERS

Precipitation



1 PROFILE. BASE CASE - EXISTING CONDITIONS

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Fair stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Loamy Sand1	0.0000	-2.0000	2.0000
Sand	-2.0000	-12.0000	10.0000

1.1 Layer. Loamy Sand1

Top Slope Length: 6000.0000
Bottom Slope Length: 6000.0000
Top Slope: 0.0000
Bottom Slope : 0.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.437	(vol/vol)
field capacity	0.105	(vol/vol)
wilting point	0.047	(vol/vol)
sat.hydr.conductivity	0.005	(cm/sec)
subsurface inflow	0	(mm/year)

1.2 Layer. Sand

Top Slope Length: 6000.0000
Bottom Slope Length: 6000.0000
Top Slope: 0.0000
Bottom Slope : 0.0000

[HELP] Lateral Drainage Layer Parameters

Parameter	Value	Units
total porosity	0.437	(vol/vol)
field capacity	0.062	(vol/vol)
wilting point	0.024	(vol/vol)
sat.hydr.conductivity	.01	(cm/sec)
subsurface inflow	0	(mm/year)

2 PROFILE. COMPOSITE_CAP

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Good stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Sandy Loam1	0.0000	-6.0000	6.0000
Sandy Clay, moderately compacted	-6.0000	-24.0000	18.0000
Drainage Net (0.5cm)	-24.0000	-24.1969	0.1969
High Density Polyethylene (HDPE)	-24.1964	-24.2358	0.0394

2.1 Layer. Sandy Loam1

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.4530	(vol/vol)
field capacity	0.1900	(vol/vol)
wilting point	0.0850	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0.0000	(cm/day)

2.2 Layer. Sandy Clay, moderately compacted

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Barrier Soil Liner Parameters

Parameter	Value	Units
total porosity	0.4	(vol/vol)
field capacity	0.366	(vol/vol)
wilting point	0.288	(vol/vol)
sat.hydr.conductivity	.000001	(cm/sec)
subsurface inflow	0	(mm/year)

2.3 Layer. Drainage Net (0.5cm)

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Geotextiles and Geonets Parameters

Parameter	Value	Units
total porosity	0.85	(vol/vol)
field capacity	0.01	(vol/vol)
wilting point	0.005	(vol/vol)
sat.hydr.conductivity	10	(cm/sec)
subsurface inflow	0	(mm/year)

2.5 Layer. High Density Polyethylene (HDPE)

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 5.0000
Bottom Slope : 5.0000

[HELP] Geomembrane Liner Parameters

Parameter	Value	Units
sat.hydr.conductivity	2E-13	(cm/sec)
pinhole density	2	(#/ha)
installation defects	2	(#/ha)
placement quality	4	(-)
geotextile transmissivity	0	(cm2/sec)

3 PROFILE. LOW-PERMEABILITY_SOIL_CAP

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Good stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Sandy Loam1	0.0000	-6.0000	6.0000
Fine Sand	-6.0000	-12.0000	6.0000
Drainage Net (0.5 cm)	-11.9995	-12.1964	0.1969
Sandy Clay, moderately compacted	-12.1959	-24.1959	12.0000

3.1 Layer. Sandy Loam1

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.4530	(vol/vol)
field capacity	0.1900	(vol/vol)
wilting point	0.0850	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0.0000	(cm/day)

3.2 Layer. Fine Sand

Top Slope Length: 0.0000
Bottom Slope Length: 1200.0000
Top Slope: 0.0000
Bottom Slope : 2.0000

[HELP] Lateral Drainage Layer Parameters

Parameter	Value	Units
total porosity	0.457	(vol/vol)
field capacity	0.083	(vol/vol)
wilting point	0.033	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0	(mm/year)

3.3 Layer. Drainage Net (0.5 cm)

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Geotextiles and Geonets Parameters

Parameter	Value	Units
total porosity	0.85	(vol/vol)
field capacity	0.01	(vol/vol)
wilting point	0.005	(vol/vol)
sat.hydr.conductivity	10	(cm/sec)
subsurface inflow	0	(mm/year)

3.4 Layer. Sandy Clay, moderately compacted

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Barrier Soil Liner Parameters

Parameter	Value	Units
total porosity	0.4	(vol/vol)
field capacity	0.366	(vol/vol)
wilting point	0.288	(vol/vol)
sat.hydr.conductivity	.000001	(cm/sec)
subsurface inflow	0	(mm/year)

4 PROFILE. SAND_COVER

Model Settings

[HELP] Case Settings

Parameter	Value	Units
Runoff Method	Model calculated	(-)
Initial Moisture Settings	Model calculated	(-)

[HELP] Surface Water Settings

Parameter	Value	Units
Runoff Area	100	(%%)
Vegetation Class	Good stand of grass	(-)

Profile Structure

Layer	Top (in)	Bottom (in)	Thickness (in)
Sandy Loam1	0.0000	-6.0000	6.0000
Fine Sand	-6.0000	-24.0000	18.0000

4.1 Layer. Sandy Loam1

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Vertical Perc. Layer Parameters

Parameter	Value	Units
total porosity	0.4530	(vol/vol)
field capacity	0.1900	(vol/vol)
wilting point	0.0850	(vol/vol)
sat.hydr.conductivity	0.001	(cm/sec)
subsurface inflow	0.0000	(cm/day)

4.2 Layer. Fine Sand

Top Slope Length: 1200.0000
Bottom Slope Length: 1200.0000
Top Slope: 2.0000
Bottom Slope : 2.0000

[HELP] Lateral Drainage Layer Parameters

Parameter	Value	Units
total porosity	0.457	(vol/vol)
field capacity	0.083	(vol/vol)
wilting point	0.033	(vol/vol)
sat.hydr.conductivity	0.0001	(cm/sec)
subsurface inflow	0	(mm/year)

APPENDIX L
COST ESTIMATE

1 INTRODUCTION

This appendix summarizes the methodology and assumptions used to determine the estimated costs of each proposed remedial action alternative at the former Reynolds Metals Reduction Plant (Reynolds Facility) in Longview, Washington. Twelve site units (SUs) have been identified across the site (see Section 8.1 and Figure L-1), and six alternatives have been proposed to achieve the remedial action objectives (RAOs; see Section 10). The proposed alternatives range from institutional controls to removal and disposal of impacted soil and waste at off-site landfills. Intermediate alternatives consist of covering SUs with soil cover or a low-permeability cap, along with excavating and consolidating smaller volume SUs with larger ones. Groundwater treatment varies in each alternative but generally consists of a combination of permeable reactive barriers (PRBs) and backfill mixed with reactive agents in areas where removal excavations extend below the groundwater table. Table L-1 summarizes the direct costs used to build the cost estimate. Table L-2 summarizes the dimensions and other relevant information for each SU. Cost estimates for each alternative are summarized in Tables L-3 through L-8.

2 COST ESTIMATE METHODOLOGY

Total costs were summed for each alternative based on costs associated with the groundwater treatments and technologies used at each SU. Unit costs for each task to accomplish a technology were multiplied by SU-specific quantities to obtain a line item cost. Unit cost values provided in the estimate are based on data from the 2012 RS Means Heavy Construction Cost Data, recent quotes from regional contractors or vendors, and actual costs from similar projects completed in the same region in 2011. Unit costs were updated to 2013 by assuming annual increases of 3 percent. Disposal costs are based on 2013 vendor quotes. Table L-1 summarizes the direct costs used to build the cost estimate.

