



October 4, 2010

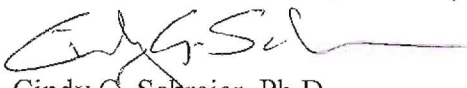
Mr. Mark Gage
Associate Engineer
Northgate Environmental Management, Inc.
300 Frank H. Ogawa Plaza, Suite 510
Oakland, CA 94612

RE: Final Report of Findings "Column Tests to Evaluate *In-situ* Soil Flushing of Perchlorate", Tronox, LLC, Henderson, Nevada

Dear Mark:

Enclosed is the final report of findings "Column Tests to Evaluate *In-Situ* Soil Flushing of Perchlorate" that describes laboratory testing conducted on soil and water from the Tronox, LLC site, located in Henderson, Nevada. If you have any questions, please give me a call. Thank you for the opportunity to be of service.

Sincerely,
PRIMA Environmental, Inc.


Cindy G. Schreier, Ph.D.
President

Report of Findings
**COLUMN TESTS TO EVALUATE
IN-SITU SOIL FLUSHING OF PERCHLORATE**

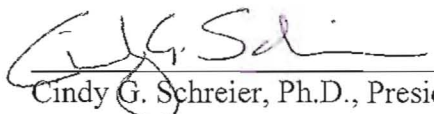
Tronox, LLC
Henderson, Nevada

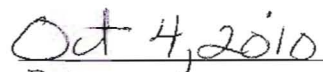
October 4, 2010

Submitted to

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Date

EXECUTIVE SUMMARY

Bench-scale treatability testing was conducted on four soils samples (SA-179, SA-189, RSAM-5 and RSAM-6) and water (stabilized Lake Mead water) from the Tronox, LLC site located in Henderson, Nevada. Testing evaluated percolation of water into near-surface soil (soil SA-179), as well as the ability of added water to flush perchlorate from vadose soils into groundwater, where the perchlorate may be more easily treated. The effect of soil flushing on the removal of other constituents was also assessed. The soil flushing tests were conducted on SA-189, RSAM-6, and RSAM-5 soils, which contained low (6.18 mg/kg) medium (145 mg/kg), and high (3,130 mg/kg) concentrations of perchlorate.

Laboratory testing clearly demonstrated that flushing soil by applying approximately 2 pore volumes of clean water can remove perchlorate and other compounds from the site soils. For each column, most of the perchlorate detected in leachate was observed in the first 0.25 to 0.38 pore volumes collected (0.88 to 1.18 pore volumes added), though some perchlorate (0.0892 to 14.3 mg/L) was detected in final leachate samples collected after application of 2.06 to 2.35 pore volumes of clean water. Greater than 99% of the perchlorate was removed from all three soils by the end of the study. However, in SA-189 soil, which contained 6.18 mg/kg perchlorate, only 33% of the perchlorate could be accounted for in leachate. For RSAM-6, which initially contained 145 mg/kg perchlorate, only 62% could be accounted for in the leachate. The fate of the unaccounted perchlorate is uncertain. Possibly the perchlorate may be unevenly distributed in soil so that the measured masses may not be representative despite thorough homogenization. Alternatively, the added water may have stimulated biodegradation of perchlorate (which has been shown to occur under anaerobic conditions in other laboratory studies using site soil), though this seems unlikely since the columns were aerobic. In contrast, all of the perchlorate initially present in RSAM-5 (3,130 mg/kg) could be accounted for in the leachate.

Arsenic and Cr(VI) were detected in leachate from all of the columns, though the concentration varied among the columns. Leachate concentrations of arsenic after application of approximately 2 pore volumes of water were 80 µg/L, 6.7 µg/L and 150 µg/L for SA-189, RSAM-6 and RSAM-5 soils, respectively, while Cr(VI) leachate concentrations were 5.3 µg/L, 5.2 µg/L, and 120 µg/L, respectively. Most detected anions and metals behaved in a manner similar to perchlorate—that is they increased within the first few leachate samples, then decreased in subsequent samples.

In the column flushing tests, water percolated steadily into site soils at a rate of 30 to 40 inches per day when water was continuously applied to the top of the soil column. Continuous application resulted in a layer of water slightly above the ½ inch dispersion disk. In the percolation column (soil SA-179) in which a finite amount of water was applied (6 inches, the equivalent of 1.5 times average annual rainfall), the water

percolated quickly for the first 2 hours, slowed, then stopped within 4 days so that all of the water was retained within the soil column.

Based on the results of this study, soil flushing appears to be an effective method of moving perchlorate off site soils. However, the amount of water needed to drive perchlorate the entire depth to groundwater as well as the impact of non-target compounds on groundwater quality and existing pump and treat remediation systems must be considered before applying this technology at this site.

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1.0 INTRODUCTION

Bench-scale treatability testing was conducted on four soils samples (SA-179, SA-189, RSAM-5 and RSAM-6) and water (stabilized Lake Mead water) from the Tronox, LLC site located in Henderson, Nevada. Testing evaluated percolation of water into near-surface soil (soil SA-179), as well as the ability of added water to flush perchlorate from vadose soils into leachate. The effect of soil flushing on the removal of other constituents was also assessed. The soil flushing tests were conducted on SA-189, RSAM-6, and RSAM-5 soils, which contained low (6.2 mg/kg) medium (145 mg/kg), and high (3,130 mg/kg) concentrations of perchlorate.

1.1 Background

Vadose zone soils at this site are impacted with perchlorate. Soil flushing is being considered to remediate these soils. Flushing would potentially push perchlorate and to a lesser extent the other salts into groundwater, where they may be more easily treated using existing pump and treat systems at the facility. Soils may also be impacted with other compounds, including pesticides such as Lindane (and its degradation products) so the effect of flushing on these parameters was also assessed.

1.2 Approach

In order to most accurately simulate field conditions, test were conducted on 6 inch diameter by 6 foot tall soil columns that had been packed to approximate the average density (1.85 g/cm³) of soils at the site. A test was conducted in one column using soil sample SA-179 to provide data regarding the rate of percolation and the water retention capacity of unsaturated soil. Flushing tests were conducted on the other three soils by adding approximately 2 pore volumes at a rate of 2 milliliters per minute (mL/min) and collecting the effluent as water flowed through the soil column by gravity. Effluent samples were analyzed for perchlorate and other parameters to assess the potential impact to groundwater.

1.3 Study Objectives

Specific goals of the bench test were to:

- Study the percolation rate of 150% of annual rainfall through a laboratory soil column.
- Measure the amount of perchlorate that can be leached from soil columns as a function of flushing volume. Tests will be conducted on samples of alluvium gathered from the Site that contain a range of initial perchlorate concentrations.
- Measure the leaching rate of other species that may be flushed out of the soil along with perchlorate.

The specific tests conducted to achieve these goals are described in Section 2.0. Results and conclusions are presented in Sections 3.0 and 4.0, respectively. PRIMA Environmental, Inc. (PRIMA) has evaluated the effectiveness of soil flushing based on the results of the laboratory tests. However, it is the responsibility of Northgate Environmental Management (NGEM) to review this report and use its knowledge and expertise to determine whether soil flushing should be applied at the site.

2.0 MATERIALS and METHODS

2.1 Preparation and Characterization of Soil and Water

2.1.1 Soil

Four soil samples (SA-179, SA-189, RSAM-5 and RSAM-6) were received on July 15, 2010. Each consisted of one 55 gallon drum of soil. For each sample, a sub-sample of approximately 30 pounds (lbs) [14 kilograms, (kg)] was submitted to Sierra Testing Laboratories (El Dorado Hill, CA) for grain size analysis and moisture content (see Section 2.5 for details on methods). Another sub-sample (approximately 200 lbs) was sieved to remove rocks greater than 0.5 in. Each sieved sample was then homogenized by mixing it in a clean cement mixer for 3 minutes. The homogenized soils were analyzed for the following using the methods discussed in Section 2.5:

- perchlorate
- hexavalent chromium, Cr(VI)
- metals (arsenic, boron, calcium, chromium, cobalt, iron, lead, magnesium, manganese, potassium, sodium, uranium)
- organochlorine pesticides (alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, hexachlorobenzene)
- total organic carbon (TOC)

2.2.2 Water

Four plastic carboys each containing approximately 6 gallons (22 liters, L) of stabilized Lake Mead water were received on July 15, 2010. The water in each container was assumed to be identical. A sub-sample from one container was analyzed for the following using the methods discussed in Section 2.5:

- perchlorate
- alkalinity (total, bicarbonate, and hydroxide)
- ammonia
- anions (bromide, chloride, fluoride, nitrate, ortho-phosphate, sulfate)
- chlorate
- Cr(VI)
- metals, dissolved (arsenic, boron, calcium, chromium, cobalt, iron, lead, magnesium, manganese, potassium, sodium, uranium)
- organochlorine pesticides (alpha-BHC, beta-BHC, gamma-BHC, delta-BHC, hexachlorobenzene)
- Oxidation reduction potential (ORP)
- pH
- TOC

2.2 Column Preparation

2.2.1 Construction

Four identical columns were built for use in the percolation and flushing tests. The design was based on that described in ASTM D 4874 – 95 (Standard Testing Method for Leaching Solid Material in a Column Apparatus). The columns were constructed from 6 in. diameter, 6 ft. long clear Schedule 40 PVC pipe. End plates were fabricated by Precision Plastics (Elk Grove, CA) from 10 in x 10 in x 1 ¼ in. thick clear acrylic (Figure 1). The bottom diffusion plates were 6 inch diameter, 1/16 inch thick sintered stainless steel with a nominal pore size of 75 microns (mm). The top diffusion plates were 6 inch diameter, 1/2 inch thick sintered glass with a nominal pore size of 70-100 mm. Glass frits were used on the top because they were available in thicker sizes than the stainless steel and thus were expected to be more effective. O-rings were Viton® (Figure 2). The endplates were bolted to the pipe via a collar welded ¾ inches from each end of the pipe as shown in Figure 3. Water was delivered to the columns via Tygon® tubing.

