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Treatment Of Fluvially Deposited Streamside
Mine Waste: Material From Canyon Creek,
Idaho

By Anthony J. Paulson, Robert Balderrama, and Eric Zahl

UNITED STATES DEPARTMENT OF ENERGY

SPOKANE RESEARCH CENTER

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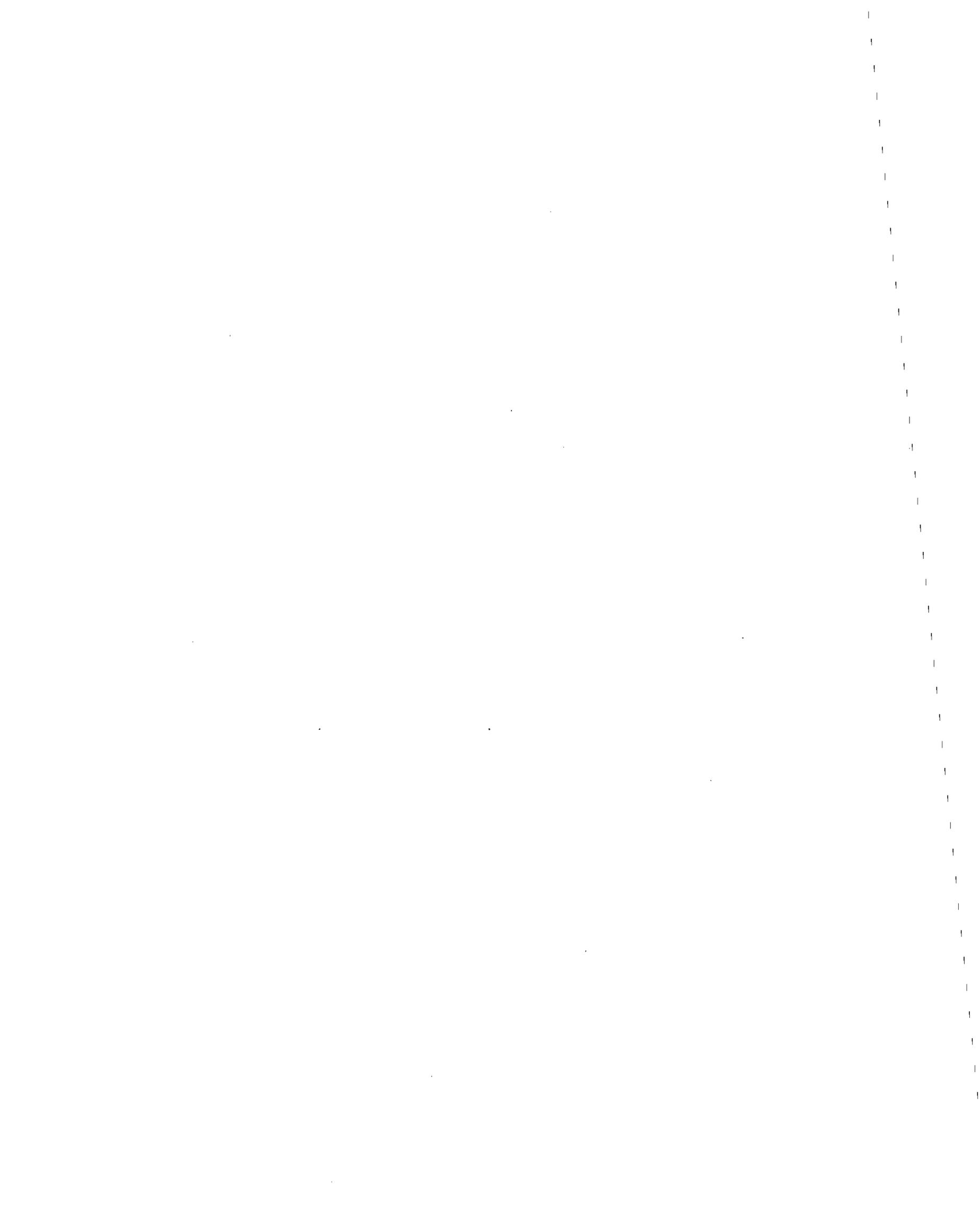
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mL	milliliter
g	gram	mm	millimeter
h	hour	mS	microsiemens
kg	kilogram	mV	millivolt
L	liter	nm	nanometer
L/kg	liter per kilogram	W	watt
m	meter	ppm	part per million
<i>M</i>	molar	wt av	weighted average
mg	milligram	wt %	weight percent
mg/L	milligram per liter	µm	micrometer
millimohs/cm	millimohs per centimeter	°C	degree Celsius
min	minute		