For indirect costs, the following percentages (of the total direct costs for a given alternative) were used:

- Mobilization/Demobilization/Site Controls/Survey: 10 percent of construction costs
- Engineering Design Costs: 5 percent

- Construction Management and Oversight: Varies from 5 to 10 percent (a higher percentage was assumed for lower cost alternatives)
- Business and Occupation/Sales Tax: 7.9 percent (determined based on capital costs subtotal)

The cost estimate assumptions and unit costs are based on the best information available at the time this report was prepared. Changes in cost elements are likely to occur as a result of new information and design modifications.

The cost estimates are provided as an engineer's estimate for a feasibility level of analysis (+50/-30 percent). Detailed design has not been completed, and estimates are likely to vary based on additional information at that point in time. The estimate is an opinion of costs and not an offer to contract for construction services. Final costs of the project will depend on many costs that will vary from the current estimated values, including labor and material, competitive market conditions, actual site conditions at time of work, final project scope, schedule, and other factors.

3 ASSUMPTIONS

Assumptions for determining costs of the proposed remedial activities consist of the following:

- Mobilization/Demobilization and Site Controls consists of mobilizing and demobilizing equipment and personnel, site surveying, erosion control, work plans, environmental protection, Health and Safety Plans, decontamination, and general construction items, such as job trailers and fencing.
- Soil cover consists of 18 inches of uncompacted soil with 6 inches of topsoil and hydroseed or compacted gravel (with geotextile filter).
- Areas to be remediated with a soil cover that already include a minimum of 12 inches of soil cover and vegetation may be enhanced by adding an additional 12 inches of uncompacted soil with top soil and hydroseed in lieu of constructing a full 2-foot cover layer.

- Low-permeability cap consists of 12 inches of a low permeability, moderately compacted soil layer overlain by a geocomposite drainage layer covered with 12 inches of topsoil and hydroseed.
- Berms will be built up around SU6 and SU7 to allow for additional storage in the alternatives where additional material from other SUs is consolidated in these areas. These costs are accounted for in the individual SUs to be consolidated.
- PRB trenches consist of 10 percent bone meal and 90 percent limestone, by mass, and are assumed to be 20 feet deep and 3 feet wide. Costs include materials, transport, and construction. Soil removed from the PRB trenches will be consolidated in SU2 and SU6/SU7.
- Removal volumes were estimated using ArcGIS by multiplying 2011 through 2013 test pit measurements (see Section 3.5.1) of depth to the base of waste by the area of associated Thiessen polygons and converting to appropriate units. Overburden, which includes the sand, silt, and gravel that overlies the fill deposit materials, was included in the removal volumes. A contingency of 12 percent was included to account for the uncertainty in volumes due to test pit sampling density.
- The average depth to the groundwater table was estimated for each SU using gauging data collected from the nearest groundwater monitoring wells during the December 2012 gauging event.
- Excavations will be dewatered, as necessary, in SU2, SU3, and SU5, where excavation would occur below the groundwater table. Water would be pumped into trenches, which drain to the existing on-site water treatment system. For costing purposes, temporary storage of dewatering fluid could occur in five rented storage tanks. Durations of dewatering assume that 45,000 square feet (300 feet by 150 feet) will be dewatered at a time, and each section will require 3 days to set-up, complete, and backfill.
- Disposal costs for SU2, SU6, and SU7 assumed bulk density values of 1.46, 1.31, and 1.31 tons/cubic yard based on calculations from corresponding residual carbon and spent lime samples collected in October 2012. For other SUs, the density was assumed to be 1.5 tons per cubic yard, the same as the density for soil.
- For Alternative 6, the cost of backfilling the void from the removal of residual carbon beneath SU1 was included under the cost for SU2.

- The surface area of SU9 was divided by 4, and its volume was reduced by 50 percent because pitch is not located throughout the area.
- Soil confirmation samples were assumed to be collected at a rate of ten samples for every acre that is removed (or approximately one sample per 5,000 square feet) For quality control purposes, one additional sample would be collected per 20 samples generated; costs for the quality control samples are not included in the cost estimates. Quality control samples are considered in the ten per acre frequency. All SUs except SU4 will have some form of soil confirmation sampling.
- Amended backfill placed in areas excavated below the groundwater table consists of a mix of 90 percent standard uncompacted backfill and 10 percent PRB trench mix (i.e., a mix of 10 percent bone meal and 90 percent limestone, by weight) by volume.
- Long-term monitoring consists of collecting, analyzing, validating data, and reporting. The frequency of long-term monitoring is summarized in Section10 of the main report.
- Cap operation and maintenance (O&M) measures include costs for mowing three times a year and erosion controls, including occasional cleanup, rilling, or other features caused by erosion.

TABLES

Table L-1
Summary of Unit Costs

Remedial Technology	Units	Unit Cost
Backfill – purchase, deliver, place, and compact	CY	$27
Dewatering – wellpoint, pump, on-site treatment	Day	$19,130
Enhance Existing Soil Cover (gravel surface)	Acre	$67,860
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440
Excavate and Load for Off-site Disposal	CY	$3
Excavate, Haul, and Consolidate On-site	CY	$12
Grading	Acre	$18,740
Gravel Surface	Acre	$19,850
Low-Permeability Cap (hydroseed surface)	Acre	$188,820
O&M – Low-Permeability Cap	Per Acre, Per Year	$340
O&M – Soil Cover	Per Acre, Per Year	$340
Increased Low Permeability Cap Area due to Consolidation	Acre	$188,820
Increased Soil Cover Area due to Consolidation	Acre	$107,820
PRB Trench	Linear Foot	$520
Reactive Backfill - purchase, deliver, place, and compact	CY	$63
Resurface Excavation with topsoil and hydroseed	Acre	$18,950
RR and Angle Residual General Fill Cover	CY	$27
Soil Confirmation Sampling (10 per acre)	Each	$500
New Soil Cover (gravel surface)	Acre	$117,250
New Soil Cover (hydroseed surface)	Acre	$107,820
Transport and Off-site Disposal (Dangerous Waste including K088)	CY	$353
Transport and Off-site Disposal (Solid Waste)	CY	$66

Notes:
CY = cubic yard
O&M = operation and maintenance
PRB = permeable reactive barriers
RR = railroad
SU = site unit

Table L-2
Summary of Site Unit Characteristics Assumed in Cost Estimate Calculations