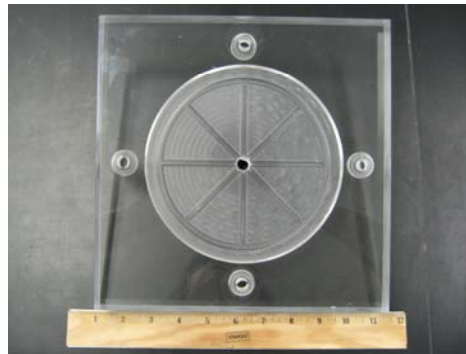


Figure 1. Endplate for Columns.



Figure 2. Bottom endplate with stainless steel disk and o-ring.



Figure 3. Column bolted to bottom endplate.

2.2.2 Filling

Each of four columns was filled with one of the screened, homogenized soils (see Section 2.1). Columns were filled in lifts (20 per column), which were tamped before adding the next lift (Figure 4). Most lifts consisted of 3.00 kg soil compacted to a depth of 3.5 inches, which generated an approximate density of 1.85 g/cm^3 . The exceptions were the first lift of column SA-179, which consisted of 3.83 kg soil, compacted to 4.625 inches, and the final lift of each column which consisted of 1.30 to 2.36 kg soil compacted appropriately. After filling, a glass frit was placed on top the soil column, then the o-ring and endplate were secured. The exact amount of soil used in each column, the average bulk density, and other parameters are shown in Table 1. Note that SA-179—the soil used for the percolation test—was filled to a height of 70.375 in order to allow for an approximately 1 inch head of water on the surface. The other columns were filled to a height of 71.5 inches.



Figure 4. Addition of the first lift to a column.

Table 1. Column Parameters.

Parameter	Percolation Column	Soil Flush Columns		
	SA-179	SA-189	RSAM-6	RSAM-5
Column diameter				
inches	5.972	5.972	5.972	5.972
cm	15.17	15.17	15.17	15.17
Bed height				
inches	70.375	71.5	71.5	71.5
cm	178.75	182	182	182
Bed volume, cm ³	32303	32820	32820	32820
Soil mass, field moist				
pounds	132.40	135.19	135.19	134.86
kg	60.18	61.45	61.45	61.3
Soil mass, dry				
pounds	123.13	128.84	124.1	123.7
kg	56.24	58.69	56.79	56.60
Bulk density, g/cm ³				
field moist	1.863	1.872	1.872	1.868
dry	1.741	1.788	1.730	1.725
Moisture content (dry basis), %	7.0	4.7	8.2	8.3
Density of solids, g/cm ³	2.63	2.62	2.66	2.66
Total Porosity	0.338	0.317	0.349	0.352
pore volume, L	10.9	10.4	11.5	11.5
Vol put through col., L	2.8	24.4	23.7	23.9
Pore volumes put through	0.26	2.34	2.07	2.07
Flowrate, mL/min	gravity feed	1.0-2.0	2.1	2.0
Duration of water addition, days	2	12.2*	7.84	8.31

* column leaked. See Section 2.4.1 for discussion.

2.3. Percolation Column (Soil SA-179)

Soil SA-179 was selected by NGEM for use in the percolation study. The column was prepared as described in Section 2.2. Stabilized Lake Mead water (2.8 L, the equivalent of 6 inches of water or 1.5 times the annual rainfall for the site) was placed in a Tedlar® bag and gravity fed into the top of the column (Figure 5). All of the water had entered the column within 2 days. The location of the wetting front was recorded over time for four days. No effluent was obtained from the column after six days.



Figure 5. Addition of Water via Gravity Feed into Percolation Column.
Note: wetting front below silver band.

2.4 Soil Flushing Columns (Soils SA-189, RSAM-6 and RSAM-5)

2.4.1 Addition of Water

Columns were constructed as described in Section 2.2. Water from the four carboys was combined into a single container, then pumped to the top of each column at a flow rate of approximately 2.0 mL/min using a peristaltic pump until about 2 pore volumes of water were added (see Table 1 for exact flow rates and number of pore volumes put through). The wetting front was monitored for each column. Once breakthrough occurred, effluent was collected (in covered plastic containers) until the next day, then approximately every 24 hours thereafter. The final sample was collected for at least two days until the rate of leachate collection was very slow (dripping was no longer evident and less than about 100 mL was collected in a 24 hour period). Effluent samples were analyzed for the parameters in Table 2, which are listed in order of priority. This priority order was followed for samples for which an insufficient volume of water was available to perform all analyses (the first and final effluent samples). Figure 6 shows a column at the beginning of the test.

The amount of water applied to each column and the volume of each effluent sample are summarized in Tables 3-5 for SA-189, RSAM-6 and RSAM-5 columns, respectively. Columns RSAM 6 and RSAM-5 behaved well and there were no difficulties adding water or collecting samples. In contrast, column SA-189 slowly leaked at the influent end for several days despite further tightening the endplate or reducing flow. The volume of water—about 900 mL total—was estimated by soaking it up with paper towels then measuring the mass of water held by the paper towel (measurement of several dry paper towels showed that the mass of each paper towel was nearly constant.) The column was run for additional time to make up for the water not put through due to the leak. Because

the leaking was due to high pressure at the influent (water squirted from the influent hose barb when the influent line was removed), the column was shut down periodically in order to allow water to drain/percolate. It is unknown why this column behaved

Table 2. Flushing Column Effluent Analyses (in order of priority).

Priority	Analyte
1	perchlorate
2	dissolved metals (As, B, Ca, Cr, Co, Fe, Pb, Mg, Mn, K, Na)
3	chlorate
4	Cr(VI)
5	dissolved metals (U)
6	organochlorine pesticides + hexchlorobenzene*
7	Chloroform (VOCs)
8	TOC
9	TDS
10	conductivity, DO, pH, ORP
11	anions (Br, Cl, F, SO ₄)
12	alkalinity (total, HCO ₃ , hydroxide)
13	ammonia
14	anions (NO ₃ , o-PO ₄)
15	TSS



Figure 6. Soil Flush Column near Beginning of Test.

Note: Wetting Front.

Table 3. Influent and Effluent Sample Volumes. SA-189.

Sample ID	Influent Added			Effluent Collected			
	sample	cumulative	# pore volumes	sample**	cumulative	# pore volumes	duration hrs
	L	L		L	L		
S1	7.60	7.60	0.71	0.69	0.69	0.07	60*
S2	4.14	11.7	1.10	2.77	3.46	0.33	118
S3	2.58	14.3	1.34	2.44	5.90	0.57	24
S4	2.88	17.2	1.61	2.89	8.79	0.85	24
S5	2.27	19.5	1.88	2.87	11.7	1.12	24
S6	2.16	21.6	2.08	2.56	14.2	1.37	24
S7	2.16	24.4	2.28	2.68	16.9	1.62	213 (8.9 days [^])

* Time from start of flow to column until stop collecting S1 sample.

**Sample volumes +/- 0.04L

[^] Additional water added during this period. See text for discussion.

Table 4. Influent and Effluent Sample Volumes. RSAM-6.

Sample ID	Influent Added			Effluent Collected			
	sample	cumulative	# pore volumes	sample**	cumulative	# pore volumes	duration hrs
	L	L		L	L		
S1	10.6	10.6	0.90	0.70	0.70	0.06	60*
S2	3.02	13.6	1.15	2.20	2.90	0.25	24
S3	3.02	16.6	1.41	2.92	5.82	0.51	24
S4	2.89	19.5	1.65	2.44	8.25	0.72	23
S5	3.02	22.5	1.91	2.73	11.0	0.96	24
S6	1.14	23.7	2.01	2.27	13.2	1.15	240 (10 days)

* Time from start of flow to column until stop collecting S1 sample.

**Sample volumes +/- 0.04L

Table 5. Influent and Effluent Sample Volumes. RSAM-5.

Sample ID	Influent Added			Effluent Collected			
	sample	cumulative	# pore volumes	sample**	cumulative	# pore volumes	duration hrs
	L	L		L	L		
S1	7.24	7.24	0.63	1.7	1.7	0.15	60*
S2	2.88	10.1	0.88	2.69	4.39	0.38	24
S3	2.88	13.0	1.13	2.77	7.16	0.62	24
S4	2.88	15.9	1.38	2.69	9.9	0.86	24
S5	2.75	18.6	1.62	2.61	12.5	1.08	23
S6	2.88	21.5	1.87	2.73	15.2	1.32	24
S7	2.41	23.9	2.08	2.57	17.8	1.54	24
S8	0.00	23.9	2.08	0.92	18.7	1.62	219 (9 days)

* Time from start of flow to column until stop collecting S1 sample.

**Sample volumes +/- 0.04L

differently from the RSAM-5 and RSAM-6 columns, which did not leak, but possibly the distinctly lower moisture content of SA-189 soil played a role. After 8 days, the column no longer leaked and flow was restored to 2.0 mL/min for the remainder of the 2.0 pore volumes put through. The column was allowed to drain for 5 days, then an additional 0.2 pore volumes of water was put through.

2.4.2 Post-treatment Soil Sampling

After the final effluent sample was collected, the soil from each column was removed, thoroughly homogenized, then analyzed for perchlorate, Cr(VI), pesticides, metals, and moisture content. Each sample was homogenized by placing it in a cement mixer and mixing for a total of 8 minutes (RSAM-5) or 10 minutes (RSAM-6 and SA-189). The mixer was stopped every 2 minutes to break up any clumps and to scrape soil from the sides of the mixer. The mixer was washed thoroughly between samples. Figure 7 shows removal of the soil, and homogenized RSAM-6 soil.

2.5 Analytical Methods

The method for each analysis and the laboratory that performed the analysis are given in Table 6. Note that each subcontracted analysis was performed by a laboratory certified by the State of Nevada or accredited through the NELAC.



Figure 7. Removal of Soil from Columns.

Left: Removal of RSAM-5 soil. *Right:* Homogenized post-treatment RSAM-6 soil.

Table 6. Analytical Methods.