Treatment Of Fluvially Deposited Streamside Mine Waste: Material From Canyon Creek, Idaho

By Anthony J. Paulson,¹ Robert Balderrama,² and Eric Zahl³

ABSTRACT

Three mine-waste-contaminated materials from the flood plain of Canyon Creek, ID, were separated by size to determine if the amount of on-site metal release could be reduced. Comparing weighted-average metal release of damp-screened, sized fractions with metal release from original materials suggested that separation marginally reduced metal releases. In contrast, wet screening of all three material types led to significant reductions in metal release without removing any solid material. However, the results from some column leaching tests suggest that some of these effects may be only temporary.

Decreases in metal releases as a result of removing the finer fraction were greatest when the mineralogical characteristics of the size fraction remaining on-site were significantly different from those of the material removed. Wet screening and removal of 23% of the mass as -2-mm fines from alluvium from below the mine waste resulted in decreases of Zn releases by 65% and Cd releases by 80%. Screening reworked tailings from the streambed removed 53% of the mass smaller than -19.5 mm and reduced Zn and Cd releases by 85% and 88%, respectively. The similar mineralogical characteristics among the size fractions minimized the benefits of separating fluvially deposited tailings.

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INTRODUCTION

In the past, waste rock and tailings were deposited along with natural sediments beside stream channels because of the absence of suitable engineered structures. These wastes were then transported downstream during periods of high flow. Such fluviually deposited mine wastes continue to degrade water quality in many mining districts, both in the United States and abroad. The physical erosion of these mine wastes and the migration of contaminants into surface and ground water are major environmental concerns. The listing of several mining sites on the National Priority List under the Comprehensive, Environmental Response, Compensation, and Liability Act (CERCLA, also known as Superfund) focused attention on metal pollution from past and present mining practices.

Tailings began to be collected in settling ponds in 1968, and this practice has resulted in cleaner mining effluents. As a consequence, metal loads from many presently operating mines and mills have decreased dramatically. In the Coeur d'Alene Basin, for example, metal concentrations decreased significantly after the passage of the Clean Water Act in 1972 (Horning and others, 1988; Colcott, 1989). However, a considerable amount of the present metal loads in mining districts originates outside of currently operating mine and mill sites (Colcott, 1989; McCulley Frick and Gilman, Inc., 1991, 1992). The South Fork of the Coeur d'Alene River is "water quality limited" because of continued release of metals from past mining activities (Coeur d'Alene Basin Restoration Project, 1993). In the South Fork of the Coeur d'Alene River and its tributaries, Zn concentrations in these surface waters seems to be limiting their use as habitat for aquatic natural resources. Controlling the release of Zn and other heavy metals from these fluviually deposited tailings in the upper basin could improve water quality to acceptable standards.

The hydrologic, physical, and chemical characteristics of mixtures of mine waste and stream sediments are probably dramatically different from those of "pure" mine waste piles and probably represent an extreme of the range found when attempting to contain mine wastes. Therefore, the hydrogeochemical behavior of metals within fluviually deposited mine wastes may establish limits on the behavior of metals that can be expected from mine waste contained in controlled structures. The types of data needed to determine the most effective technology for controlling releases from fluviually deposited mine wastes have not been established. The study of a selected treatment for containing metals from fluviually deposited tailings will provide additional knowledge about the physical and chemical variables that govern the effectiveness of treatments in general. This knowledge should be transferable to other waste treatment technologies as well as to wastes from geographic regions having different mineralogies.

