Final
Remedial Investigation/ Feasibility Study

Remediation Area 2 - Salmon Bay Steel - North Section

The Port of Seattle Southwest Harbor
Cleanup and Redevelopment Project

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Appendices A-L

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Prepared by
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APPENDIX C

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TECHNICAL MEMORANDUM

Port of Seattle
Southwest Harbor Project
Subject: Column Leaching Studies

BVWS Project No.: 40439
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Appendix C

Column Leaching Studies

1.0 Introduction

Column leaching studies were performed on six slag/soil samples collected from three test pit locations in RA2. The purpose of this study was to gain a more thorough understanding of mobility of metals in slag/soil material at RA2 by simulating in situ conditions using a method designed for leaching solid waste (ASTM D 4874-89, Modified). Three slag/soil samples were collected from the unsaturated zone and leached with reagent grade water and three samples were collected from the saturated zone and leached with groundwater. Leachate was collected from every void volume and selected leachate samples were submitted to an analytical laboratory for chemical analysis. The laboratory analyzed the samples for metals (arsenic, chromium, copper, iron, lead, and zinc) and total dissolved solids concentrations. Results were reviewed to determine the extent of metals mobility from the slag/soil to the groundwater at this site.

2.0 Objectives

Column leaching studies were performed to help evaluate potential leaching and relative mobility of metals in the slag/soil. Results from the column leaching studies were compared and evaluated against Phase I and Phase II soil and groundwater results. Findings from this evaluation are discussed in the results section of this memorandum.

Test pits TP20, TP21, and TP27 (TP27 was located in pilot test excavation TE01) were selected for column leaching studies from areas of concern that were identified in the Phase I Summary Report (Black & Veatch 1994a). The test pit locations and the rationale for their selection are as follows:

- Test pit TP20 was located adjacent to monitoring well MW-202 and test pit TP03 where elevated concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc were detected during Phase I.

- Test pit TP21 was located within the vicinity of the pickle liquor disposal area and adjacent to monitoring well MW-209 and test pit TP02 where elevated concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc were detected during Phase I.
- Test Pit TP27 (TP27 was located in pilot test excavation TE01) was located adjacent to monitoring well MW-204 and test pit TP08 where elevated concentrations of arsenic, beryllium, cadmium, chromium, copper, lead, nickel, and zinc were detected during Phase I.

These locations also contained elevated TPH and PCB concentrations as a result of past site use. These locations were identified in the Phase I Summary Report as areas requiring further investigation.

3.0 Methodology

The following sections provide detailed descriptions of how slag/soil samples were collected and column leaching studies were performed and analyzed.

3.1 Overview

Six slag/soil samples were collected April 25 through April 26, 1994 from three test pits TP20, TP21, and TP27. Three of the column leaching studies were performed on samples collected from midway between ground surface and the top of the water table to mimic rainwater infiltration and subsequent leaching of metals from the unsaturated zone. The other three column leaching studies were performed on slag/soil samples collected from below the water table to mimic groundwater leaching and transport of metals from the saturated zone. Groundwater, the leaching media for the saturated zone, was collected on April 25 from monitoring well MW-213. This well is an upgradient well that is believed to represent background water quality conditions (Section 7.4). This water is representative of groundwater entering the slag fill area and is, therefore, critical for predicting water quality after the site is capped. Additionally, because the groundwater is relatively free of metals it has the greatest potential to leach metals from the slag. A sample of fresh slag was also collected. Samples were submitted to Soil Technology, Inc., for column leaching tests.

3.2 Sample Collection From Test Pits

The test pits were excavated using the methodology outlined in Appendix B, Test Pit Excavations. Test pit samples collected for column leaching studies were deposited by the trackhoe bucket on top of clean plastic sheeting. The samples were then sorted using a 1-inch screen. The percentage of the minus 1-inch fraction was estimated by screening a known volume of soil, estimating the minus 1-inch fraction, and calculating the percentage. Two 5-gallon buckets of the minus 1-inch slag/soil were collected from the saturated and unsaturated zones at each of the three test pit locations. Equipment used to collect and screen test pit samples was decontaminated between sample locations using the methodology outlined in Appendix B. One 5-gallon bucket of fresh slag was collected from the surface of a hot slag pile at the current location of the slag sorting equipment using the same method of collection described above. Column leaching tests were not performed on this sample because this material is tested by Salmon Bay Steel. Sample custody followed the procedures described in the SAP (Black & Veatch 1994b). A total of six slag/soil samples and one fresh slag sample were collected from the site. A sample key which identifies test pit locations and the sample identifications is presented in Table C-1. Appendix B contains the test pit excavation logs for TP20, TP21, and TP27.