Analyte	Filter Y/N	Method	Lab*
perchlorate	N	314	Alpha
alkalinity (total, HCO ₃ , hydroxide)	Y	301.1	Alpha
ammonia	N	350.3	Alpha
anions (NO ₃)	N	300	Alpha
anions (Br, Cl, F, o-PO ₄ , SO ₄)	Y	300	Alpha
chlorate	N	300	Alpha - subbed to MWH Labs
conductivity, DO, pH, ORP	N	probes	PRIMA
Cr(VI)	Y	7199	Kiff
metals, dissolved (As, B, Ca, Cr, Co, Fe, Pb, Mg, Mn, K, Na)	Y	6020	Alpha
metals, dissolved (U)	Y	6020^	Alpha - subbed to Sierra Environmental
moisture content	n.a.	ASTM D2216	Sierra Testing Labs
organochlorine pesticides + hexchlorobenzene*	N	8081a	Alpha or CLS
particle size distribution	n.a.	ASTM D422, T27, T88	Sierra Testing Labs
specific gravity, soil	n.a.	ASTM D854	Sierra Testing Labs
TOC	N	9060	Alpha
TDS	Y	160.1	Alpha
TSS	N	160.2	Alpha
VOCs (Chloroform)	N	8260	Alpha

* Alpha Analytical (Sparks, NV), CLS (Rancho Cordova, CA), Kiff Analytical (Davis, CA), MWH Laboratories (Monrovia, CA), Sierra Environmental Monitoring (Sparks, NV), Sierra Testing Labs (El Dorado Hills, CA)

3.0 RESULTS and DISCUSSION

Analytical results are presented in this Section. Complete analytical reports for subcontracted analyses are provided in Appendix B.

3.1 Untreated Soil and Water

The results of the chemical analyses in untreated soils and stabilized Lake Mead water are shown in Table 7. The grain size distributions for the soils are summarized in Table 8. All four soils were impacted with perchlorate, with concentrations ranging from 6,180 $\mu\text{g}/\text{kg}$ (6.18 mg/kg) in SA-189 to 3,130,000 $\mu\text{g}/\text{kg}$ (3,130 mg/kg) in RSAM-5. Arsenic was found in all four soils at concentrations ranging from 2.8 mg/kg (RSAM-6) to 7.2 mg/kg (SA-189). Most of the other metals and cations measured were also detected in all of the soils, except for boron, which was not observed in any soil. TOC was similar across the soils, ranging from 5,000 to 7,800 mg/kg . Cr(VI) was not detected in any soil. The soils had similar distributions of gravel (19-26%), sands (58-67%) and fines (14-21%), though SA-189 was somewhat drier than the other soils, with moisture content of 4.7%, compared to 7.0 to 8.3% for the other soils.

Stabilized Lake Mead water contained 2.19 $\mu\text{g}/\text{L}$ perchlorate, but neither arsenic, nor Cr(VI) was detected above their respective reporting limits. The pH of the water was 7.87. DO was 7.5 mg/L and ORP was 228 mV, indicating aerobic, oxidizing conditions. TOC was found to be 2.8 mg/L TOC.

3.2 Percolation Test Results

Movement of the wetting front versus time for the percolation test is shown in Figure 8. Water moved down the column quickly for about the first 2 hours, then began to slow. The front was clearly evident early on, but became more difficult to discern over time. By 67 hours it was faint and by 93 hours, it is uncertain whether the front reached the bottom of the column or was simply too faint to detect. Although all of the water drained into the column within 2 days, no effluent was detected, even after 6 days. This is expected since the amount of water put through (2.8L) is only 0.25 pore volumes.

3.3 Soil Flushing Columns

3.3.1 Wetting Fronts

Movement of the wetting front versus time for the soil flushing columns is shown in Figure 9. Movement of all three fronts was nearly linear, moving at approximately 30 inches per day for SA-189 and RSAM-6 and at 40 inches per day for RSAM-5. It is expected that these rates would continue as long as water is applied to the top of the soil

Table 7. Perchlorate and Other Parameters in Untreated Soils and Water.

Analyte	Units	SA-179 Soil	SA-189 Soil	RSAM-6 Soil	RSAM-5 Soil	Stabilized Lake Mead Water
Chemical Properties						
Perchlorate	µg/kg or µg/L	258,000	6,180	145,000	3,130,000	2.19
Alkalinity						
bicarbonate	mg/L CaCO ₃	n.a.	n.a.	n.a.	n.a.	160
hydroxide		n.a.	n.a.	n.a.	n.a.	< 10
total (pH 4.5)		n.a.	n.a.	n.a.	n.a.	160
Ammonia	mg/L	n.a.	n.a.	n.a.	n.a.	< 0.1
Chlorate	mg/L	n.a.	n.a.	n.a.	n.a.	< 0.02 (0.025)*
Conductivity	µS	n.a.	n.a.	n.a.	n.a.	885
Cr(VI)	mg/kg or mg/L	< 0.400	< 0.400	< 0.400	< 0.400	< 0.001
DO	mg/L	n.a.	n.a.	n.a.	n.a.	7.5
ORP	mV	n.a.	n.a.	n.a.	n.a.	228
pH	--	n.a.	n.a.	n.a.	n.a.	7.87
TDS	mg/L	n.a.	n.a.	n.a.	n.a.	620
TOC - (dry wt. for soil)	mg/kg or mg/L	7,800	5,900	5,000	7,600	2.8
TSS	mg/L	n.a.	n.a.	n.a.	n.a.	< 2.5
Anions						
Bromide	mg/L	n.a.	n.a.	n.a.	n.a.	< 0.25
Chloride	mg/L	n.a.	n.a.	n.a.	n.a.	84
Fluoride	mg/L	n.a.	n.a.	n.a.	n.a.	0.34
Nitrate	mg/L	n.a.	n.a.	n.a.	n.a.	0.64
Ortho Phosphate	mg/L	n.a.	n.a.	n.a.	n.a.	< 0.5
Sulfate	mg/L	n.a.	n.a.	n.a.	n.a.	75

n.a. - not applicable

* < 0.02 measured by CLS (Jul 2010), which is not certified by NV or NELAC for this analyte; 0.025 mg/L measured by MWH Laboratories (Sep 2010), certified by NELAC

Table 7. - continued. Perchlorate and Other Parameters in Untreated Soils and Water.

Analyte	Units	SA-179 Soil	SA-189 Soil	RSAM-6 Soil	RSAM-5 Soil	Stabilized Lake Mead Water
Metals						
Arsenic	mg/kg or mg/L	5.5	7.2	2.8	3.6	< 0.005
Boron	mg/kg or mg/L	< 20	< 20	< 20	< 20	0.23
Calcium	mg/kg or mg/L	65,000	69,000	22,000	28,000	68
Chromium	mg/kg or mg/L	18	13	15	15	0.007
Cobalt	mg/kg or mg/L	6.8	5.2	6.9	5.8	< 0.005
Iron	mg/kg or mg/L	20,000	16,000	18,000	17,000	0.65
Lead	mg/kg or mg/L	7.4	6.0	8.8	5.4	< 0.005
Magnesium	mg/kg or mg/L	14,000	12,000	9000	9,700	25
Manganese	mg/kg or mg/L	330	300	440	270	< 0.005
Potassium	mg/kg or mg/L	2,800	2,100	2,700	2,300	4.5
Sodium	mg/kg or mg/L	580	900	490	1900	83
Uranium	mg/kg or mg/L	1.3	1.9	< 1.2	< 1.2	0.0042 (< 0.02)^
Pesticides						
alpha-BHC	µg/kg or µg/L	< 1.7	< 1.7	< 1.7	< 1.7	< 0.05
gamma-BHC (Lindane)	µg/kg or µg/L	< 1.7	< 1.7	< 1.7	< 1.7	< 0.05
beta-BHC	µg/kg or µg/L	4.0	23	17	6.8	< 0.05
delta-BHC	µg/kg or µg/L	2.0	< 1.7	< 1.7	< 1.7	< 0.05
4,4'-DDE	µg/kg or µg/L	< 3.3	4.1	< 3.3	< 3.3	< 0.10
dieldrin	µg/kg or µg/L	< 3.3	< 3.3	< 3.3	< 3.3	< 0.10
hexachlorobenzene	µg/kg or µg/L	12	16	8.5	5.6	< 0.05
VOCs						
chloroform	µg/kg or µg/L	< 20	< 20	< 20	< 20	1.3

n.a. - not applicable.

^ 0.0042 mg/L measured by BSK (Jul 2010) which is not certified by NV or NELAC for this analyte; < 0.02 mg/L measured by Sierra Environmental (Sep 2010), NV certified

Table 8. Physical Parameters of Bulk Soil.

Analyte	Units	SA-179 Soil	SA-189 Soil	RSAM-6 Soil	RSAM-5 Soil
Grain Size Summary*					
'+3 inches	%	0	0	0	0
Gravel	%				
coarse		13	5.3	11.3	5.2
fine		13	13.3	14.1	15.6
Sand	%				
coarse		18.3	14.1	3.0	12.1
medium		20.1	27.4	22.4	18.1
fine		21.4	25.2	28.5	28.2
Fines	%				
silt		10.6	10.6	14.3	16.6
clay		3.6	4.1	6.4	4.2
Moisture content	%	7	4.7	8.3	8.2
Specific gravity	--	2.63	2.62	2.66	2.66

See Appendix B for analytical report with full particle size distribution.