The rationale for choosing size fractionation as the remediation technology and the criteria for selecting a site for the

demonstration project were presented in detail in the first phase of this project (Paulson and others, 1996). Size separation reduces metal release in segregated fractions by changing hydrologic and geochemical interactions. The chemically reactive finer fractions are isolated from the porous coarser fractions. The wet separation of unsaturated flood plain material from the East Fork of Nine Mile Creek reduced Zn release by 60%, one-third of which was removed during the separation process. Finer material left on the coarser fraction as a result of incomplete separation had a significant effect on the release of metals from the coarser fraction. For instance, anglesite (PbSO_4), which was a major component of the finest fraction, controlled the release of Pb in the coarser fraction. The dramatic decrease in SO_4^- from the segregated fractions as a result of separation actually resulted in an increase in Pb release because of the solubility control of Pb by anglesite. The difference in chemical composition between the finer and coarser fractions also dictated decreases in metal release from the segregated coarser fraction.

In the second phase of this project, funded by an interagency agreement between the U.S. Bureau of Mines (USBM) and the Environmental Protection Agency (EPA), the results of which are presented in this Report of Investigations (RI), the effects of size separation on metal release from flood plain tailings was examined in more detail. The appropriateness of this remediation technology for saturated flood plain material was investigated. In addition, we examined whether the reduction in metal release was maximized when the coarser fraction is mostly natural alluvial material. The selected treatment for a specific site was implemented after consultation with the land owner, the EPA, and the Coeur d'Alene Basin Restoration Project and its constituencies. The effectiveness of the demonstration project was monitored until the termination of the interagency agreement with EPA.

SITE SELECTION

Six sites were evaluated within the context of specific technologies. The Bureau of Land Management (BLM) nominated four sites under its oversight: (1) the East Fork of Nine Mile Creek, (2) Nine Mile Creek at McCarthy, (3) the Woodland Park area on Canyon Creek, and (4) low-gradient areas in Highland Creek in the Pine Creek watershed. The U.S. Forest Service nominated (1) Tributary Creek below the Jack Waite Mine and (2) Moon Creek at the Silver Crescent mill-site. No sites were nominated by private parties.

The geometry of the McCarthy site was found to present access problems for most types of on-site remediation techniques. Because the major sources of metals in Tributary Creek have been attributed to the adit and seeps from the toes of tailings piles, rather than from fluviually deposited tailings (Gillette and Ralston, 1979), the Jack Waite site was

eliminated from consideration. Likewise, the USBM's recent investigation at the Silver Crescent millsite (Paulson, 1996) clearly indicated that the source of metal release was not from fluvially deposited tailings.

Of the remaining sites, Nine Mile Creek had already been investigated during the preliminary study, and Highland Creek is not a significant contributor of metals. Therefore, Canyon Creek was chosen for further study. In the spirit of cooperation with which the Coeur d'Alene Basin Restoration Project was established, it was recognized that the preliminary characterization data on the material at Canyon Creek obtained during this project would assist the site remediation project being undertaken by the Silver Valley Natural Resources State Trustees.

OVERVIEW OF SIZE FRACTIONATION STUDY

The material within the flood plain of Canyon Creek has been visually categorized into several types: flood plain tailings, reworked tailings, alluvium, slimes, organic soils, and jig tailings. However, most of the material consists of the first three types, and the studies described in this report were limited to these materials. The flood plain tailings are a mixture of materials having a high mine waste content. The reworked tailings are found in the stream bed and are a mixture of stream cobbles, stream gravels, and mine waste. The alluvium is found below the organic layer, which is thought to have been the ground level prior to deposition of mine wastes on the flood plain. However, the finer fraction of the alluvium does contain elevated concentrations of some metals.