3.3 Groundwater Collection

Groundwater was collected from monitoring well MW-213 on April 25, 1994. A total of three 15-gallon carboy containers were collected immediately after MW-213 was purged and sampled for a full suite of analyses. Table H-2 in Appendix H provides a list of required analyses for groundwater collected from monitoring well MW-213. Groundwater collected from MW-213 was used to leach the samples collected from the saturated zone. The hydrochemistry of monitoring well MW-213

Table C-1
Column Leaching Study Sample Key and Analytical Schedule

Station ID	Depth (ft/bgs)	Pore Volume	Date	Sample ID	Superior or Soil Tech. Lab ID	Matrix	QA/QC Information	Total Metals	Column Leaching Studies	Leachate Media	Leachate Metals (As, Cr, Cu, Fe, Pb, Zn)	TDS	Physical Parameters (pH, Eh, Ec)	Full Parameter Suite for Soils & Waters (Refer to Appendices B & H)
TP20	4	-	4/25/94	RA2TP20-SB003	58003	Soil/Slag		1						X
TP20	10	-	4/25/94	RA2TP20-SB004	58003	Soil/Slag		1						X
TP20	4	-	4/25/94	RA2TP20-CL001	Soil Tech	Soil/Slag			1					
TP20	10	-	4/25/94	RA2TP20-CL002	Soil Tech	Soil/Slag			1					
TP20-CL001	-	1	5/3/94	RA2CL20-HP001	91603-6	Leachate				X	X	X	X	
TP20-CL001	-	2	5/5/94	RA2CL20-HL002	HOLD	Leachate				X			X	
TP20-CL001	-	4	5/7/94	RA2CL20-HL004	91629-4	Leachate				X	X	X	X	
TP20-CL001	-	8	5/10/94	RA2LL20-HL008	91641-4	Leachate				X	X	X	X	
TP20-CL002	-	1	5/3/94	RA2CL20-GL001	91603-1	Leachate				X	X	X	X	
TP20-CL002	-	2	5/4/94	RA2CL20-GL002	HOLD	Leachate				X			X	
TP20-CL002	-	4	5/6/94	RA2CL20-GL004	91615-1	Leachate				X	X	X	X	
TP20-CL002	-	8	5/10/94	RA2LL20-GL008	91641-2	Leachate				X	X	X	X	
TP20-CL002	-	8	5/10/94	RA2CL20-GL025	91641-1	Leachate	Duplicate			X	X	X	X	
TP21	4	-	4/25/94	RA2TP21-SB002	58003	Soil/Slag		1						X
TP21	10	-	4/25/94	RA2TP21-SB003	58003	Soil/Slag		1						X
TP21	4.5	-	4/25/94	RA2TP21-CL001	Soil Tech	Soil/Slag			1					
TP21	6	-	4/25/94	RA2TP21-CL002	Soil Tech	Soil/Slag			1					
TP21-CL001	-	1	5/4/94	RA2CL21-HP001	91603-5	Leachate				X	X	X	X	
TP21-CL001	-	2	5/4/94	RA2CL21-HP002	HOLD	Leachate				X			X	
TP21-CL001	-	4	5/7/94	RA2CL21-HL004	91629-1	Leachate				X	X	X	X	
TP21-CL001	-	8	5/11/94	RA2LL21-HL008	91641-5	Leachate				X	X	X	X	