Time	Depth Below Soil Surface
hours	inches
0.00	0
0.09	2
0.16	2.8
0.33	4.3
0.51	5.1
0.85	6.8
1.8	9.6
2.5	11.6
2.8	12.4
3.3	13.4
8.9	21.8
11	24.5
20	34.1
20	34.3
28	40.9
44	48.3
67	54.4
93	70?*

* Front not discernable

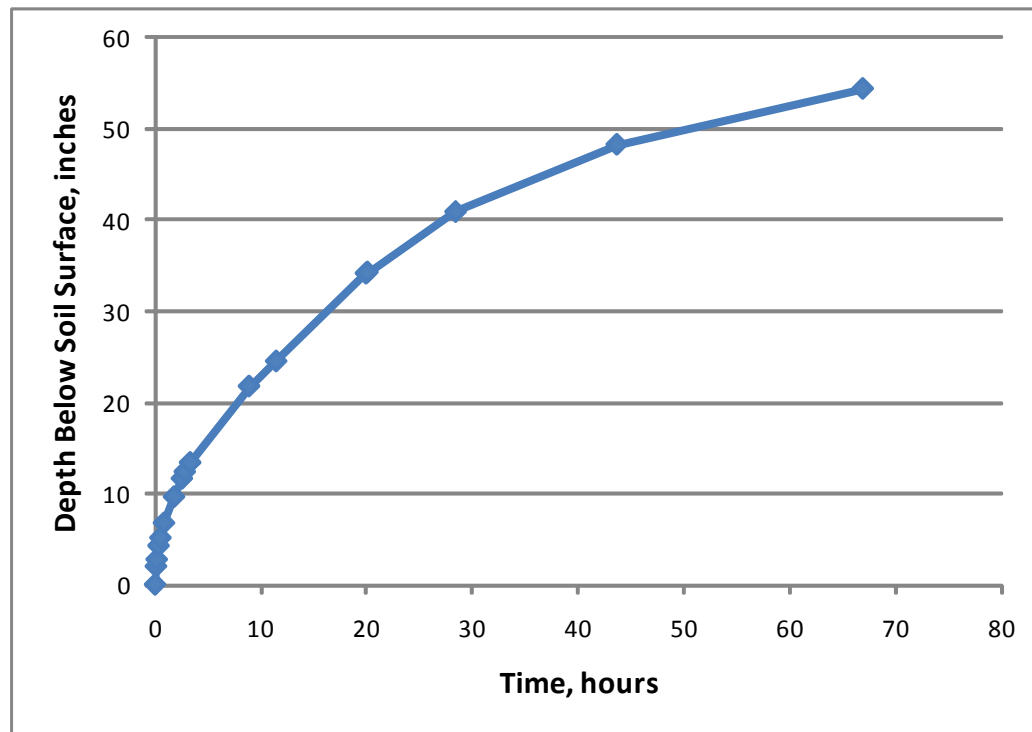


Figure 8. Movement of Wetting Front. Percolation Column Test.

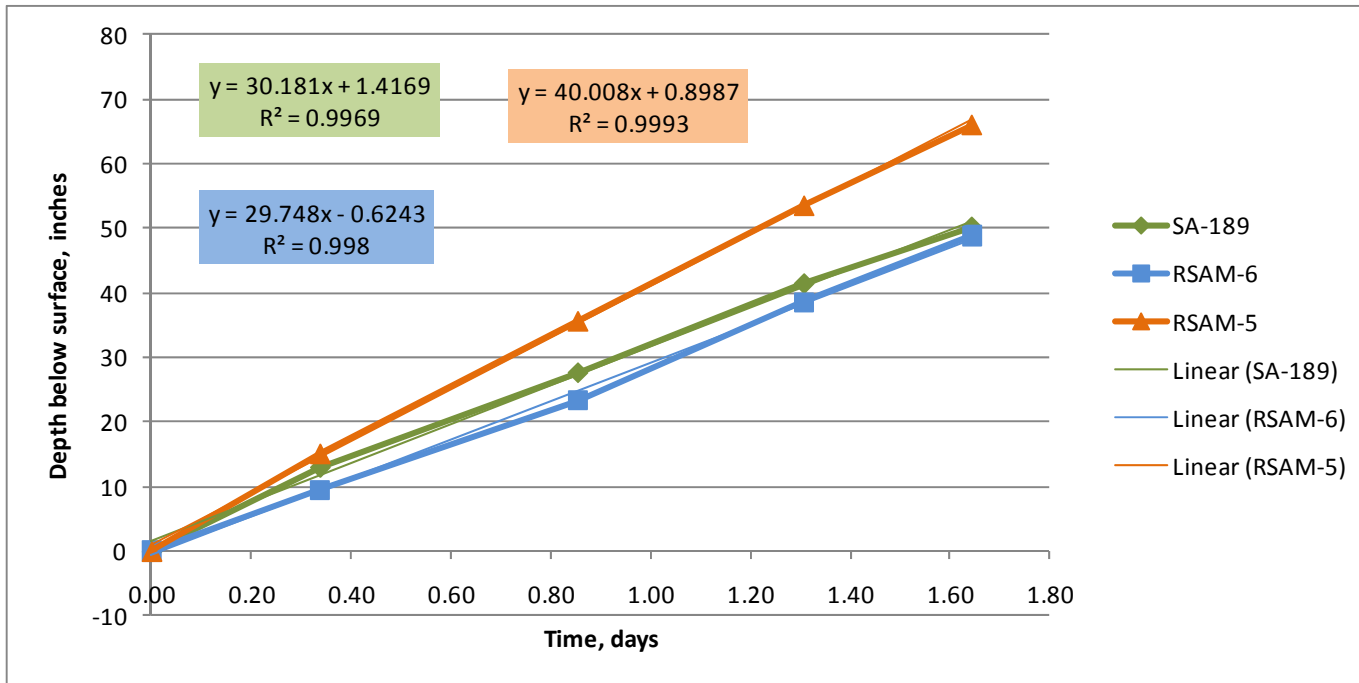


Figure 9. Movement of Wetting Front. Soil Flushing Tests.

columns. Once application of water ceases, the downward movement of the water would slow as in the percolation test.

3.3.2 SA-189 Soil

3.3.2.1 Leachate Data

The concentrations of perchlorate in the leachate samples and the accumulated mass removed are shown in Figure 10. The concentration of perchlorate decreased over time, though some perchlorate (0.0892 mg/L) was still present in the final sample, after application of 2.35 pore volumes of Lake Mead water. Most of the perchlorate was detected in the first two leachate samples. These samples together constituted 0.33 pore volumes of water and contained 0.123 g perchlorate, which was 32% of the perchlorate initially present in the column (see Section 3.3.1.2 for further discussion of soil and perchlorate mass balance). The remaining leachate samples, which together constituted 1.29 pore volumes of water, contained only 0.003 g perchlorate. Thus, the total mass of perchlorate collected was only 33% of the initial mass present.

The slight increase in perchlorate concentration between the S6 and the S7 samples may be due to resuming flow during collection of S7. S6 was collected about 4 hours after flow to the column was initially stopped (after 2 pore volumes were put through). After draining for 5 days, flow was resumed for 18 hours (0.2 pore volumes was added), then the column allowed to drain again. The small increase in perchlorate suggests that starting and stopping flow during soil flushing could potentially enhance removal, although it should be noted that the additional mass removed is very low compared to the mass of perchlorate in the S1 and S2 samples.

The concentrations of arsenic and Cr(VI) in leachate samples are shown in Figure 11. Arsenic increased slowly from 15 µg/L in the S1 sample to 80 µg/L by the final leachate sample. Cr(VI) initially increased, then decreased, with the maximum concentration [8.3 µg/L Cr(VI)] occurring in the S3 and S4 samples.

The concentrations of other parameters in SA-189 leachate are shown in Tables 9-12 for Anions, General Minerals, Metals, and Pesticides+Chloroform, respectively. Refer to Table 3 in Section 2.0 for the number of pore volumes added and collected for the various samples. Bromide, fluoride, nitrate, phosphate, cobalt, nitrate, ammonia and chloroform were not detected in any sample. Chloride, sulfate, calcium, iron, magnesium, potassium, sodium, TDS and TOC concentrations all followed a similar pattern as perchlorate—that is, they were highest in early samples, then declined in subsequent samples. Chloride decreased from 1,200 mg/L at S2 to 89 mg/L by S7; sulfate from 1,300 mg/L in S2 to 290 mg/L by S7; calcium from 1,800 mg/L in S1 to 23 mg/L in S7; iron from 9.3 mg/L in S1 to < 0.1 mg/L by S3; magnesium from 560 mg/L in S1 to 7.7 mg/L by S7; potassium from 27 mg/L in S1 to 2.9 mg/L by S7; sodium from 2,100 mg/L in S1 to 220 mg/L by S7; TDS from 3,600 mg/L in S1 to 710 mg/L in S7 and TOC

Sample ID	# pore volumes		Perchlorate in Effluent		Perchlorate Removed		
	Added	Collected	mg/L	g	sample	cumulative	
					% of total*	g	%
S1	0.73	0.06	117	0.076	20.0	0.076	20
S2	1.13	0.33	17.1	0.047	12.5	0.123	32
S3	1.38	0.56	0.427	0.00104	0.27	0.124	33
S4	1.65	0.84	0.179	0.00052	0.14	0.125	33
S5	1.93	1.12	0.0597	0.00017	0.045	0.125	33
S6	2.14	1.36	0.0547	0.00014	0.037	0.125	33
S7	2.35	1.62	0.0892	0.00024	0.063	0.126	33

* Based on mass initially in soil

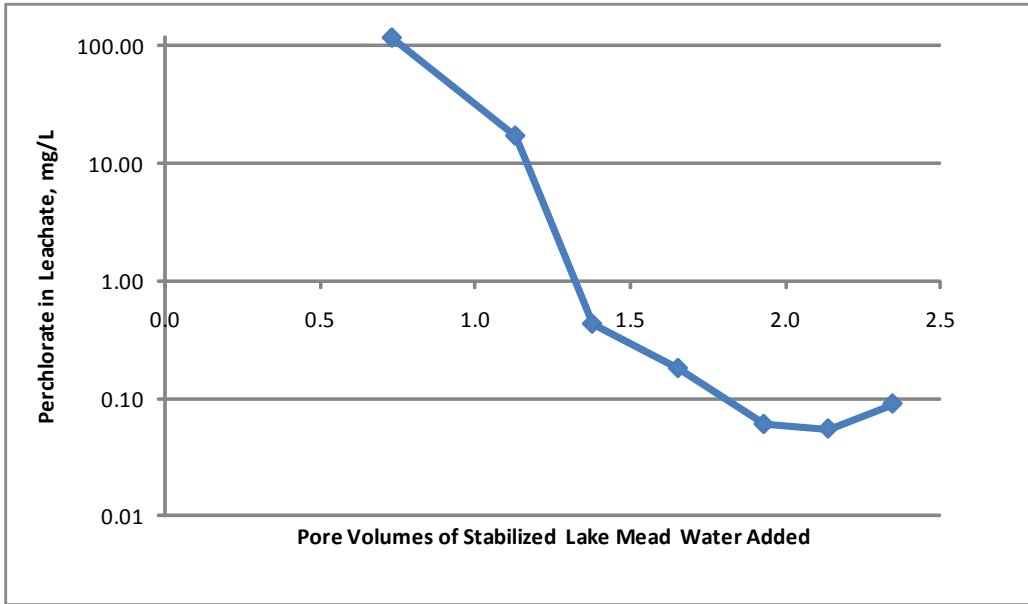


Figure 10. Perchlorate in Leachate. SA-189.

from 6.9 mg/L in S1 to 2.4 mg/L in S7. Uranium was detected at 0.010 to 0.012 mg/L in S3 through S7. Chromium was detected sporadically, with concentrations consistent with Cr(VI) values. Boron increased steadily from 2.9 mg/L in S1 to 3.9 mg/L in S4, then declined to 2.7 mg/L in S7. DO, ORP, and pH varied slightly over the study, ranging from 8.3 to 8.8 mg/L, 110-261 mV, respectively. The pH increased steadily from 7.90 to 8.40. Alkalinity also increased steadily (from 61 to 160 mg/L CaCO₃). Pesticides were not detected by the S7 sample.