Previous research on material from Nine Mile Creek indicated that the amount of fines remaining attached to the

surface of the coarser fraction had a considerable effect on the initial metal leaching rate from columns containing the coarser material (Paulson and others, 1996). Although the use of water during the screening process was shown to be the primary factor in reductions of metal release in subsequent bottle roll leaching tests, the costs of wet screening are significant because treatment of the wash water is required. In the column experiments described in this RI, each of the three material types was tested using two types of screening: (1) damp screening (generally ineffective) and (2) aggressive wet screening (more effective).

The number of size fractions subjected to column leaching tests was kept to a minimum so that the resources of the interagency agreement could be used to study all three types of material. For each of the three materials, a composite sample was obtained and separated at a primary size cutoff. However, the size cutoff was dictated by the characteristics of each material type and differed among the different materials. The dependence of the methods used on the results of the initial size fractionation analysis presented a problem in organizing the results of this research. For this reason, the results of the size fraction analysis will be given in the section on "Methods" before the separation of each of the three materials and the leaching studies are described.

The reactivity of the metals determined from the column leaching tests compared with the results of the static tests is discussed. The release of metals is also related to the efficiency of separation. The knowledge gained from these experiments of separation technology will not only benefit the proposed remediation of the site, but will be extremely valuable nationwide in directing the wise allocation of resources where remediation funds are limited.

METHODS

This project was managed by USBM researchers at the Spokane Research Center (SRC) with assistance from USBM scientists at the Reno Research Center (RERC) and the Rolla Research Center (RORC). The preparation and analysis of the composite samples, the large-volume dry separation, and the column leaching experiments were conducted by SRC personnel. The large-volume wet separation was conducted at RORC. The kinetic humidity cell tests on the fine alluvial fraction were conducted at RERC.

In most cases, different tasks were performed at each center. Although different instruments and analytical methods were used at each center, the quality control-quality assurance procedures outlined below give confidence that the results of analyses from the different types of tests can be compared.

SAMPLING

As part of the characterization of the Canyon Creek flood plain, the consulting firm of McCulley Frick and Gilman, Inc.,

Wallace, ID, under contract to the Silver Valley Natural Resources State Trustees, was charged with collecting grab samples from two depths (upper and lower) in 80 pits. For each pit, sampling personnel then used a rock pick to scrape material from the face of the lower half of the pit into a 30-L plastic bucket. This procedure was repeated for the upper half of each pit. Because many of the pits retained water, much of the material collected, especially from the lower depths, was taken from the saturated zone. On the basis of pit lithology and visual observations, the contents of each bucket were categorized as one of the types of materials found on the site. The buckets were sealed until their contents were selected for incorporation into large-volume samples used for the remediation experiments. Consultant personnel independently screened the 160 pit samples at 80 mesh and had the -80-mesh material analyzed for a variety of metals by a subcontractor.

The samples from Canyon Creek were collected for the sole purpose of providing material for this demonstration project. Although the results of chemical analyses of these

materials may raise interesting scientific and legal questions, the nature of grab samples collected by backhoe precludes the use of these analyses for other scientific and legal purposes. Investigators interested in pursuing questions arising from these studies should undertake independent investigations using sampling and analytical procedures consistent with their purposes.

ANALYSIS

Solids

Randomly selected samples of the three types of materials were analyzed to determine the distribution of metals as a function of size. A subsample of an alluvial sample from a bucket sample, a subsample of reworked tailings from a bucket sample, a subsample of flood plain tailings from a bucket sample, and one flood plain tailings grab sample randomly collected from an excavated pit were dried and sized into 10 fractions using a vibrating, percussion size analyzer with brass screens. These 10 sized fractions were crushed, milled in a roll mill, pulverized, and dissolved in a mixture of hydrochloric (HCl), nitric (HNO₃) and hydrofluoric (HF) acids. To prevent cross-contamination, the crusher, roller, and pulverizer were thoroughly cleaned before each sample was processed, and the samples were processed in order of expected increasing metal concentration (first alluvium, then reworked tailings, and lastly flood plain tailings). A sample weighing 0.5 g was placed in a Saville digestion vessel (part 568) and 6 mL of HCl, 2 mL of HNO₃, and 2 mL of HF were added. The vessel was heated for 2 min per sample in a microwave at 250 W and then cooled. Twenty milliliters of saturated boric acid (H₃BO₃) was added, and the sample was diluted to a volume of 100 mL. The acid solution was analyzed by an inductively coupled plasma (ICP) emission spectrometer in a manner similar to that used in the analyses of chemical leachate liquids. The recovery of the Standard Reference Material MP1 (CANMET, ON) was 82%, 91%, and 72% for Pb, Cu, and Zn, respectively.