FS Site Unit	Description	Area (square feet)	Area (Acres)	Maximum Material Thickness (feet)	Overburden Thickness[2] (feet)	Estimated Material Volume[7] (CY)	Estimated Removal Volume[8] (CY)	Average Depth to Groundwater[9] (feet)	Volume below Groundwater Table (CY)	Backfill Volume (CY)	Material Classification	Notes
SU1[3]	Landfill # 2 (Industrial)	126,702	3.0	14	0	46,081	51,620	N/A	N/A	0	Solid Waste	2 feet is the maximum overburden (fill sand) thickness observed during 2012 test pits at SU1. No backfill is planned since SU1 is mounded atop the ground surface of SU2.
SU2[4]	Fill Deposit B-3 (Residual Carbon)	753,807	17.4	6	2	138,468	155,090	8.9	0	181,160	DW (K088)	2 feet of overburden observed during 2012 test pits at SU2. Fill deposit pinches out at edges. Backfill volume includes the volume of the void left by the removal of SU1.
SU3[5]	Fill Deposit B-2 (Residual Carbon)	182,999	4.3	6	2	35,990	40,310	2.1	26,077	40,310	DW (K088)	2 feet overburden observed during 2012 test pits at SU3.
SU4	Former Cryolite Ditches	19,411	0.5	4	--	0	0	N/A	N/A	1,479	N/A	Backfill thicknesses assumed: 6 inches for railroad and angle ditches, 4 feet for cryolite ditch
SU5	Former Stockpile Area	59,697	1.4	2.5	0	5,155	5,780	1.6	2,242	4,240	Solid Waste	Material is not residual carbon (K088). Backfill thicknesses assumed: 4 feet for former SPL ditch, otherwise 2.5 feet
SU6	Fill Deposit B-1 (Residual Carbon)	373,227	8.6	14	2	205,550	230,220	N/A	N/A	0	DW (K088)	2 feet of overburden observed during Fall 2012 test pits. No backfill is planned since this SU is mounded above the ground surface.
SU7	Fill Deposit A (Spent Lime)	198,021	4.6	6	2	56,433	63,210	1.1	55,142	63,210	Solid Waste	2 feet of overburden observed during 2012 test pits.
SU8	Landfill # 1 (Floor Sweeps)	104,729	2.5	15.5	0	47,238	52,910	8.2	21,103	52,910	Solid Waste	No overburden.
SU9[6]	Pitch Storage Area	2,890	0.3	2	--	107	120	4.7	0	120	State-only DW	
SU10	Landfill # 3 (Construction Debris)	54,597	1.3	9	0	12,099	13,560	4.9	3,652	13,560	Solid Waste	No overburden.
SU11	Flat Storage Area	7,781	0.2	1	1	61	70	2.9	0	70	Solid Waste	1 foot of overburden observed during 2012 and 2013 test pits.

Notes:
1 = Removal and backfill volumes correspond to the maximum values per SU for any of the six remedial alternatives.
2 = Overburden includes sand, silt and gravel that overlies fill deposit materials.
3 = Volume is only above the residual deposit of SU2.
4 = Area does not include area below SU1. Consolidated area in extreme east and west portions of SU2 for Alternatives 3, 4, and 5: 215,808 square feet
5 = Area does not include cryolite ditch.
6 = SU9 area is divided by 4 and volume reduced by 50 percent because pitch is not located throughout area.
7 = Except for SU4 and SU9 where no test pit information was available, removal volumes were estimated using ArcGIS by multiplying 2011 through 2013 test pit measurements of depth to the base of waste by the areas of associated Thiessen polygons and converting to appropriate units.
8 = A contingency of 12 percent was included to account for the uncertainty in volumes due to test pit sampling density.
9 = Average depth to groundwater was estimated for each SU using nearby gauging data for the nearest groundwater monitoring wells during the December 2012 gauging event.
See Appendix D-1 for test pit data.
bgs = below ground surface
CY = cubic yards
DW = Dangerous Waste
FS = Feasibility Study
N/A = not available or not applicable
SPL = spent potliner
SU = site unit

Table L-3
Estimated Cost of Alternative 1

Alternative 1: Remedial Action Summary				
● No remedial construction				
● Institutional controls would be established				
● Long-term monitoring would occur quarterly for 14 years at existing wells				
FS Site Unit	**Units**	**Unit Cost**	**No. of Units**	**Cost**
DIRECT CONSTRUCTION COSTS				
West Groundwater Area				
Groundwater				
No construction	--	--	--	--
Subtotal				**$0**
SU1 - Landfill # 2 (Industrial)				
No construction	--	--	--	--
Subtotal				**$0**
SU2 - Fill Deposit B-3 (Residual Carbon)				
No construction	--	--	--	--
Subtotal				**$0**
East Groundwater Area				
Groundwater				
No construction				
Subtotal				**$0**
SU3 - Fill Deposit B-2 (Residual Carbon)				
No construction	--	--	--	--
Subtotal				**$0**
SU4 - Former Cryolite Ditches				
No construction	--	--	--	--
Subtotal				**$0**
SU5 - Former Stockpile Area				
No construction	--	--	--	--
Subtotal				**$0**
SU6 - Fill Deposit B-1 (Residual Carbon)				
No construction	--	--	--	--
Subtotal				**$0**
SU7 - Fill Deposit A (Spent Lime)				
No construction	--	--	--	--
Subtotal				**$0**
SU8 - Landfill # 1 (Floor Sweeps)				
No construction	--	--	--	--
Subtotal				**$0**
SU9 - Pitch Storage Area				
No construction	--	--	--	--
Subtotal				**$0**
SU10 - Landfill # 3 (Construction Debris)				
No construction	--	--	--	--
Subtotal				**$0**
SU11 - Flat Storage Area				
No construction	--	--	--	--
Subtotal				**$0**
Construction Cost Subtotal (CCS)				***$0***

Table L-3
Estimated Cost of Alternative 1

Alternative 1: Remedial Action Summary

- No remedial construction
- Institutional controls would be established
- Long-term monitoring would occur quarterly for 14 years at existing wells

FS Site Unit	Units	Unit Cost	No. of Units	Cost
OTHER CONTRACTOR COSTS				
Construction Mob-Demob/Site Controls/Survey	% of CCS	10%		$0
Tax	% of CCS	7.9%		$0
Subtotal				**$0**
Total Construction Costs (TCC)				***$0***
OTHER PROJECT COSTS				
Institutional Controls	Lump Sum	$20,000	1	$20,000
Engineering/Permitting	% of TCC (less tax)	5%		**$0**
Construction Oversight and Management	% of TCC (less tax)	Varies		**$0**
Long-term Monitoring	All (14Q)			$840,000
O&M for Soil Covers and Caps (30 years)	Per Acre, Per Year	$340	0	$0
Subtotal				**$860,000**
Upland Remediation Estimated Total Cost (EST) [1]				***$860,000***

Note:
1 = Appropriate range of contingency is applied to total costs in Table 10-3.

Table L-4
Estimated Cost of Alternative 2

Alternative 2: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with 2-foot soil cover
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 20 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 25 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
DIRECT CONSTRUCTION COSTS				
West Groundwater Area				
Groundwater				
No construction	--	--	--	--
Subtotal				**$0**
SU1 - Landfill # 2 (Industrial)				
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440	3.0	$175,320
Subtotal				**$175,000**
SU2 - Fill Deposit B-3 (Residual Carbon)				
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440	17.4	$1,016,856
Subtotal				**$1,017,000**
East Groundwater Area				
Groundwater				
No construction	--	--	--	--
Subtotal				**$0**
SU3 - Fill Deposit B-2 (Residual Carbon)				
New Soil Cover (gravel surface)	Acre	$117,250	4.3	$504,175
Increased Soil Cover Area due to Consolidation	Acre	$107,820	0.2	$19,307
Subtotal				**$523,000**
SU4 - Former Cryolite Ditches				
RR and Angle Residual General Fill Cover	CY	$27	199	$5,386
Cryolite Backfill - purchase, deliver, place, and compact	CY	$27	1,280	$34,552
Cryolite Ditch - New Soil Cover(gravel surface)	Acre	$117,250	0.2	$23,251
Subtotal				**$63,000**
SU5 - Former Stockpile Area				
SPL Ditch Backfill - purchase, deliver, place, and compact	CY	$27	703	$18,976
Enhance Existing Soil Cover (gravel surface)	Acre	$67,860	1.4	$95,004
Subtotal				**$114,000**
SU6 - Fill Deposit B-1 (Residual Carbon)				
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440	8.6	$502,584
Subtotal				**$503,000**
SU7 - Fill Deposit A (Spent Lime)				
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440	4.6	$268,824
Subtotal				**$269,000**
SU8 - Landfill # 1 (Floor Sweeps)				
Grading	Acre	$18,740	2.5	$46,850
New Soil Cover (hydroseed surface)	Acre	$107,820	2.5	$269,550
Subtotal				**$316,000**
SU9 - Pitch Storage Area				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	3	$1,500
Excavate and Load for Off-site Disposal - Pitch Unloading Area	CY	$3	120	$360
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	120	$42,360