SA-189

Sample ID	# Pore Volumes Added	Leachate Concentration	
		Arsenic	Cr(VI)
		mg/L	µg/L
S1	0.73	15	3.8
S2	1.13	36	13 [^]
S3	1.38	56	8.3 [^]
S4	1.65	66	8.8 [^]
S5	1.93	73	3.9
S6	2.14	80	2.9
S7	2.35	80	5.3

[^] sample analyzed out of hold time because sample collected on weekend or holiday.

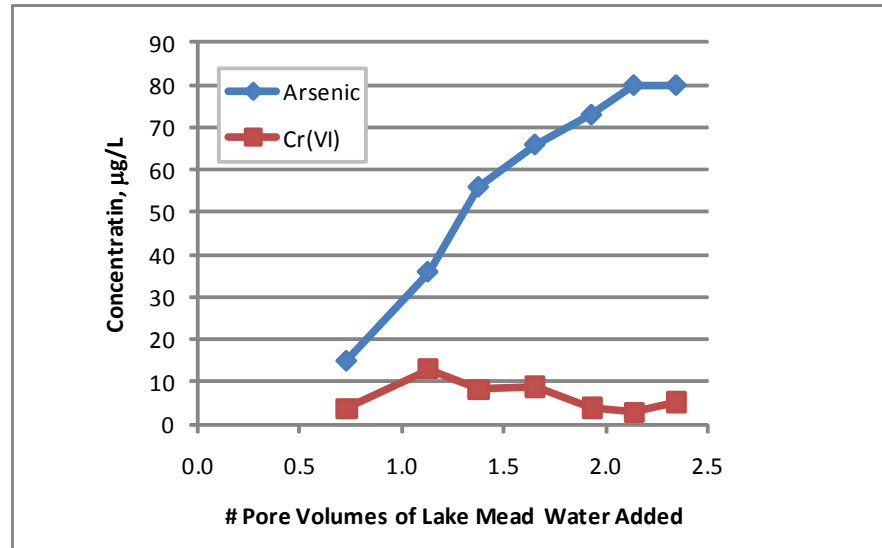


Figure 11. Arsenic and Cr(VI) in Leachate. SA-189.

Table 9. Anions in Leachate. SA-189.

Sample ID	Bromide	Chloride	Fluoride	Nitrate - N	o-Phosphate	Sulfate
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
S1	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
S2	< 25	1,200	< 130	< 130	< 500	1,300
S3	< 25	110	< 25	< 25	< 100	560
S4	< 25	< 100	< 25	< 25	< 100	340
S5	< 25	< 100	< 25	< 25	< 100	250
S6	< 13	86	< 13	< 13	< 50	260
S7	< 13	89	< 13	< 13	< 50	290

Table 10. General Minerals in Leachate. SA-189.

Sample ID	Alkalinity (as CaCO ₃)			Ammonia	Chlorate	EC	DO	ORP	pH	TDS	TOC	TSS
	bicarbonate mg/L	hydroxide mg/L	Total mg/L	mg/L - N	mg/L	mS	mg/L	mV	--	mg/L	mg/L	mg/L
S1	n.m.	n.m.	n.m.	n.m.	22	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
S2	61	< 20	61	< 1.0	4.0	4.41	8.8	151	7.90	3,600	6.9	24
S3	130	< 20	130	< 1.0	0.13	1.45	8.8	110	8.24	1,100	6.3	< 2.5
S4	150	< 20	150	< 1.0	0.068	1.14	8.9	171	8.27	800	5.1	< 2.5
S5	160	< 20	160	< 1.0	0.070	1.05	8.4	204	8.26	750	4.2	< 2.5
S6	160	< 20	160	< 1.0	0.039	0.99	8.3	261	8.33	680	4.2	< 2.5
S7	160	< 20	160	< 1.0	0.048	1.00	8.5	219	8.40	710	2.4	< 2.5

Table 11. Metals in Leachate. SA-189.

Sample ID	Arsenic mg/L	Boron mg/L	Calcium mg/L	Chromium mg/L	Cobalt mg/L	Iron mg/L	Lead mg/L	Magnesium mg/L	Manganese mg/L	Potassium mg/L	Sodium mg/L	Uranium mg/L
S1	0.015	2.9	1,800	< 0.0050	< 0.0050	9.3	< 0.0050	560	0.19	27	2,100	< 0.02
S2	0.036	3.4	380	0.0086	< 0.0050	1.8	< 0.0050	120	0.010	10	760	< 0.02
S3	0.056	3.6	46	< 0.0050	< 0.0050	< 0.10	< 0.0050	15	< 0.0050	4.0	290	0.010
S4	0.066	3.9	30	< 0.0050	< 0.0050	< 0.10	< 0.0050	9.9	< 0.0050	3.5	250	0.011
S5	0.073	3.7	26	< 0.0050	< 0.0050	< 0.10	< 0.0050	8.3	< 0.0050	3.3	230	0.011
S6	0.080	3.3	24	< 0.0050	< 0.0050	< 0.10	< 0.0050	7.9	< 0.0050	3.1	240	0.012
S7	0.080	2.7	23	0.0059	< 0.0050	< 0.10	< 0.0050	7.7	< 0.0050	2.9	220	0.011

Table 12. Pesticides and VOCs in Leachate. SA-189.

Sample ID	Chloroform µg/L	alpha BHC µg/L	beta BHC µg/L	delta BHC µg/L	gamma BHC µg/L	HCB µg/L	Dieldrin µg/L
S1	n.m	n.m	n.m.	n.m.	n.m.	n.m.	n.m.
S2	< 1.0	< 0.068	0.90	< 0.068	< 0.068	< 0.012	< 0.14
S3	< 1.0	< 0.066	0.89	< 0.066	< 0.066	< 0.012	< 0.13
S4	< 1.0	< 0.068	1.0	< 0.068	< 0.068	< 0.012	< 0.14
S5	< 1.0	< 0.068	0.42	< 0.068	< 0.068	< 0.12	< 0.14
S6	< 1.0	< 0.041	0.73	< 0.041	< 0.041	< 0.0076	< 0.082
S7	< 1.0	< 0.21	< 0.21	< 0.21	< 0.21	< 0.21	< 0.42

3.3.2.2 Soil Results

The concentrations of perchlorate and other parameters in homogenized post-treatment soil are provided in Table 13. The mass balance for perchlorate is shown in Table 14. SA-189 soil contained <0.02 mg/kg perchlorate, implying that greater than 99.7% was removed during treatment. However, only 33% of the perchlorate initially present can be accounted for in the leachate. The fate of the remaining perchlorate is uncertain, may be due to uneven distribution of perchlorate in soil so that the measured masses may not be representative despite thorough homogenization of both pre-treatment and post-treatment samples. Alternatively, the added water may have stimulated biodegradation of perchlorate (which has been shown to occur under anaerobic conditions in other laboratory studies using site soil), though this seems unlikely since the columns were aerobic.

The concentrations of calcium, magnesium, potassium, and sodium decreased somewhat after soil flushing, as expected by the presence of these cations in leachate.

3.3.2.3 Observations

As discussed in Section 2.4.1, SA-189 initially leaked at the influent end. The reason is uncertain since the soil was similar to RSAM-6 and RSAM-5, which behaved well, and tightening the endplate was ineffective. Possibly, the lower moisture content of this soil made initial displacement of soil vapor more difficult. After several days, water flowed well through the column and no further leaking occurred.

3.3.3 RSAM-6 Soil

3.3.3.1 Leachate Data

The concentrations of perchlorate in the leachate samples and the accumulated mass removed are shown in Figure 12. The concentration of perchlorate decreased over time, though some perchlorate (1.29 mg/L) was still present in the final sample, after application of 2.06 pore volumes of Lake Mead water. Most of the perchlorate was detected in the first two leachate samples. These samples together constituted 0.25 pore volumes of water and contained 5.5 g perchlorate, which was 61% of the perchlorate initially present in the column (see Section 3.3.2.2 for further discussion of soil and perchlorate mass balance). The remaining leachate samples, which together constituted 0.9 pore volumes of water, contained <0.1 g perchlorate. Thus, the total mass of perchlorate collected was only 62% of the initial mass present.

The concentrations of arsenic and Cr(VI) in leachate samples are shown in Figure 13. Arsenic was nearly constant throughout the test, ranging from 6.0 to 7.2 µg/L. Cr(VI) initially increased, then decreased, with the maximum concentration [7.9 µg/L Cr(VI)] occurring in the S2 sample.

Table 13. Perchlorate and Other Parameters in Post-Treatment Soils.