Table C-1 (continued)
Column Leaching Study Sample Key and Analytical Schedule

Station ID	Depth (ft/bgs)	Pore Volume	Date	Sample ID	Superior or Soil Tech. Lab ID	Matrix	QA/QC Information	Total Metals	Column Leaching Studies	Leachate Media	Leachate Metals (As, Cr, Cu, Fe, Pb, Zn)	TDS	Physical Parameters (pH, Eh, Ec)	Full Parameter Suite for Soils & Waters Refer to Appendices B & H)
TP21-CL002	-	1	5/3/94	RA2CL21-GL001	91603-2	Leachate				X	X	X	X	
TP21-CL002	-	2	5/4/94	RA2CL21-GL002	HOLD	Leachate				X			X	
TP21-CL002	-	4	5/6/94	RA2CL21-GL004	91615-5	Leachate				X	X	X	X	
TP21-CL002	-	8	5/10/94	RA2LL21-GL008	91641-3	Leachate				X	X	X	X	
TP27 aka TE01	4	-	4/26/94	RA2TP27-SB002	58011	Soil/Slag		1						X
TP27 aka TE01	6	-	4/26/94	RA2TP27-SB004	58011	Soil/Slag		1						X
TE01	4	-	4/26/94	RA2TE01-CL001	Soil Tech	Soil/Slag			1					
TE01	10	-	4/26/94	RA2TE01-CL002	Soil Tech	Soil/Slag			1					
TE01-CL001	-	1	5/4/94	RA2CL01-HP001	91603-4	Leachate				X	X	X	X	
TE01-CL001	-	2	5/5/94	RA2CL01-HP002	HOLD	Leachate				X			X	
TE01-CL001	-	4	5/7/94	RA2CL01-HL004	91629-3	Leachate				X	X	X	X	
TE01-CL001	-	4	5/7/94	RA2CL11-HL004	91629-2	Leachate	Duplicate			X	X	X	X	
TE01-CL001	-	8	5/11/94	RA2LL01-HL008	91641-6	Leachate				X	X	X	X	
TE01-CL002	-	1	5/4/94	RA2CL01-GL001	91603-3	Leachate				X	X	X	X	
TE01-CL002	-	2	5/6/94	RA2CL01-GL002	HOLD	Leachate				X			X	
TE01-CL002	-	4	5/12/94	RACL01-GL004	91662-1	Leachate				X	X	X	X	
TE01-CL002	-	8	5/21/94	RACL01-GL008	91703-1	Leachate				X	X	X	X	
Fresh Slag	Surface	-	4/26/94	RAHTSG-CL001	Soil Tech	Slag								
MW13	-	-	4/25/94	RA2MW13-GW001	Soil Tech	GW				X				X

Notes:
Metals and TDS concentrations were not analyzed for in pore volume number two samples.
Refer to the appendix for a complete list of soil and groundwater analytes.

is discussed in Section 7.4 of the RI. Monitoring well MW-213 is considered an upgradient, background well.

The groundwater was delivered by EcoChem to Soil Technology, Inc. on April 27, 1994. Sample custody followed the procedures described in the SAP (Black & Veatch 1994b).

3.4 Column Leaching Tests

Upon sample receipt, Soil Technology Inc. prepared test pit samples for column leaching tests. One bucket from each sample was archived by Soil Technology Inc. for potential further use. Analysis using ASTM Method 4874-89 requires that soil samples be packed in the column in such a manner that the samples are representative of field conditions. Preliminary screening of the slag/soil was conducted because the maximum particle diameter for leaching studies cannot exceed 1/10 of the inside diameter of the column.

Each column, including its end caps and other miscellaneous fittings, were weighed and its mass was recorded. The height and diameter of columns (12" x 8") were each measured and recorded. Slag/soil samples were added and compacted in five equal scarified layers to the top of each respective column. Care was taken to compact the material evenly to prevent channeling. The entire column was weighed and the sample mass was recorded.

The leachate media were placed on a shelf directly above the columns and gravity fed so that leachate would flow up from the bottom to top of the column to further decrease the chance of channelized flow. Column samples were then saturated with the appropriate leaching media; the three samples from the unsaturated zone with "rainwater" (reagent grade distilled water was used as an equivalent) and three samples from the saturated zone with groundwater. Void volumes (also referred to as the interstitial volume) were calculated per ASTM Method 4874-89. After saturation, influent and effluent flows were adjusted to allow for one complete void volume change in a 24-hour period (±3 hours). Effluent flows in the saturated zone sample columns were adjusted to correlate with the estimated groundwater flow rate (Black & Veatch 1994a). Physical parameters such as pH, redox potential (Eh), and electrical conductivity (Ec) were monitored throughout the study. Methods used to perform these tests were ASTM D1293, ASTM D1125, and ASTM D1498. Flows were continuous throughout the column leaching studies. A minimum of eight void volumes were flushed through each column. After collection, column effluent contact with oxygen was reduced by filling headspace with purified nitrogen gas and storing the samples at 4° Celsius. Void volumes 1, 2, 4, and 8 were divided into sample aliquots and submitted to Superior Precision Analytical Inc., ~~(Superior), San Francisco, California for chemical analysis.~~

Samples submitted for metals analysis were filtered using a .45 micron filter and were preserved with nitric acid. Samples were filtered because dissolved metals are more predictive of actual leaching than total metals. The increased size of the sample voids in the hand-packed columns increased the potential for particulate matter in the leachate which may not be representative of the total metal concentrations in leachate. The sample pH was verified to ensure that the pH was less than 2. Total dissolved solid samples were collected directly from the void volume sample container. All samples were chilled on blue ice to 4°C and submitted to Superior for analyses. Sample custody followed the procedures outlined in the SAP (Black & Veatch 1994b).