Table L-4
Estimated Cost of Alternative 2

Alternative 2: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with 2-foot soil cover
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 20 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 25 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
Gravel Surface	Acre	$19,850	0.3	$5,955
Subtotal				**$50,000**
SU10 - Landfill # 3 (Construction Debris)				
New Soil Cover (hydroseed surface)	Acre	$107,820	1.3	$140,166
Subtotal				**$140,000**
SU11 - Flat Storage Area				
Backfill - purchase, deliver, place, and compact	CY	$27	70	$1,890
Excavate and Load for Off-site Disposal	CY	$3	70	$210
Soil Confirmation Sampling (10 per acre removed)	Each	$500	2	$1,000
Transport & Off-site Disposal (Solid Waste)	CY	$66	70	$4,620
Subtotal				**$8,000**
Construction Cost Subtotal (CCS)				***$3,178,000***
OTHER CONTRACTOR COSTS				
Construction Mob-Demob/Site Controls/Survey	% of CCS	10%		$317,800
Tax	% of CCS	7.9%		$251,000
Subtotal				**$569,000**
Total Construction Costs (TCC)				***$3,747,000***
OTHER PROJECT COSTS				
Institutional Controls	Lump Sum	$20,000	1	$20,000
Engineering/Permitting	% of TCC (less tax)	5%		$175,000
Construction Oversight and Management	% of TCC (less tax)	Varies		$350,000
Long-term Groundwater Monitoring	West (10Q, 20A); East (5Q, 25A)		--	$2,062,500
O&M for Soil Covers and Caps (30 years)	Per Acre, Per Year	$340	43.3	$441,600
Subtotal				**$3,049,000**
Upland Remediation Estimated Total Cost (EST) [1]				***$6,800,000***

Note:
1 = Appropriate range of contingency is applied to total costs in Table 10-3.

Table L-5
Estimated Cost of Alternative 3

Alternative 3: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with 2-foot soil cover
- 6 acres of impacted soil, fill deposit and landfill materials would be excavated and consolidated
- PRBs would be installed adjacent to SU3 and downgradient of SU2
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 20 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 25 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
DIRECT CONSTRUCTION COSTS				
West Groundwater Area				
Groundwater				
PRB Trench at SU2	Linear Foot	$520	350	$182,000
Consolidate Trench Soil in SU2	CY	$12	778	$9,333
Subtotal				**$191,000**
SU1 - Landfill # 2 (Industrial)				
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440	3.0	$175,320
Subtotal				**$175,000**
SU2 - Fill Deposit B-3 (Residual Carbon)				
Grading	Acre	$18,740	11.4	$213,636
New Soil Cover (hydroseed surface)	Acre	$107,820	11.4	$1,229,148
Excavate, Haul, & Consolidate on-site	CY	$12	54,800	$657,600
Backfill - purchase, deliver, place, and compact	CY	$27	46,550	$1,256,850
Reactive - purchase, deliver, place, and compact	CY	$63.0	2,450	$154,350
Soil Confirmation Sampling (10 per acre removed)	Each	$500	50	$25,000
Subtotal				**$3,537,000**
East Groundwater Area				
Groundwater				
PRB Trench at SU3	Linear Foot	$520	1,000	$520,000
Consolidate Trench Soil in SU6/7	CY	$12	2,222	$26,667
Subtotal				**$547,000**
SU3 - Fill Deposit B-2 (Residual Carbon)				
New Soil Cover (gravel surface)	Acre	$117,250	4.3	$504,175
Increased Soil Cover Area due to Consolidation	Acre	$107,820	0.2	$19,307
Subtotal				**$523,000**
SU4 - Former Cryolite Ditches				
RR and Angle Residual Reactive Cover	CY	$63.0	199	$12,567
Cryolite Backfill - purchase, deliver, place, and compact	CY	$27	640	$17,276
Cryolite Reactive - purchase, deliver, place, and compact	CY	$63.0	640	$40,311
Cryolite Ditch - New Soil Cover(gravel surface)	Acre	$117,250	0.2	$23,251
Subtotal				**$93,000**
SU5 - Former Stockpile Area				
SPL Ditch Backfill - purchase, deliver, place, and compact	CY	$27	351	$9,488
SPL Ditch Reactive - purchase, deliver, place, and compact	CY	$63.0	351	$22,139
Enhance Existing Soil Cover (gravel surface)	Acre	$67,860	1.4	$95,004
Subtotal				**$127,000**
SU6 - Fill Deposit B-1 (Residual Carbon)				
Enhance Existing Soil Cover (hydroseed surface)	Acre	$58,440	8.6	$502,584
Subtotal				**$503,000**

Table L-5
Estimated Cost of Alternative 3

Alternative 3: Remedial Action Summary
- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with 2-foot soil cover
- 6 acres of impacted soil, fill deposit and landfill materials would be excavated and consolidated
- PRBs would be installed adjacent to SU3 and downgradient of SU2
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 20 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 25 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
SU7 - Fill Deposit A (Spent Lime)				
Grading	Acre	$18,740	4.6	$86,204
New Soil Cover (hydroseed surface)	Acre	$107,820	4.6	$495,972
Subtotal				**$582,000**
SU8 - Landfill # 1 (Floor Sweeps)				
Grading	Acre	$18,740	2.5	$46,850
New Soil Cover (hydroseed surface)	Acre	$107,820	2.5	$269,550
Subtotal				**$316,000**
SU9 - Pitch Storage Area				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	3	$1,500
Excavate and Load for Off-site Disposal - Pitch Unloading Area	CY	$3	120	$360
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	120	$42,360
Gravel Surface	Acre	$19,850	0.3	$5,955
Subtotal				**$50,000**
SU10 - Landfill # 3 (Construction Debris)				
New Soil Cover (hydroseed surface)	Acre	$107,820	0.0	$0
Excavate, Haul, & Consolidate on-site	CY	$12	13,560	$162,720
Increased Soil Cover Area due to Consolidation	Acre	$107,820	0.1	$6,436
Soil Confirmation Sampling (10 per acre removed)	Each	$500	13.0	$6,500
Backfill - purchase, deliver, place, and compact	CY	$27	13,560	$366,120
Subtotal				**$542,000**
SU11 - Flat Storage Area				
Backfill - purchase, deliver, place, and compact	CY	$27	70	$1,890
Excavate and Load for Off-site Disposal	CY	$3	70	$210
Soil Confirmation Sampling (10 per acre removed)	Each	$500	2	$1,000
Transport & Off-site Disposal (Solid Waste)	CY	$66	70	$4,620
Subtotal				**$8,000**
Construction Cost Subtotal (CCS)				***$7,194,000***
OTHER CONTRACTOR COSTS				
Construction Mob-Demob/Site Controls/Survey	% of CCS	10%		$719,400
Tax	% of CCS	7.9%		$568,000
Subtotal				**$1,287,000**
Total Construction Costs (TCC)				***$8,481,000***