Analyte	Units	Soil (Post-Treatment)		
		SA-189	RSAM-6	RSAM-5
COCs				
Perchlorate	mg/kg	< 0.020	0.153	2.1
Metals				
arsenic	mg/kg	4.2	2.5	3.5
boron	mg/kg	< 20	< 20	< 20
calcium	mg/kg	29,000	20,000	36,000
chromium	mg/kg	11	13	15
cobalt	mg/kg	7.4	8.1	7.0
iron	mg/kg	14,000	19,000	18,000
magnesium	mg/kg	11,000	7,800	9,600
manganese	mg/kg	290	410	330
lead	mg/kg	7.7	8.4	7.5
potassium	mg/kg	2,000	2,600	2,500
sodium	mg/kg	800	380	900
uranium	mg/kg	1	< 1	1
Pesticides				
alph-BHC	µg/kg	< 20	< 20	< 20
beta- BHC	µg/kg	< 100	< 100	< 100
gamma-BHC (lindane)	µg/kg	< 100	< 100	< 100
delta-BHC	µg/kg	< 100	< 100	< 100
hexachlorobenzene	µg/kg	< 50	< 50	< 50
Other Parameters				
Cr(VI)	mg/kg	< 0.400	< 0.460*	< 0.470*
Moisture Content	%	14	13.3	15.1
TOC	mg/kg	9200*	4,700*	6,200*

Notes:

* results reported on a dry-weight basis. All other results wet-weight.

Table 14. Perchlorate Mass Balance for Soils.

Soil ID	Pre-treatment Perchlorate			Post-treatment Perchlorate			% Removed
	mg/kg - wet	mg/kg - dry	g	mg/kg - wet	mg/kg dry	g	
SA-189	6.18	6.5	0.380	< 0.020	< 0.023	< 0.0013	> 99.7
RSAM-6	145	157	8.88	0.153	0.173	0.00981	99.89
RSAM-5	3,130	3390	193	2.1	2.4	0.14	99.93

Sample ID	# pore volumes		Perchlorate in Effluent		Perchlorate Removed		
	Added	Collected	mg/L	g	sample	cummulative	
					% of total*	g	%
S1	0.92	0.06	3,780	2.66	29.8	2.7	30
S2	1.18	0.25	1,280	2.82	31.6	5.5	61
S3	1.45	0.51	20.4	0.0595	0.7	5.5	62
S4	1.70	0.72	3.24	0.00789	0.1	5.5	62
S5	1.96	0.96	1.57	0.00429	0.05	5.5	62
S6	2.06	1.15	1.29	0.00292	0.03	5.5	62

* Based on mass initially in soil

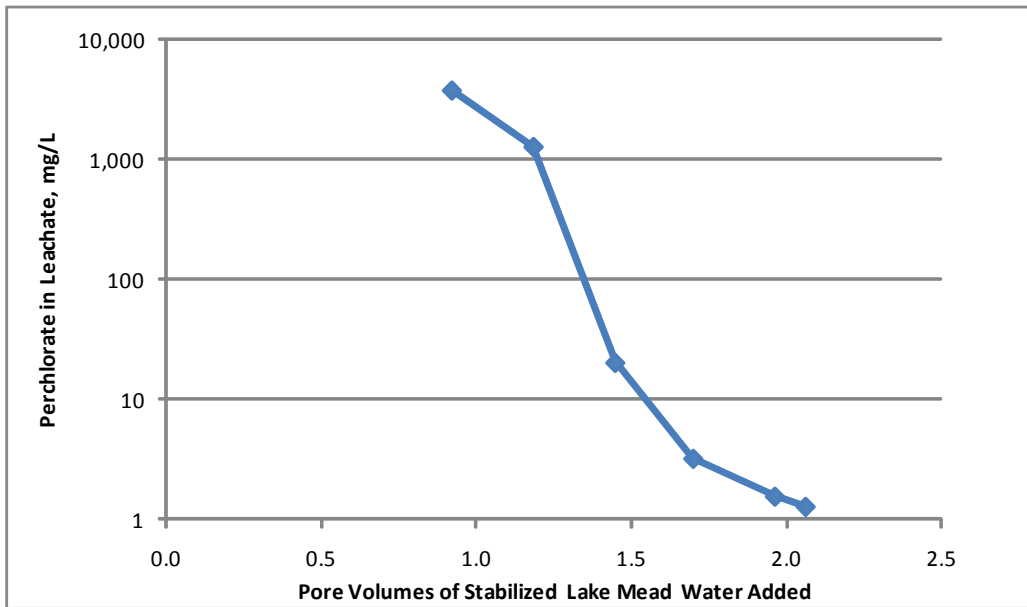


Figure 12. Perchlorate in Leachate. RSAM-6.

The concentrations of other parameters in RSAM-6 leachate are shown in Tables 15-18 for Anions, General Minerals, Metals, and Pesticides+Chloroform, respectively. Refer to Table 4 in Section 2.0 for the number of pore volumes added and collected for the various samples. Bromide, fluoride, phosphate, cobalt, uranium, ammonia, chloroform, and most pesticides were not detected in any sample. Chlorate, chloride, sulfate, calcium, iron, magnesium, potassium, sodium, and TDS concentrations all followed a similar pattern as perchlorate—that is, they were highest in early samples, then declined in subsequent samples. Chlorate decreased from 39 mg/L in the S1 sample to 0.049 mg/L in S6; chloride decreased from 1,800 mg/L at S2 to 88 mg/L by S6; sulfate from 2,000 mg/L in S2 to 350 mg/L by S6; calcium from 2,000 mg/L in S1 to 73 mg/L in S6; iron from 11 mg/L in S1 to 0.32 mg/L by S6; magnesium from 610 mg/L in S1 to 19 mg/L by S6; manganese from 0.25 mg/L at S1 to < 0.005 by S5; potassium from 89 mg/L in S1 to 16 mg/L by S6; sodium from 970 mg/L in S1 to 140 mg/L by S6; and TDS from 10,000 mg/L in S2 to 780 mg/L in S6. TOC declined from 14 mg/L in S1 to 3.6 in S5.

RSAM-6

Sample ID	# Pore Volumes Added	Leachate Concentration	
		Arsenic	Cr(VI)
		mg/L	µg/L
S1	0.92	6.7	3.9
S2	1.18	7.2	7.9
S3	1.45	6.0	6.0
S4	1.70	6.5	5.7
S5	1.96	7.0	5.7 [^]
S6	2.06	6.7	5.2

[^] sample analyzed out of hold time because sample collected on weekend or holiday.

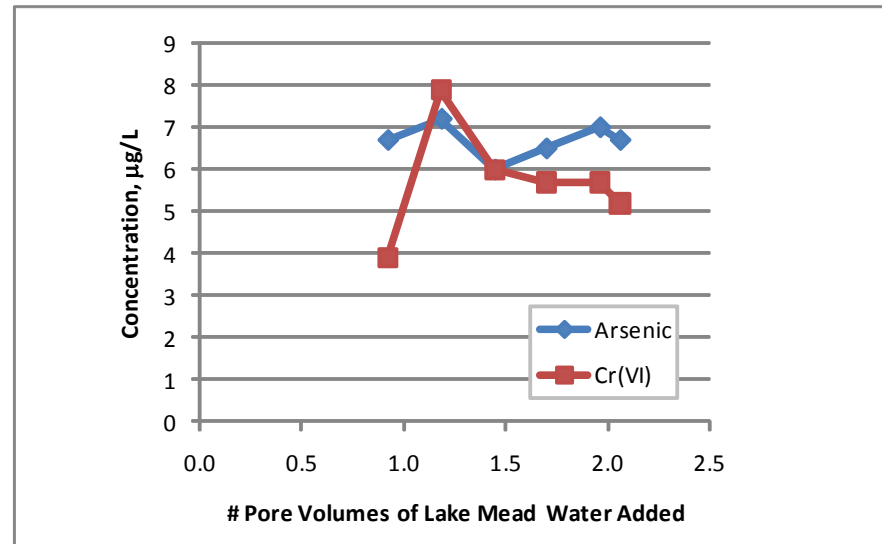


Figure 13. Arsenic and Cr(VI) in Leachate. RSAM-6.

Table 15. Anions in Leachate. RSAM-6.

Sample ID	Bromide	Chloride	Fluoride	Nitrate - N	o-Phosphate	Sulfate
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
S1	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
S2	< 130	1,800	< 130	280	< 130	2,000
S3	< 25	100	< 25	890	< 25	2,600
S4	< 25	< 100	< 25	< 25	< 100	1,600
S5	< 25	< 100	< 25	< 25	< 100	540
S6	< 13	88	< 13	< 13	< 50	350

Table 16. General Minerals in Leachate. RSAM-6.

Sample ID	Alkalinity (as CaCO3)			Ammonia	Chlorate	EC	DO	ORP	pH	TDS	TOC	TSS
	bicarbonate mg/L	hydroxide mg/L	Total mg/L	mg/L - N	mg/L	mS	mg/L	mV	--	mg/L	mg/L	mg/L
S1	n.m.	n.m.	n.m.	n.m.	39	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.
S2	41	< 20	41	< 5.0	22	16	8.9	81	7.28	10,000	14	6.7
S3	61	< 20	61	< 1.0	0.34	3.17	8.3	209	7.85	4,300	8.6	< 2.5
S4	85	< 20	85	< 1.0	0.065	2.37	8.7	127	7.96	2,600	4.7	5.7
S5	100	< 20	100	< 1.0	0.069	1.33	8.9	144	8.14	1,000	3.6	11
S6	260	< 20	260	< 1.0	0.049	1.07	8.6	164	8.16	780	4.0	< 2.5

Table 17. Metals in Leachate. RSAM-6

Sample ID	Arsenic mg/L	Boron mg/L	Calcium mg/L	Chromium mg/L	Cobalt mg/L	Iron mg/L	Lead mg/L	Magnesium mg/L	Manganese mg/L	Potassium mg/L	Sodium mg/L	Uranium mg/L
S1	0.0067	1.2	2,000	0.0050	< 0.0050	11	< 0.0050	610	0.25	89	970	< 0.02
S2	0.0072	1.2	1,300	0.0071	< 0.0050	7.3	< 0.0050	400	0.025	67	750	< 0.02
S3	0.0060	1.3	630	0.0077	< 0.0050	2.8	< 0.0050	170	0.0095	46	500	< 0.02
S4	0.0065	1.3	360	0.0057	< 0.0050	1.6	< 0.0050	100	0.0052	32	340	< 0.02
S5	0.0070	1.5	100	< 0.0050	< 0.0050	0.51	< 0.0050	30	< 0.0050	17	180	< 0.02
S6	0.0067	1.5	73	< 0.0050	< 0.0050	0.32	< 0.0050	19	< 0.0050	16	140	< 0.02

Table 18. Pesticides and VOCs in Leachate. RSAM-6.