Soil classification and physical property test results were performed on several soil samples collected from the site to further supplement field soil classification and define soil physical and/or hydraulic properties. These results are discussed in Section 6.3.1 and presented in Appendix K. Test pit logs are presented in Appendix B. Soil samples collected from test pits were visually examined and classified. Representative samples collected from each lithology type were submitted for geotechnical analysis. Laboratory physical property tests included moisture content, particle size distribution, soil density, atterberg limits, permeability of granular soils, and hydraulic conductivity of soils.

3.5 Modifications to ASTM D 4874-89 Method

Several modifications to the ASTM D4874-89 Method were made due to the nature of the material from the site. The ASTM D4874-89 Method was originally designed for solid waste and not for slag/soil material. A 4-inch diameter column is the standard used for this test, however, due to larger particle sizes at RA2, 8-inch diameter columns were used for these studies. Samples were screened in the field to remove material greater than 1 inch in diameter because the maximum particle size cannot exceed one tenth the diameter of the column.

The material was highly compacted on the site. It was not feasible to compact the columns to the required field density, particularly since the larger material had been removed during the screening process. It was determined that compacting the material as much as possible and replicating the mass of soil in each column would yield representative results.

For the saturated zone sample, the initial pore volume was held stagnant to duplicate field conditions more accurately. After the stagnant period (8 to 24 hours), void volumes were released at a rate similar to the estimated groundwater flow rate in water as discussed in the Phase I Summary Report (Black & Veatch 1994a). While awaiting results from the analytical laboratory, pore volume 9 was held stagnant in the soil for an extended period of time (approximately 7 days) and released upon receipt of pore volume 4 results.

This column containing the sample from the saturated zone in test pit TP27 behaved differently from the other samples. Review of porosity and test pit logs indicate that this sample was less permeable. It took longer than 24 hours for the column to drain one pore volume by gravity flow and it was determined that a slight vacuum pressure was necessary. These adjustments were recorded for review.

4.0 Deviations from the SAP

While collecting slag/soil samples from designated test pits at the site, a sample of the "hot slag" was collected for possible column leaching analysis. Column leaching tests were not performed on this sample because Salmon Bay Steel reports that the slag is tested and meets compliance with the Dangerous Waste Regulations (Chapter 173-303 WAC).

Duplicate column leaching studies were not performed, because data results indicated an acceptably low variance. It was determined that repeating the study would not provide information on the variability of the leaching potential.

5.0 Results

Table C-1 provides a sample key and analytical schedule for the Column Leaching Study including the related slag/soil samples from test pits and groundwater samples collected during the Phase II Investigation. Appendix M presents a detailed data quality assessment report for all Phase II analytical results. The column leaching data are considered acceptable for use without qualification based on a QA review.

5.1 Soil/Slag Characterization

Analytical results (total metals) of soil samples collected from test pit locations TP20, TP21, and TP27 at approximately 4.0 through 10.0 feet bgs are presented in Table C-2. Metals were detected in these test pits at the following concentration ranges:

- Arsenic: 3 mg/kg to 9 mg/kg.
- Chromium: 500 mg/kg (J) to 1800 mg/kg.
- Copper: 170 mg/kg (J) to 690 mg/kg.
- Lead: 39 mg/kg to 680 mg/kg.
- Zinc: 120 mg/kg (J) to 1500 mg/kg (J).

The slag/soil pH varied from 10.3 to 12.2. Additional analytical results from these test pits are summarized in Section 8.2 and are fully presented in Appendix O.

A variety of geotechnical tests were performed on 35 soil boring samples collected from 13 monitoring well locations. Of these, tests were performed on seven soil samples, with results ranging from 2.17×10^{-4} to 7.23×10^{-7} cm/s. The highest permeability results were measured in a sample collected from MW-204B at the depth of 7.5 to 9 feet below ground surface. Soil densities were measured in 8 of the

Table C-2
Chemical and Physical Characteristics of Soils Used for Column Leaching Studies

Metals and pH Results for Soils Collected From Test Pits[a]
Metals Quantified by EPA Methods 6010/7000 Series
pH Measured by EPA Method 9045

	Sample ID and Depth (feet below ground surface)						
Parameter	PQL (mg/kg)	TP20 (4.0 feet)	TP20 (10.0 feet)	TP21 (4.0 feet)	TP21 (10.0 feet)	TP27[b] (4.0 feet)	TP27[b] (6.0 feet)
Arsenic	1	5.0	7.0	8.0	9.0	3.0	8.0
Chromium	5	1800	1000	980	540	1200 J	500 J
Copper	5	180	410	690	470	170 J	290 J
Lead	5	39	310	680	130	40	100
Zinc	5	120 J	1500 J	290 J	620 J	170	250
pH	NA	12.2	11.7	11.3	10.6	11.2	10.3