Table L-5
Estimated Cost of Alternative 3

Alternative 3: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with 2-foot soil cover
- 6 acres of impacted soil, fill deposit and landfill materials would be excavated and consolidated
- PRBs would be installed adjacent to SU3 and downgradient of SU2
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 20 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 25 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
OTHER PROJECT COSTS				
Institutional Controls	Lump Sum	$20,000	1	$20,000
Engineering/Permitting	% of TCC (less tax)	5%		$396,000
Construction Oversight and Management	% of TCC (less tax)	Varies		$554,000
Long-term Groundwater Monitoring	West (10Q, 20A); East (5Q, 25A)		--	$2,062,500
O&M for Soil Covers and Caps (30 years)	Per Acre, Per Year	$340	36.0	$367,200
Subtotal				**$3,400,000**
Upland Remediation Estimated Total Cost (EST) [1]				***$11,900,000***

Note:
1 = Appropriate range of contingency is applied to total costs in Table 10-3.

Table L-6
Estimated Cost of Alternative 4

Alternative 4: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with low-permeability caps
- 14 acres of impacted soil, fill deposit and landfill materials would be excavated and consolidated
- Reactive backfill would be used in excavated areas exceeding groundwater cleanup levels
- PRB would be installed downgradient of SU2 and at the northwest corner of the Closed BMP Facility
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 4 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 9 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
DIRECT CONSTRUCTION COSTS				
West Groundwater Area				
Groundwater				
PRB Trench at SU2	Linear Foot	$520	350	$182,000
PRB Trench at northwest corner	Linear Foot	$520	725	$377,000
Consolidate Trench Soil in SU2	CY	$12	2389	$28,667
Subtotal				**$588,000**
SU1 - Landfill # 2 (Industrial)				
Grading	Acre	$18,740	3.0	$56,220
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	3.0	$566,460
Subtotal				**$623,000**
SU2 - Fill Deposit B-3 (Residual Carbon)				
Grading	Acre	$18,740	11.4	$213,636
Excavate, Haul, & Consolidate on-site	CY	$12	54,800	$657,600
Backfill - purchase, deliver, place, and compact	CY	$27	46,550	$1,256,850
Reactive - purchase, deliver, place, and compact	CY	$63	2,450	$154,350
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	11.4	$2,152,548
Soil Confirmation Sampling (10 per acre removed)	Each	$500	50	$25,000
Subtotal				**$4,460,000**
East Groundwater Area				
Groundwater				
No construction	--	--	--	--
Subtotal				**$0**
SU3 - Fill Deposit B-2 (Residual Carbon)				
Excavate, Haul, & Consolidate on-site	CY	$12	40,310	$483,720
Increased Low Permeability Cap Area due to Consolidation	Acre	$188,820	0.2	$33,811
Reactive - purchase, deliver, place, and compact	CY	$63	2,608	$164,283
Backfill - purchase, deliver, place, and compact	CY	$27	37,702	$1,017,963
Gravel Surface	Acre	$19,850	4.3	$85,355
Dewatering- wellpoint, pump, on-site treatment	Acre	$19,130	13.0	$248,690
Transport & Off-site Disposal (Dangerous Waste including K088)	Each	$500	43	$21,500
Subtotal				**$2,055,000**
SU4 - Former Cryolite Ditches				
RR and Angle Residual Reactive Cover	CY	$63	199	$12,567
Cryolite Backfill - purchase, deliver, place, and compact	CY	$27	640	$17,276
Cryolite Reactive - purchase, deliver, place, and compact	CY	$63	640	$40,311
Subtotal				**$70,000**
SU5 - Former Stockpile Area				
SPL Ditch Backfill - purchase, deliver, place, and compact	CY	$27	351	$9,488

Table L-6
Estimated Cost of Alternative 4

Alternative 4: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with low-permeability caps
- 14 acres of impacted soil, fill deposit and landfill materials would be excavated and consolidated
- Reactive backfill would be used in excavated areas exceeding groundwater cleanup levels
- PRB would be installed downgradient of SU2 and at the northwest corner of the Closed BMP Facility
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 4 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 9 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
SPL Ditch Reactive - purchase, deliver, place, and compact	CY	$63.0	351	$22,139
Excavate, Haul, & Consolidate on-site	CY	$12	5,780	$69,360
Backfill - purchase, deliver, place, and compact	CY	$27	3,538	$95,515
Reactive - purchase, deliver, place, and compact	CY	$63	2,242	$141,271
Gravel Surface	Acre	$19,850	1	$27,790
Soil Confirmation Sampling (10 per acre removed)	Each	$500	14	$7,000
Subtotal				**$373,000**
SU6 - Fill Deposit B-1 (Residual Carbon)				
Grading	Acre	$18,740	8.6	$161,164
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	8.6	$1,623,852
Subtotal				**$1,785,000**
SU7 - Fill Deposit A (Spent Lime)				
Grading	Acre	$18,740	4.6	$86,204
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	4.6	$868,572
Subtotal				**$955,000**
SU8 - Landfill # 1 (Floor Sweeps)				
Grading	Acre	$18,740	2.5	$46,850
Excavate, Haul, & Consolidate onsite	CY	$12	52,910	$634,920
Increased Low Permeability Cap Area due to Consolidation	Acre	$188,820	0.2	$37,192
Soil Confirmation Sampling (10 per acre removed)	Each	$500	25.0	$12,500
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	2.5	$47,375
Subtotal				**$779,000**
SU9 - Pitch Storage Area				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	3	$1,500
Excavate and Load for Off-site Disposal - Pitch Unloading Area	CY	$3	120	$360
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	120	$42,360
Gravel Surface	Acre	$19,850	0.3	$5,955
Subtotal				**$50,000**
SU10 - Landfill # 3 (Construction Debris)				
New Soil Cover (hydroseed surface)	Acre	$107,820	0.0	$0
Excavate, Haul, & Consolidate on-site	CY	$12	13,560	$162,720
Increased Low Permeability Cap Area due to Consolidation	Acre	$188,820	0.1	$11,270
Soil Confirmation Sampling (10 per acre removed)	Each	$500	13	$6,500
Backfill - purchase, deliver, place, and compact	CY	$27	13,560	$366,120
Subtotal				**$547,000**

Table L-6
Estimated Cost of Alternative 4

Alternative 4: Remedial Action Summary

- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with low-permeability caps
- 14 acres of impacted soil, fill deposit and landfill materials would be excavated and consolidated
- Reactive backfill would be used in excavated areas exceeding groundwater cleanup levels
- PRB would be installed downgradient of SU2 and at the northwest corner of the Closed BMP Facility
- Approximately 400 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 4 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 9 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
SU11 - Flat Storage Area				
Backfill - purchase, deliver, place, and compact	CY	$27	70	$1,890
Excavate and Load for Off-site Disposal	CY	$3	70	$210
Soil Confirmation Sampling (10 per acre removed)	Each	$500	2	$1,000
Transport & Off-site Disposal (Solid Waste)	CY	$66	70	$4,620
Subtotal				**$8,000**
Construction Cost Subtotal (CCS)				***$12,293,000***
OTHER CONTRACTOR COSTS				
Construction Mob-Demob/Site Controls/Survey	% of CCS	10%		$1,229,300
Tax	% of CCS	7.9%		$971,147
Subtotal				**$2,200,000**
Total Construction Costs (TCC)				***$14,493,000***
OTHER PROJECT COSTS				
Institutional Controls	Lump Sum	$20,000	1	$20,000
Engineering/Permitting	% of TCC (less tax)	5%		$676,000
Construction Oversight and Management	% of TCC (less tax)	Varies		$947,000
Long-term Groundwater Monitoring	West (10Q, 4A); East (5Q, 9A)		--	$1,362,500
O&M for Soil Covers and Caps (30 years)	Per Acre, Per Year	$340	27.6	$281,500
Subtotal				**$3,287,000**
Upland Remediation Estimated Total Cost (EST) [1]				***$17,800,000***

Note:
1 = Appropriate range of contingency is applied to total costs in Table 10-3.