Sample ID	Chloroform µg/L	alpha BHC µg/L	beta BHC µg/L	delta BHC µg/L	gamma BHC µg/L	hexachlorob µg/L	Dieldrin µg/L
S1	n.m.	< 0.050	1.1	< 0.050	< 0.050	< 0.05	< 0.10
S2	< 10	< 0.050	1.7	< 0.050	< 0.050	< 0.050	< 0.10
S3	< 2.0	< 0.050	1.9	< 0.050	< 0.050	< 0.050	< 0.10
S4	< 1.0	< 0.050	1.9	< 0.050	< 0.050	< 0.050	< 0.10
S5	< 1.0	< 0.068	2.8	< 0.068	< 0.068	< 0.012	< 0.14
S6	< 1.0	< 0.042	1.2	< 0.042	< 0.042	< 0.0077	< 0.083

Chromium increased then decreased, with concentrations consistent with Cr(VI) values. Nitrate increased to 890 mg/L-N by S3, then was not detected in the remaining samples. Boron increased slightly from 1.2 mg/L to 2.5 mg/L by S5. DO and ORP varied slightly over the study, ranging from 8.3 to 8.9 mg/L and 81-209 mV, respectively. The pH increased steadily from 7.28 to 8.16. Alkalinity also increased steadily (from 41 to 260 mg/L CaCO₃). The only pesticide detected was beta BHC, which was present from 1.1 to 1.9 µg/L.

3.3.3.2 Soil Results

The concentrations of perchlorate and other parameters in homogenized post-treatment soil are provided in Table 13. The mass balance for perchlorate is shown in Table 14. RSAM-6 soil contained 0.153 mg/kg perchlorate, implying that greater than 99.89% was removed during treatment. However, only 62% of the perchlorate initially present can be accounted for in the leachate. The fate of the remaining perchlorate is uncertain, may be due to uneven distribution of perchlorate in soil so that the measured masses may not be representative despite thorough homogenization of both pre-treatment and post-treatment samples. Alternatively, the added water may have stimulated biodegradation of perchlorate (which has been shown to occur under anaerobic conditions in other laboratory studies using site soil), though this seems unlikely since the columns were aerobic.

The concentrations of calcium, magnesium, potassium, and sodium decreased somewhat after soil flushing, as expected by the presence of these cations in leachate.

3.3.3.3 Observations

The RSAM-6A column ran smoothly. There were no leaks and no difficulties sampling leachate or post-treatment soil. Post-treatment soil had no noticeable odor.

3.3.4 RSAM-5 Soil

3.3.4.1 Leachate Data

The concentrations of perchlorate in the leachate samples and the accumulated mass removed are shown in Figure 14. The concentration of perchlorate decreased over time, though some perchlorate (14.3 mg/L) was still present in the final sample, after application of 2.08 pore volumes of Lake Mead water. Most of the perchlorate was detected in the first two leachate samples. These samples together constituted 0.38 pore volumes of water and contained 183 g perchlorate, which was 96% of the perchlorate initially present in the column (see Section 3.3.3.2 for further discussion of soil and perchlorate mass balance). The remaining leachate samples, which together constituted 1.24 pore volumes of water, contained 25 g perchlorate. Thus, the total mass of perchlorate collected appears to have been greater than the initial mass present, but this is

Sample ID	# pore volumes		Perchlorate in Effluent		Perchlorate Removed		
	Added	Collected	mg/L	g	sample	cummulative	
					% of total*	g	%
S1	0.63	0.15	46,900	79.7	41.6	80	42
S2	0.88	0.38	38,500	104	54.0	183	96
S3	1.13	0.62	8,920	24.7	13	208	108
S4	1.38	0.86	66.8	0.189	0.10	208	109
S5	1.62	1.08	23.8	0.0620	0.032	208	109
S6	1.87	1.32	13.9	0.0379	0.020	208	109
S7	2.08	1.54	10.3	0.0265	0.014	208	109
S8	2.08	1.62	14.3	0.0132	0.007	208	109

* Based on mass initially in soil

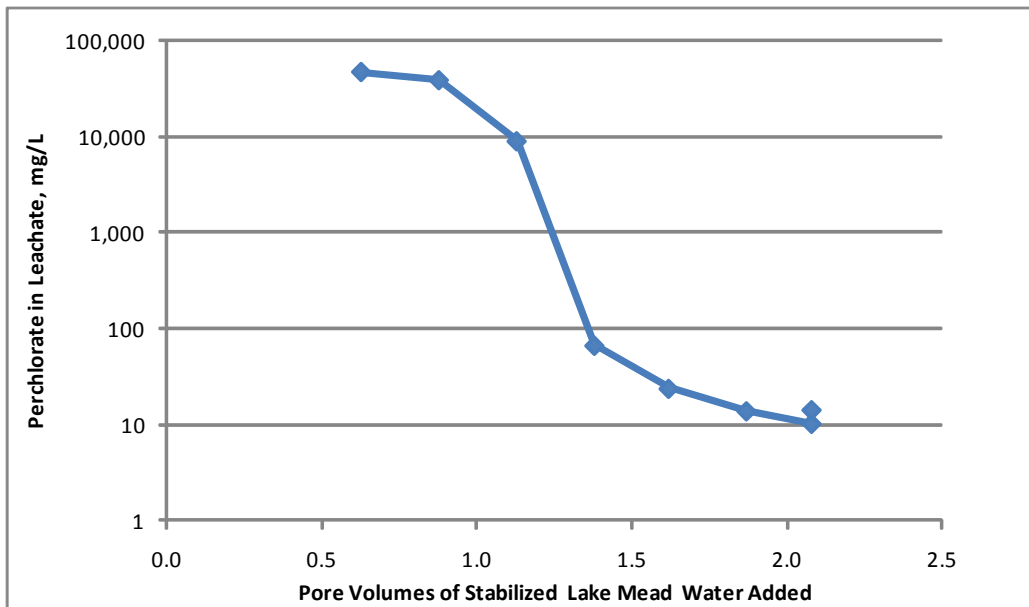


Figure 14. Perchlorate in Leachate. RSAM-5.

probably due to some uncertainty in the initial concentration. The concentrations of arsenic and Cr(VI) in leachate samples are shown in Figure 15.

Arsenic increased by an order of magnitude over time, increasing from 14 $\mu\text{g/L}$ in the S1 sample to 150 $\mu\text{g/L}$ in the S8 sample. Cr(VI) increased from an estimated value of 4.5 $\mu\text{g/L}$ in the S1 sample to a maximum of 150 $\mu\text{g/L}$ by S4, then slowly declined to 120 $\mu\text{g/L}$ by S8.

The concentrations of other parameters in RSAM-5 leachate are shown in Tables 19-22 for Anions, General Minerals, Metals, and Pesticides+Chloroform, respectively. Refer to Table 5 in Section 2.0 for the number of pore volumes added and collected for the various samples. Bromide, fluoride, phosphate, lead, chloroform, and pesticides were not

RSAM-5

Sample ID	# Pore Volumes Added	Leachate Concentration	
		Arsenic	Cr(VI)
		mg/L	µg/L
S1	0.63	14	4.5 J
S2	0.88	17	14
S3	1.13	37	110
S4	1.38	73	150
S5	1.62	100	140
S6	1.87	120	130^
S7	2.08	150	110^
S8	2.08	150	120

^ sample analyzed out of hold time because sample collected on weekend or holiday.

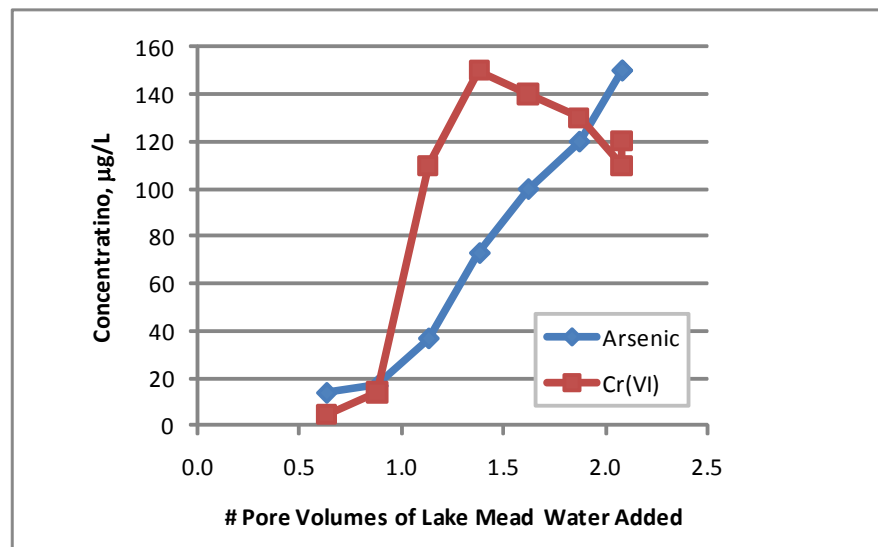


Figure 15. Arsenic and Cr(VI) in Leachate. RSAM-5.

Table 19. Anions in Leachate. RSAM-5.

Sample ID	Bromide	Chloride	Fluoride	Nitrate	o-Phosphate	Sulfate
	mg/L	mg/L	mg/L	mg/L - N	mg/L	mg/L
S1	< 130	32,000	< 130	480	< 500	3,500
S2	< 25	55,000	< 25	470	< 100	11,000
S3	< 130	4,400	< 130	< 130	< 130	6,500
S4	< 25	130	35	1,000	< 25	880
S5	< 25	< 100	< 25	< 25	< 100	350
S6	< 25	< 100	< 25	< 25	< 100	320
S7	< 25	< 100	< 25	< 25	< 100	300
S8	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.