Description and Screening Results for Material Used in Column Leaching Studies

	Sample ID and Depth (feet below ground surface)					
Characteristic	TP20 (4.0 feet)	TP20 (10.0 feet)	TP21 (4.5 feet)	TP21 (6.0 feet)	TP27[b] (4.0 feet)	TP27[b] (10.0 feet)
<1 inch fraction screening results	~67%	~75%	50%	75%	88%	75%
Classification/Description of Material	Dark grey slag and millscale	Dark brown millscale/ millscale fill	Silty gravely SAND, Abundant slag fragments	Silty, gravelly SAND, Abundant slag fragments	silty, sand, Gravel, slag	Silty, gravelly SAND, slag fragments
Porosity	.33	.38	.36	.38	.35	.29
Specific Gravity	3.33	3.60	3.25	3.15	3.00	3.10
Remolded Bulk Density[c]	148	166	142	129	136	155

Notes:

[a] Column leaching samples were collected from the following test pits:
TP20: 4.0 feet and 10.0 feet below ground surface (bgs)
TP21: 4.5 feet and 6.0 feet bgs
TP27: 4.0 feet and 10.0 feet bgs
These results approximate starting metals concentrations for column leaching studies.

[b] Test pit TP27 was located in Pilot Test Excavation TE01.

[c] Remolded bulk density in pounds per cubic foot were calculated before and after the leaching study. Data shown in the table represent before study conditions.

PQL: Practical quantitation limit. PQLs are based on Superior Analytical Data, 1994.
NA: Not applicable.
mg/kg: Milligrams per kilograms J: Estimated value.

35 soil samples and ranged from 76.4 to 143.2 pounds per cubic foot (pcf) in dry soil and 109.9 to 143.2 pcf in wet soil. These ranges are comparable to density measurements on soils submitted for leaching studies. Grain size distribution tests were performed on 24 soil boring samples collected from 13 monitoring well locations during Phase II of the investigation. Results from grain size tests indicated that silt and clay fractions in soil ranged from 1 percent to 97 percent and averaged 28 percent. These results are summarized in Section 6.0.

As presented in Table C-2, porosity values ranged from 29 percent to 38 percent in the ~~slag/soil material. Test pit soil sample, TP27 (TE01-CL002)~~, collected from the saturated zone, retained leachate for significantly longer periods of time due its low porosity (29 percent). Remolded bulk density values before the study ranged from 129 to 166 pcf, and after the study from 145 to 163 pcf. These values are considered to be very high indicating that the material is extremely dense (concrete is approximately 165 pcf) but still fairly permeable.

5.2 Leachate Characterization

Conventional and Physical Parameters. Physical parameters of the leachate samples were measured and recorded by Soil Technology Inc. The results are presented in Table C-3. Physical parameters of the leachate media were also measured before initiating the column leaching study.

Review of the physical parameter data shows a dramatic pH, Eh, and Ec increase from measurements made on the initial leaching media to measurements made after collection of pore volume 1. Throughout the study physical parameter changes exhibited small upward and downward trends: pH ranged from approximately 10.39 to 11.92; Eh from -71 to 18 millivolts; and specific conductivity from 520 to 3160 micromhos per centimeter (μmhos/cm). All "rainwater" and groundwater leached columns showed either a slight or no decrease in pH. Electrical conductivity measurements decreased over time in each column. Redox potentials in the rainwater and groundwater leached columns showed dissimilar trends over time. The redox measurements are not directly relevant to the study since the amount of oxygen

Table C-3
Physical Parameters (pH, Eh, and Electrical Conductivity)