Table L-7
Estimated Cost of Alternative 5

Alternative 5: Remedial Action Summary ● Institutional controls would be established ● All fill deposits, landfills and soils exceeding cleanup levels would be capped with low-permeability caps ● 5 acres of fill deposit materials would be excavated and consolidated ● Reactive backfill would be used in excavated areas exceeding groundwater cleanup levels ● PRB would be installed downgradient of SU2 and at the northwest corner of the Closed BMP Facility ● Approximately 134,000 cy soil would be excavated and transported for off-site disposal ● Long-term monitoring would occur quarterly for 10 years and annually for 4 years in the West Groundwater Area ● Long-term monitoring would occur quarterly for 5 years and annually for 9 years in the East Groundwater Area				
FS Site Unit	**Units**	**Unit Cost**	**No. of Units**	**Cost**
DIRECT CONSTRUCTION COSTS				
West Groundwater Area				
Groundwater				
PRB Trench at SU2	Linear Foot	$520	350	$182,000
PRB Trench at northwest corner	Linear Foot	$520	725	$377,000
Consolidate Trench Soil in SU2	CY	1200%	2389	$28,667
Subtotal				**$588,000**
SU1 - Landfill # 2 (Industrial)				
Grading	Acre	$18,740	3.0	$56,220
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	3.0	$566,460
Excavate and Load for Off-site Disposal	CY	$3	51,620	$154,860
Transport & Off-site Disposal (Solid Waste)	CY	$66	51,620	$3,406,920
Soil Confirmation Sampling (10 per acre removed)	Each	$500	30	$15,000
Subtotal				**$4,199,000**
SU2 - Fill Deposit B-3 (Residual Carbon)				
Grading	Acre	$18,740	12.4	$232,376
Excavate, Haul, & Consolidate on-site	CY	$12	44,401	$532,810
Backfill - purchase, deliver, place, and compact	CY	$27	68,249	$1,842,717
Reactive - purchase, deliver, place, and compact	CY	$63	2,220	$139,863
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	12.4	$2,341,368
Soil Confirmation Sampling (10 per acre removed)	Each	$500	50	$25,000
Subtotal				**$5,114,000**
East Groundwater Area				
Groundwater				
PRB Trench at SU6/SU7	Linear Foot	$520	1,850	$962,000
Consolidate Trench Soil in SU6/7	CY	$12	4,111	$49,333
Subtotal				**$1,012,000**
SU3 - Fill Deposit B-2 (Residual Carbon)				
Increased Low Permeability Cap Area due to Consolidation	Acre	$188,820	0.2	$33,811
Reactive - purchase, deliver, place, and compact	CY	$63	2,608	$164,283
Backfill - purchase, deliver, place, and compact	CY	$27	37,702	$1,017,963
Gravel Surface	Acre	$19,850	4.3	$85,355
Dewatering- wellpoint, pump, on-site treatment	Day	$19,130	13	$248,690
Excavate and Load for Off-site Disposal	CY	$3	40,310	$120,930
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	40,310	$14,229,430
Soil Confirmation Sampling (10 per acre removed)	Each	$500	43	$21,500
Subtotal				**$15,922,000**

Table L-7
Estimated Cost of Alternative 5

Alternative 5: Remedial Action Summary
- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with low-permeability caps
- 5 acres of fill deposit materials would be excavated and consolidated
- Reactive backfill would be used in excavated areas exceeding groundwater cleanup levels
- PRB would be installed downgradient of SU2 and at the northwest corner of the Closed BMP Facility
- Approximately 134,000 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 4 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 9 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
SU4 - Former Cryolite Ditches				
RR and Angle Residual Reactive Cover	CY	$63	199	$12,567
Cryolite Backfill - purchase, deliver, place, and compact	CY	$27	640	$17,276
Cryolite Reactive - purchase, deliver, place, and compact	CY	$63	640	$40,311
Subtotal				**$70,000**
SU5 - Former Stockpile Area				
SPL Ditch Backfill - purchase, deliver, place, and compact	CY	$27	351	$9,488
SPL Ditch Reactive - purchase, deliver, place, and compact	CY	$63.0	351	$22,139
Backfill - purchase, deliver, place, and compact	CY	$27	3,538	$95,515
Reactive - purchase, deliver, place, and compact	CY	$63	2,242	$141,271
Gravel Surface	Acre	$19,850	1.4	$27,790
Soil Confirmation Sampling (10 per acre removed)	Each	$500	14	$7,000
Excavate and Load for Off-site Disposal	CY	$3	5,780	$17,340
Transport & Off-site Disposal (Solid Waste)	CY	$66	5,780	$381,480
Subtotal				**$702,000**
SU6 - Fill Deposit B-1 (Residual Carbon)				
Grading	Acre	$18,740	8.6	$161,164
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	8.6	$1,623,852
Subtotal				**$1,785,000**
SU7 - Fill Deposit A (Spent Lime)				
Grading	Acre	$18,740	4.6	$86,204
Low-Permeability Cap (hydroseed surface)	Acre	$188,820	4.6	$868,572
Subtotal				**$955,000**
SU8 - Landfill # 1 (Floor Sweeps)				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	25	$12,500
Excavate and Load for Off-site Disposal	CY	$3	52,910	$158,730
Backfill - purchase, deliver, place, and compact	CY	$27	52,910	$1,428,570
Transport & Off-site Disposal (Solid Waste)	CY	$66	52,910	$3,492,060
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	3	$47,375
Subtotal				**$5,139,000**
SU9 - Pitch Storage Area				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	3	$1,500
Excavate and Load for Off-site Disposal - Pitch Unloading Area	CY	$3	120	$360
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	120	$42,360
Gravel Surface	Acre	$19,850	0.3	$5,955
Subtotal				**$50,000**