Table 20. General Minerals in Leachate. RSAM-5.

Sample ID	Alkalinity (as CaCO3)			Ammonia	Chlorate	EC	DO	ORP	pH	TDS	TOC	TSS
	bicarbonate mg/L	hydroxide mg/L	Total mg/L	mg/L - N	mg/L	mS	mg/L	mV	--	mg/L	mg/L	mg/L
S1	160	< 20	160	4,400	75	275	7.1	93	7.19	110,000	41	n.m
S2	180	< 20	180	3,700	57	169	8.1	97	7.18	85,000	26	47
S3	300	< 20	300	930	14	66	9.4	35	7.77	15,000	67	< 2.5
S4	550	< 20	680	180	0.15	2.56	8.2	133	8.53	1,600	30	< 2.5
S5	560	< 20	740	< 1.0	0.18	1.88	8.7	111	8.71	960	13	< 2.5
S6	470	< 20	740	120	0.18	1.82	8.5	104	8.82	880	14	< 2.5
S7	340	< 20	580	110	0.16	1.70	8.7	119	8.88	820	12	< 2.5
S8	n.m.	n.m.	n.m.	n.m.	0.13	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.	n.m.

Table 21. Metals in Leachate. RSAM-5

Sample ID	Arsenic mg/L	Boron mg/L	Calcium mg/L	Chromium mg/L	Cobalt mg/L	Iron mg/L	Lead mg/L	Magnesium mg/L	Manganese mg/L	Potassium mg/L	Sodium mg/L	Uranium mg/L
S1	0.014	0.30	3,400	0.0079	0.062	21	< 0.0050	1,400	1.3	720	18,000	< 0.02
S2	0.017	0.32	2,800	0.020	0.068	12	< 0.0050	1,200	0.91	620	15,000	< 0.02
S3	0.037	0.45	540	0.099	0.066	3.2	< 0.0050	240	0.16	170	4,200	< 0.02
S4	0.073	0.54	10	0.16	0.033	0.11	< 0.0050	3.9	0.0054	23	490	< 0.02
S5	0.10	0.49	4.2	0.15	0.022	0.13	< 0.0050	1.6	< 0.0050	16	330	< 0.02
S6	0.12	0.54	3.1	0.11	0.017	< 0.10	< 0.0050	1.2	< 0.0050	13	290	< 0.02
S7	0.15	0.67	3.1	0.11	0.019	< 0.10	< 0.0050	1.0	< 0.0050	14	280	0.005
S8	0.15	0.5	2.9	0.11	0.015	< 0.10	< 0.010	0.96	< 0.0050	12	260	< 0.02

Table 22. Pesticides and VOCs in Leachate. RSAM-5.

Sample ID	Chloroform	alpha BHC	beta BHC	delta BHC	gamma BHC (Lindane)	hexachlorobenzene	Dieldrin
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
S1	< 5.0	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.10
S2	< 10	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.10
S3	< 10	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.10
S4	< 2.0	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.10
S5	< 1.0	< 0.050	< 0.050	< 0.050	< 0.050	< 0.050	< 0.10
S6	< 1.0	< 0.067	0.53	< 0.067	< 0.067	< 0.012	< 0.13
S7	< 1.0	< 0.068	0.42	< 0.068	< 0.068	< 0.012	< 0.14
S8	< 1.0	< 0.042	< 0.042	< 0.042	< 0.042	< 0.0077	< 0.084

Note: Endosulfan II was detected at 0.31 ug/kg in S1 sample only. All other samples were non-detect.

detected in any sample. Chlorate, ammonia, chloride, sulfate, calcium, cobalt, iron, magnesium, manganese, potassium, sodium, and TDS concentrations all followed a similar pattern as perchlorate—that is, they were highest in early samples, then declined in subsequent samples. Chlorate decreased from 75 mg/L in the S1 sample to 0.13 mg/L in S8; ammonia decreased from 4,400 mg/L-N in S1 to 110 mg/L-N by S8; chloride from 32,000 mg/L at S1 to < 100 mg/L by S5; sulfate from 11,000 mg/L in S2 to 300 mg/L by S8; calcium from 3,400 mg/L in S1 to 2.9 mg/L in S8; iron from 21 mg/L in S1 to < 0.10 mg/L by S6; magnesium from 1,400 mg/L in S1 to 0.96 mg/L by S8; manganese from 1.3 mg/L at S1 to < 0.005 by S5; potassium from 720 mg/L in S1 to 12 mg/L by S8; sodium from 18,000 mg/L in S1 to 260 mg/L by S8; and TDS from 110,000 mg/L in S1 to 820 mg/L in S8. TOC peaked at 67 mg/L in S3, then declined to 12 mg/L by S7. Uranium was detected at 0.005 mg/L in the S7 sample only. Chromium increased steadily with concentrations consistent with Cr(VI) values. Nitrate increased to 1,000 mg/L-N by S4, but was not detected in the remaining samples. Boron increased from 0.30 mg/L in the S1 sample to 0.67 mg/L by S7. It decreased to 0.5 mg/L by S8, but there is insufficient data to determine whether this is a downward trend or normal analytical variation. DO and ORP varied slightly over the study, typically ranging from 7.1 to 8.7 mg/L and 93 to 133 mV, respectively. It should be noted that at S3, there appeared to be a spike in DO (to 9.4 mg/L) and a drop in ORP (to 35 mV), which were occurred at the same time as an anomalously low nitrate value, though whether these results are related or coincidental is unknown. The pH in RSAM-5 leachate steadily increased from 7.19 to 8.88. Alkalinity increased through S5, then began to decrease. Bicarbonate alkalinity peaked at 560 mg/L CaCO₃, then declined to 340 mg/L CaCO₃. In contrast, total alkalinity peaked at 740 mg/L CaCO₃, then declined to 580 mg/L CaCO₃. Since no hydroxide alkalinity was detected, the difference between total and bicarbonate may be due to ammonia, which is a weak base.

3.3.4.2 Soil Results

The concentrations of perchlorate and other parameters in homogenized post-treatment soil are provided in Table 12. The mass balance for perchlorate is shown in Table 13. RSAM-6 soil contained 2.1 mg/kg perchlorate, implying that greater than 99.93% was removed during treatment. All of the perchlorate lost from the column could be accounted for in the leachate, implying that flushing is the primary mechanism of removal from this column. (Note: 208 g of perchlorate were detected in leachate, which is more than appeared to be initially present in the column. However, given the high concentration in the untreated soil, it is likely that perchlorate was not evenly distributed, despite efforts to homogenize the soil, and may even have been present as the free salt. Thus, obtaining a representative sub-sample would be difficult.) The concentrations of magnesium and sodium decreased somewhat after soil flushing, as expected by the presence of these cations in leachate. Calcium and potassium were also detected in leachate, but did not noticeably decrease in soil. This may be due to the difficulty of obtaining accurate measurements due to the high concentrations and potentially heterogeneous distribution of these parameters and the small change in mass expected.

3.3.4.3 Observations

The RSAM-5 column ran smoothly. There were no leaks and no difficulties sampling leachate or post-treatment soil. However, post-treatment soil had strong ammonia odor.

4.0 SUMMARY and CONCLUSIONS

Laboratory testing clearly demonstrated that flushing soil by applying approximately 2 pore volumes of clean water can remove perchlorate and other compounds from the site soils. For each column, most of the perchlorate detected in leachate was observed in the first 0.25 to 0.38 pore volumes collected (0.88 to 1.18 pore volumes added), though some perchlorate (0.0892 to 14.3 mg/L) was detected in final leachate samples collected after application of 2.06 to 2.35 pore volumes of clean water. Greater than 99% of the perchlorate was removed from all three soils by the end of the study. However, in SA-189 soil, which contained 6.18 mg/kg perchlorate, only 33% of the perchlorate could be accounted for in leachate. For RSAM-6, which initially contained 145 mg/kg perchlorate, only 62% could be accounted for in the leachate. The fate of the unaccounted perchlorate is uncertain. Possibly the perchlorate may be unevenly distributed in soil so that the measured masses may not be representative despite thorough homogenization. Alternatively, the added water may have stimulated biodegradation of perchlorate (which has been shown to occur under anaerobic conditions in other laboratory studies using site soil), though this seems unlikely since the columns were aerobic. In contrast, all of the perchlorate initially present in RSAM-5 (3,130 mg/kg) could be accounted for in the leachate, though it must be noted that some perchlorate was present in the final leachate sample in and soil post-treatment.

Arsenic and Cr(VI) were detected in leachate from all of the columns, though the concentration varied from column to column. Leachate concentrations of arsenic after application of approximately 2 pore volumes of water were 80 µg/L, 6.7 µg/L and 150 µg/L for SA-189, RSAM-6 and RSAM-5 soils, respectively, while Cr(VI) leachate concentrations were 5.3 µg/L, 5.2 µg/L, and 120 µg/L, respectively. Most detected anions and metals behaved in a manner similar to perchlorate—that is they increased within the first few leachate samples, then decreased in subsequent samples.

In the column flushing tests, water percolated steadily into site soils at a rate of 30 to 40 inches per day when water was continuously applied to the top of the soil column. Continuous application resulted in a layer of water slightly above the ½ inch dispersion disk. In the percolation column (soil SA-179) in which a finite amount of water was applied (6 inches, the equivalent of 1.5 times average annual rainfall), the water percolated quickly for the first 2 hours, slowed, then stopped within 4 days so that all of the water was retained within the soil column.

Based on the results of this study, soil flushing appears to be an effective method of moving perchlorate off site soils. However, the amount of water needed to drive perchlorate the entire depth to groundwater as well as the impact of non-target compounds on groundwater quality and existing pump and treat remediation systems must be considered before applying this technology at this site.

APPENDIX A
(Chain of Custody)

APPENDIX B
(Analytical Reports)