Metal	Pore Volume	Detected Concentrations (µg/L)							
		TP20		TP21		TP27		Leaching Media	
		Rainwater	Groundwater	Rainwater	Groundwater	Rainwater	Groundwater	Unsaturated Columns[a]	Saturated Columns[b]
pH	**1**	**11.36**	**11.56**	**11.20**	**10.80**	**11.18**	**11.92**	**6.25**	**6.72**
	2	11.32	11.77	11.11	10.95	11.04	11.91	NA	NA
	3	11.43	11.69	11.24	10.87	11.26	11.75	NA	NA
	4	**11.36**	**11.65**	**11.19**	**10.92**	**11.00**	**11.78**	NA	NA
	5	11.17	11.61	11.08	10.39	10.91	11.65	NA	NA
	6	11.32	11.46	11.18	10.66	10.99	11.69	NA	NA
	7	11.18	11.57	11.07	11.80	10.93	11.79	NA	NA
	8	**11.38**	**11.51**	**10.85**	**10.72**	**10.56**	**11.79**	NA	NA
Eh (mV)	**1**	**-33**	**-29**	**-32**	**-45**	**-35**	**-71**	**68**	**123**
	2	-26	-18	-25	-2	-23	-62	NA	NA
	3	-49	-41	-45	0	-15	-56	NA	NA
	4	**-38**	**-50**	**-34**	**-19**	**-34**	**-59**	NA	NA
	5	-40	-39	-20	18	-35	-44	NA	NA
	6	-31	-40	-26	5	-26	-42	NA	NA
	7	-22	-33	-23	3	-23	-47	NA	NA
	8	**-23**	**-31**	**-50**	**11**	**-38**	**-25**	NA	NA
Electrical Conductivity (µmhos/cm)	**1**	**1040**	**1530**	**960**	**850**	**840**	**2890**	**10**	**470**
	2	1020	1670	800	690	710	3160	NA	NA
	3	990	1630	740	630	650	3160	NA	NA
	4	**970**	**1610**	**720**	**620**	**630**	**2970**	NA	NA
	5	930	1530	690	520	600	2160	NA	NA
	6	890	1520	670	580	590	2170	NA	NA
	7	880	1500	660	580	580	2230	NA	NA
	8	**860**	**1470**	**570**	**560**	**560**	**1990**	NA	NA

[a] Leaching media used for the saturated columns was groundwater collected from MW-213.

[b] Leaching media used for the unsaturated columns was reagent-grade distilled water.

Notes:

Bold and underlined type indicates samples sent for metals and TDS analyses.

pH: Units are 0.01.

Eh: Redox potential. Units are expressed as millivolts.

Electrical conductivity: Units are expressed as microohms/cm.

in the headspace of the leaching containers is controlled using nitrogen.

Total dissolved solids (TDS) concentrations in leachate samples collected from void volumes 1, 4, and 8 were analyzed by Superior. Concentrations ranged from 210 to 920 mg/L as shown in Table C-4. TDS concentrations in each column decreased throughout the study. These results correlate well with electrical conductivity which also decreased over time.

Metals. Leachate samples were also submitted to Superior for dissolved metals analysis. Leachate metals results are presented in Table C-4. Sample and sample duplicate (split) leachate results are presented in Table C-5. Generally, rainwater leached columns had higher concentrations of metals than groundwater leached columns. Table C-6 presents a summary of metals detected in each leaching media and in leachate collected from unsaturated and saturated columns.

Analytical results (metals and TDS) from monitoring well MW-213 and all other groundwater samples collected from monitoring wells during the Phase I and II investigation are presented and discussed in Sections 7.4 and 8.3.

6.0 Discussion

Column leachate study results indicated that little or no iron, lead, and zinc leached from either the saturated and unsaturated columns. Chromium was detected in leachate samples collected from the unsaturated columns and was generally not detected in leachate samples collected from saturated columns. Table C-7 compares the concentration ranges of metals detected in groundwater during the Phase I and Phase II investigations (from summary tables in Section 8.3.2) with concentration ranges of metals detected in the column leaching study samples.

Arsenic, lead, and zinc results from both saturated and unsaturated column leachate samples appear to be similar to concentration ranges detected in groundwater samples. The high iron concentrations in groundwater occurred in areas where pickle liquor containing iron sulfate was disposed of. The process was not duplicated (intentionally) in the column studies. However, the chromium and copper results in the leachate column studies show different trends compared to what was

Table C-4
Column Leaching Tests
Quantified by EPA Methods 3050, 6010, and the 7000 Series