Table L-7
Estimated Cost of Alternative 5

Alternative 5: Remedial Action Summary
- Institutional controls would be established
- All fill deposits, landfills and soils exceeding cleanup levels would be capped with low-permeability caps
- 5 acres of fill deposit materials would be excavated and consolidated
- Reactive backfill would be used in excavated areas exceeding groundwater cleanup levels
- PRB would be installed downgradient of SU2 and at the northwest corner of the Closed BMP Facility
- Approximately 134,000 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 10 years and annually for 4 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 5 years and annually for 9 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
SU10 - Landfill # 3 (Construction Debris)				
New Soil Cover (hydroseed surface)	Acre	$107,820	0.0	$0
Soil Confirmation Sampling (10 per acre removed)	Each	$500	13	$6,500
Backfill - purchase, deliver, place, and compact	CY	$27	13,560	$366,120
Excavate and Load for Off-site Disposal	CY	$3	13,560	$40,680
Transport & Off-site Disposal (Solid Waste)	CY	$66	13,560	$894,960
Subtotal				**$1,308,000**
SU11 - Flat Storage Area				
Backfill - purchase, deliver, place, and compact	CY	$27	70	$1,890
Excavate and Load for Off-site Disposal	CY	$3	70	$210
Soil Confirmation Sampling (10 per acre removed)	Each	$500	2	$1,000
Transport & Off-site Disposal (Solid Waste)	CY	$66	70	$4,620
Subtotal				**$8,000**
Construction Cost Subtotal (CCS)				***$36,852,000***
OTHER CONTRACTOR COSTS				
Construction Mob-Demob/Site Controls/Survey	% of CCS	10%		$3,685,200
Tax	% of CCS	7.9%		$2,911,000
Subtotal				**$6,596,000**
Total Construction Costs (TCC)				***$43,448,000***
OTHER PROJECT COSTS				
Institutional Controls	Lump Sum	$20,000	1	$20,000
Engineering/Permitting	% of TCC (less tax)	5%		$2,027,000
Construction Oversight and Management	% of TCC (less tax)	Varies		$2,027,000
Long-term Groundwater Monitoring	West (10Q, 4A); East (5Q, 9A)		--	$1,362,500
O&M for Soil Covers and Caps (30 years)	Per Acre, Per Year	$340	28.6	$291,700
Subtotal				**$5,728,000**
Upland Remediation Estimated Total Cost (EST) [1]				***$49,200,000***

Notes:
SU2 backfill volume includes volume left in the middle of the SU after the excavation of SU1.
1 = Appropriate range of contingency is applied to total costs in Table 10-3.

Table L-8
Estimated Cost of Alternative 6

Alternative 6: Remedial Action Summary
- Institutional controls would be established
- PRB would be installed at the northwest corner of the Closed BMP Facility
- Approximately 587,000 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 8 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 3 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
DIRECT CONSTRUCTION COSTS				
West Groundwater Area				
Groundwater				
PRB Trench at northwest corner	Linear Foot	520	725	$377,000
Consolidate Trench Soil in SU2	CY	12	1,611	$19,333
Subtotal				**$396,333**
SU1 - Landfill # 2 (Industrial)				
Excavate and Load for Off-site Disposal	CY	$3	51,620	$154,860
Transport & Off-site Disposal (Solid Waste)	CY	$66	51,620	$3,406,920
Soil Confirmation Sampling (10 per acre removed)	Each	$500	30	$15,000
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	3	$56,850
Subtotal				**$3,634,000**
SU2 - Fill Deposit B-3 (Residual Carbon)				
Backfill - purchase, deliver, place, and compact	CY	$27	181,160	$4,891,320
Reactive - purchase, deliver, place, and compact	CY	$63.0	0	$0
Excavate and Load for Off-site Disposal	CY	$3	155,090	$465,270
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	155,090	$54,746,770
Soil Confirmation Sampling (10 per acre removed)	Each	$500	174	$87,000
Dewatering- wellpoint, pump, on-site treatment	Day	$19,130	50	$961,355
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	17.4	$329,730
Subtotal				**$61,481,000**
East Groundwater Area				
Groundwater				
No construction	--	--	--	--
Subtotal				**$0**
SU3 - Fill Deposit B-2 (Residual Carbon)				
Increased Low Permeability Cap Area due to Consolidation	Acre	$188,820	0.2	$33,811
Reactive - purchase, deliver, place, and compact	CY	$63	2,607.7	$164,283
Backfill - purchase, deliver, place, and compact	CY	$27	37,702	$1,017,963
Gravel Surface	Acre	$19,850	4.3	$85,355
Dewatering- wellpoint, pump, on-site treatment	Day	$19,130	13.0	$248,690
Excavate and Load for Off-site Disposal	CY	$3	40,310	$120,930
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	40,310	$14,229,430
Soil Confirmation Sampling (10 per acre removed)	Each	$500	43	$21,500
Subtotal				**$15,922,000**
SU4 - Former Cryolite Ditches				
RR and Angle Residual Reactive Cover	CY	$63	199	$12,567
Cryolite Backfill - purchase, deliver, place, and compact	CY	$27	640	$17,276
Cryolite Reactive - purchase, deliver, place, and compact	CY	$63	640	$40,311
Subtotal				**$70,000**
SU5 - Former Stockpile Area				
SPL Ditch Backfill - purchase, deliver, place, and compact	CY	$27	351	$9,488

Table L-8
Estimated Cost of Alternative 6

Alternative 6: Remedial Action Summary

- Institutional controls would be established
- PRB would be installed at the northwest corner of the Closed BMP Facility
- Approximately 587,000 cy soil would be excavated and transported for off-site disposal
- Long-term monitoring would occur quarterly for 8 years in the West Groundwater Area
- Long-term monitoring would occur quarterly for 3 years in the East Groundwater Area

FS Site Unit	Units	Unit Cost	No. of Units	Cost
SPL Ditch Reactive - purchase, deliver, place, and compact	CY	$63.0	351	$22,139
Backfill - purchase, deliver, place, and compact	CY	$27	3,538	$95,515
Reactive - purchase, deliver, place, and compact	CY	$63	2,242	$141,271
Gravel Surface	Acre	$19,850	1.4	$27,790
Soil Confirmation Sampling (10 per acre removed)	Each	$500	14	$7,000
Excavate and Load for Off-site Disposal	CY	$3	5,780	$17,340
Transport & Off-site Disposal (Solid Waste)	CY	$66	5,780	$381,480
Subtotal				**$702,000**
SU6 - Fill Deposit B-1 (Residual Carbon)				
Excavate and Load for Off-site Disposal	CY	$3	230,220	$690,660
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	230,220	$81,267,660
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	8.6	$162,970
Soil Confirmation Sampling (10 per acre removed)	Each	$500	86	$43,000
Subtotal				**$82,164,000**
SU7 - Fill Deposit A (Spent Lime)				
Excavate and Load for Off-site Disposal	CY	$3	63,210	$189,630
Backfill - purchase, deliver, place, and compact	CY	$27	63,210	$1,706,670
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	5	$87,170
Transport & Off-site Disposal (Solid Waste)	CY	$66	63,210	$4,171,860
Soil Confirmation Sampling (10 per acre removed)	Each	$500	46	$23,000
Subtotal				**$6,178,000**
SU8 - Landfill # 1 (Floor Sweeps)				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	25	$12,500
Excavate and Load for Off-site Disposal	CY	$3	52,910	$158,730
Backfill - purchase, deliver, place, and compact	CY	$27	52,910	$1,428,570
Transport & Off-site Disposal (Solid Waste)	CY	$66	52,910	$3,492,060
Resurface Excavation with topsoil and hydroseed	Acre	$18,950	3	$47,375
Subtotal				**$5,139,000**
SU9 - Pitch Storage Area				
Soil Confirmation Sampling (10 per acre removed)	Each	$500	3	$1,500
Excavate and Load for Off-site Disposal - Pitch Unloading Area	CY	$3	120	$360
Transport & Off-site Disposal (Dangerous Waste including K088)	CY	$353	120	$42,360
Gravel Surface	Acre	$19,850	0.3	$5,955
Subtotal				**$50,000**
SU10 - Landfill # 3 (Construction Debris)				
New Soil Cover (hydroseed surface)	Acre	$107,820	0.0	$0
Soil Confirmation Sampling (10 per acre removed)	Each	$500	13	$6,500
Backfill - purchase, deliver, place, and compact	CY	$27	13,560	$366,120
Excavate and Load for Off-site Disposal	CY	$3	13,560	$40,680
Transport & Off-site Disposal (Solid Waste)	CY	$66	13,560	$894,960
Subtotal				**$1,308,000**