Metal	Pore Volume	Method Reporting Limit (µg/L)	Detected Concentrations (µg/L)					
			TP20		TP21		TP27	
			Rainwater	Groundwater	Rainwater	Groundwater	Rainwater	Groundwater
Arsenic	1	5	5 U	5 U	5	9	18	5
	4	5	5 U	5 U	5 U	10	17	5 U
	8	5	5 U	5 U	5 U	13	18	5 U
Chromium	1	20	390	20 U	70	20 U	170	30
	4	20	140	20 U	20 U	20 U	40	20 U
	8	20	130	20 U	20 U	20 U	20 U	20 U
Copper	1	20	60	30	90	40	50	110
	4	20	60	20 U	40	20 U	30	90
	8	20	40	20 U	30	20 U	20	50
Iron	1	20	20 U	20 U	60	20	50	20 U
	4	20	20 U	20 U	20 U	20 U	20 U	20 U
	8	20	20 U	20 U	20 U	30	30	20 U
Lead	1	5	5 U	5 U	5 U	5 U	5 U	5 U
	4	5	5 U	5 U	5 U	5 U	5 U	5 U
	8	5	5 U	5 U	5 U	5 U	5 U	5 U
Zinc	1	20	20 U	20 U	30	20	20 U	20 U
	4	20	20 U	20 U	20 U	20 U	20 U	30
	8	20	90	20 U	40	20 U	30	20 U
TDS[a]	1	10	350	550	500	560	480	920
	4	10	280	450	250	380	220	750
	8	10	240	400	220	320	210	510
pH[b]	1	-	11.36	11.56	11.20	10.80	11.18	11.92
	4	-	11.36	11.65	11.19	10.92	11.00	11.78
	8	-	11.38	11.51	10.85	10.72	10.56	11.79

[a] Units of measure: mg/L (milligrams per liter).
[b] Units of measure: Standard units.

Notes:
Test pit TP27 was located in Pilot Test Excavation TE01.
U: Not detected at the listed practical quantitation limit (PQL).

Table C-5
Column Leaching Test - Duplicate Results
Quantified by EPA Methods 6010/7000 Series
Port of Seattle

Metals	Pore Volume	Practical Quantitation Limit (µg/L)	TP20		TP27[a]	
			Groundwater	Duplicate Groundwater	Rainwater	Duplicate Rainwater
Arsenic	1	5 U	5 U	NA	18	NA
	4	5 U	5 U	NA	17	18
	8	5 U	5 U	5 U	18	NA
Chromium	1	20 U	20 U	NA	170	NA
	4	20 U	20 U	NA	40	100
	8	20 U	20 U	20 U	20 U	NA
Copper	1	20 U	30	NA	50	NA
	4	20 U	20 U	NA	30	40
	8	20 U	20 U	20 U	20	NA
Iron	1	20 U	20 U	NA	50	NA
	4	20 U	20 U	NA	20 U	20 U
	8	20 U	20 U	20 U	30	NA
Lead	1	5 U	5 U	NA	5 U	NA
	4	5 U	5 U	NA	5 U	5 U
	8	5 U	5 U	5 U	5 U	NA
Zinc	1	20 U	20 U	NA	20 U	NA
	4	20 U	20 U	NA	20 U	20 U
	8	20 U	20 U	20 U	30	NA
TDS mg/L	1	10	550	NA	480	NA
	4	10	450	NA	220	270
	8	10	400	410	210	NA
pH Standard Units	1	--	11.56	NA	11.18	NA
	4	--	11.65	NA	11.00	11.00
	8	--	11.51	11.51	10.56	NA

[a] Test pit TP27 was located in Pilot Test Excavation TE01.
µg/L: Micrograms per liter. mg/L: Milligrams per liter. NA: Not available.
U: Not detected at listed Practical Quantitation Limit (PQL).

Table C-6
Comparison of Saturated and Unsaturated Zone Columns

Metal (Dissolved)	Concentration Ranges (µg/L)			
	Leach Media (Distilled Water)	Unsaturated Columns	Leach Media Monitoring Well MW-213	Saturated Columns
Arsenic	5 U	5 to 18	5 U	5 to 13
Chromium	20 U	<20 to 390	20 U	<20 to 30
Copper	20 U	<20 to 90	20 U	<20 to 110
Iron	20 U	<20 to 60	1200	<20 to 30
Lead	5 U	5 U	5	5 U
Zinc	20 U	<30 to 90	20	<20 to 30

NOTES:
U: Not detected at the Practical Quantitation Limit (PQL).
µg/L: Micrograms per liter.

Table C-7
Comparison Between Groundwater and Column Leaching Study

Metal (Dissolved) (µg/L)	Concentration Ranges (µg/L)			
	Groundwater		Column Leach Study	
	Range	Average	Range	Average
Arsenic	<5 to 91	12	<5 to 18	6
Chromium	20 U	20 U	<20 to 390	60
Copper	20 U	20 U	<20 to 90	43
Iron	<20 to 65,000	2969	<20 to 60	20 U
Lead	<5 to 20	5 U	5 U	5 U
Zinc	<20 to 640	37	<20 to 90	20 U

NOTES:
U: Not detected at the Practical Quantitation Limit (PQL).
µg/L: Micrograms per liter.

observed in groundwater. Overall detection frequencies of dissolved chromium and copper were low in groundwater but chromium and copper detection frequencies were high in unsaturated columns.

Chromium in the unsaturated columns was detected in decreasing concentrations throughout the column leaching study. A previous study (Confidential 1992) observed that chromium concentrations increased in the beginning of the study and decreased at the end of the study. This study suggested that hexavalent chromium may have leached from the fill matrix due to the salinity of the infiltrating waters (Confidential 1992). Woodward-Clyde, during the Phase II Investigation, collected six slag samples from the RA3 site from a variety of slag matrices and analyzed them for hexavalent chromium concentrations (Woodward-Clyde 1994). Hexavalent chromium was not detected (PQL = 0.20 mg/kg) in the slag samples submitted for analysis. Since the leaching media used for the column leaching studies were not saline and the prevalent form of chromium was chromium (III), other likely transport mechanisms were considered.

Chromium(III) is slightly soluble at neutral pH but readily precipitates as a hydroxide at pH greater than nine (Bodeck, et al. 1988). One explanation of the leaching study results is that rain water or salt water at a neutral pH infiltrates the slag/soil fill and leaches chromium(III) from the slag. At the same time, the water reacts with the lime to produce carbonate and hydroxide and the pH of the leachate rapidly rises above 10. The chromium (III) which was initially leached, now precipitates from solution as a very finely dispersed hydroxide. This finely dispersed chromium hydroxide is now present throughout the unsaturated zone. Whenever the unsaturated zone is leached with near-neutral solutions such as rainfall some of the chromium temporarily leaches and then re-precipitates further down in the soil column. No chromium is detected in the groundwater because the groundwater pH remains high enough to keep the chromium precipitated. With time, even the unsaturated zone of the slag stops releasing chromium because all the readily dissolved chromium has been leached from that zone into the saturated zone where it is not mobile.

Copper generally behaved similarly to chromium. Copper leached from the unsaturated zone column study samples and was detected at concentrations just above the PQL. Mobility of copper in the environment is also highly dependent on pH-consequent copper sorption to soil.

Pore volumes were equated to the measured 39 inches of annual rainfall for the RA2 area (Black & Veatch 1994a) to obtain a rough idea of how many equivalent inches of annual rainfall were percolated through the unsaturated soil samples. Approximately 4,000 mls (4,000 mls = 1 pore volume) were eluted through each of the unsaturated columns for eight pore volumes. The surface area of the soil in the column was approximated to be 324 cm^2 (soil column height was 12 inches). An annual rainfall of 39 inches, of which an estimated one half is lost to evapotranspiration prior to infiltration, is approximately equal to 16,000 mls or roughly four pore volumes. Approximately two years worth of rainfall was leached through the unsaturated column study samples during the leaching study.

Column study results were compared with other leaching study tests. TCLP extracts of samples collected from test pits during the Phase I and II investigations were analyzed for metals. Section 3.0, Potential Contaminant Sources, presents the TCLP results in Table 3-3. Barium, cadmium, and lead were detected in TCLP results during the Phase I investigation at concentrations ranging from 900 to 72,000 μg/L. During the Phase II investigation only barium and lead were detected in TCLP concentrations at concentrations ranging from 1300 to 1500 μg/L. The column leaching study is considerably more representative of environmental conditions than TCLP analyses for slag containing residual lime. As was shown with both the rainwater and groundwater leached columns, the residual lime in the slag rapidly raises the pH of the leaching medium, unless it is heavily buffered to an acidic pH as in the TCLP extraction. The strong acidic buffer (based on acetic acid) was designed in the TCLP extraction to mimic the acidic leachate produced during the first phase of a municipal landfill when oxidative degradation of fresh, putrescible waste is occurring. For landfills, this first phase is when metal leaching is the highest (USEPA SW-846 1992).

There are no conditions at RA2 that are similar to the TCLP conditions. The alkaline leachate produced by the slag leaches metals very differently than the acidic leachate in the TCLP extraction. Consequently, the TCLP extraction is a poor predictor of slag leaching behavior.

7.0 Conclusions

The results of the Column Leaching Studies indicate that little to no iron, lead, or zinc leached out of the soils in the column studies. Low concentrations of arsenic and copper leached primarily from the unsaturated soil columns. Elevated chromium concentrations were detected in the initial leachate samples collected from the unsaturated soil columns. Similar elevated chromium concentrations were observed in the infiltration study conducted at the site (Confidential 1992). However, the chromium does not leach under groundwater conditions and it rapidly precipitates in the alkaline water.

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