Table L-8
Estimated Cost of Alternative 6

FS Site Unit	Units	Unit Cost	No. of Units	Cost
Alternative 6: Remedial Action Summary ● Institutional controls would be established ● PRB would be installed at the northwest corner of the Closed BMP Facility ● Approximately 587,000 cy soil would be excavated and transported for off-site disposal ● Long-term monitoring would occur quarterly for 8 years in the West Groundwater Area ● Long-term monitoring would occur quarterly for 3 years in the East Groundwater Area				
SU11 - Flat Storage Area				
Backfill - purchase, deliver, place, and compact	CY	$27	70	$1,890
Excavate and Load for Off-site Disposal	CY	$3	70	$210
Soil Confirmation Sampling (10 per acre removed)	Each	$500	2	$1,000
Transport & Off-site Disposal (Solid Waste)	CY	$66	70	$4,620
Subtotal				**$8,000**
Construction Cost Subtotal (CCS)				***$177,052,333***
OTHER CONTRACTOR COSTS				
Construction Mob-Demob/Site Controls/Survey	% of CCS	10%		$17,705,233
Tax	% of CCS	7.9%		$13,987,000
Subtotal				**$31,692,000**
Total Construction Costs (TCC)				***$208,744,333***
OTHER PROJECT COSTS				
Institutional Controls	Lump Sum	$20,000	1	$20,000
Engineering/Permitting	% of TCC (less tax)	5%		$9,738,000
Construction Oversight and Management	% of TCC (less tax)	Varies		$9,738,000
Long-term Groundwater Monitoring	West (8Q); East (3Q)		--	$687,500
O&M for Soil Covers and Caps (30 years)	Per Acre, Per Year	$340	0.0	$0
Subtotal				**$20,184,000**
Upland Remediation Estimated Total Cost (EST) [1]				***$228,900,000***

Notes:
SU2 backfill volume includes volume left in the middle of the SU after the excavation of SU1.
1 = Appropriate range of contingency is applied to total costs in Table 10-3.

FIGURE

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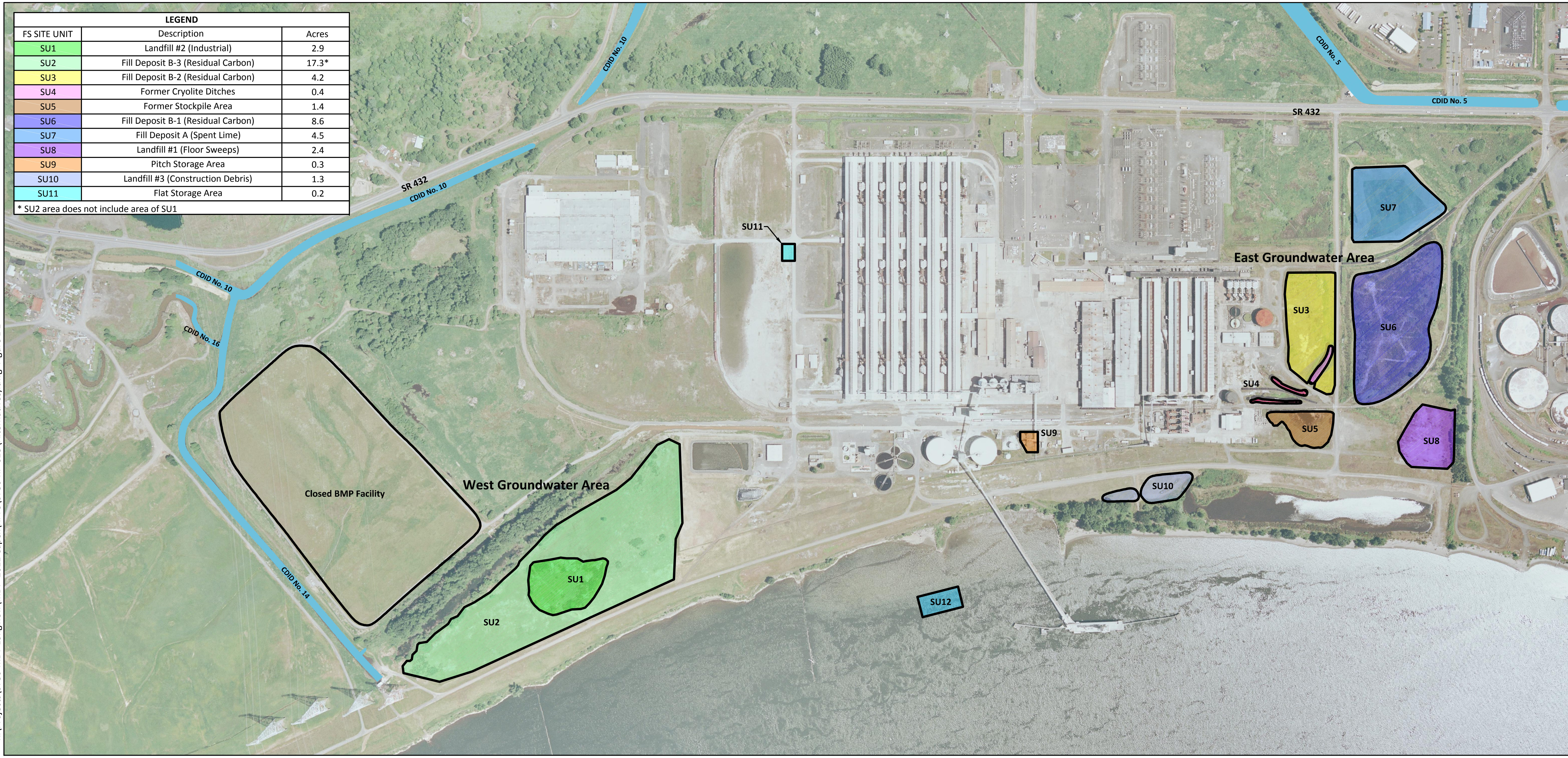
LEGEND

FS SITE UNIT	Description	Acres
SU1	Landfill #2 (Industrial)	2.9
SU2	Fill Deposit B-3 (Residual Carbon)	17.3*
SU3	Fill Deposit B-2 (Residual Carbon)	4.2
SU4	Former Cryolite Ditches	0.4
SU5	Former Stockpile Area	1.4
SU6	Fill Deposit B-1 (Residual Carbon)	8.6
SU7	Fill Deposit A (Spent Lime)	4.5
SU8	Landfill #1 (Floor Sweeps)	2.4
SU9	Pitch Storage Area	0.3
SU10	Landfill #3 (Construction Debris)	1.3
SU11	Flat Storage Area	0.2

* SU2 area does not include area of SU1



SOURCE: Aerial image from Aerometric dated June 2013.

0 600
Scale in Feet

Figure L-1
FS Site Units with Approximate Acreage
Remedial Investigation/Feasibility Study
Former Reynolds Metals Reduction Plant – Longview

ANCHOR QEA