One-kilogram samples (27 samples) from individual buckets were dried and split into two fractions to determine their

suitability as representative samples of the respective material types. The fractions were crushed, rolled, and pulverized in the manner described above to reduce contamination (i.e., coarser alluvium and reworked tailings fractions were processed first and the finer flood plain tailings sample last). The relative standard deviations (RSTD) for duplicate analyses of randomly selected samples are given in table 1. The RSTD's were generally below 10% except when the metal content of a sample was low (alluvium sample B24) or when a sample was not homogeneous (i.e., the coarser reworked fraction C4).

Elements in Liquids

Column Leaching Tests and Total Dissolution Solutions (SRC)

The major cations (Na, K, Ca, and Mg) were analyzed by ICP (Perkin Elmer Plasma II) on wavelengths of 558.995, 589.593, 393.366, and 279.553 nm, respectively. Zn, Al, Mn, Fe, Cu, Cd, and Pb concentrations were determined by ICP at 213.860, 396.152, 257.610, 259.940, 324.754, 228.802, and 220.353 nm, respectively. Total S was determined at 180.731 nm. In all cases, a 1-point calibration was performed, and a calibration blank containing 1% HNO₃ was used. A calibration verification was performed after each calibration. A drift check (standard QC) was run after each group of 15 samples was analyzed. Any time the check samples for a group varied by more than 5% from the expected value, a recalibration was performed, and all samples in a group were reanalyzed. The RSTD of replicate analyses of major ions was excellent, usually being below 5% (table 2). Variations in the calibrations among analytical sequences were determined by replicate analyses of the quality control (QC) sample and blind standards. For most elements, the RSTD's of results of the QC were less than 5% for the 21 analyses during the duration of this study. The low concentrations of S, Si, and Al in the QC resulted in large RSTD's. The recovery of blind standards was within 10% of the expected value (table 3).

Table 1.—Relative standard deviations of duplicate analyses of solids

Location	Depth interval, cm	Size fraction, mm	Element, percentage of mean											
			Al	Ca	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
ALLUVIUM														
B24	46-152	-0.21 +0.15	2.6	24.7	<1	0.6	4.8	10.3	5.6	11.6	5.0	23.6	5.9	
REWORKED TAILINGS														
C24	0-91	-50 +19.5	2.3	4.5	12.9	0.5	10.5	1.2	<1	0.7	2.9		4.2	4.0
C4	0-76	-50 +19.5	9.6	14.6	23.6	2.5	1.9	15.7	47	33	141	141	1.9	7.3
FLOOD PLAIN TAILINGS														
C08	Grab	-2.0 +0.85	1.6	0.6	4.1	4.1	8.5	3.6	6.5	4.6	9.4	4.6	1.2	11.9
C08	Grab	-0.08 +0.075	9.2	7.0	4.0	6.5	9.4	6.4	1.5	18.0	6.5	8.0	15.5	6.3
C08	0-51	-2.0	5.7	11.7	3.7	3.7	1.0	23.6	9.4	14.9	0.1	6.8	1.0	35
A8	0-61	-4.8 +2.0	6.3	19.6	20.2	3.5	4.0	13.3	3.3	24.5	2.5	21.2	5.0	10.2
A8	0-61	-0.075	0.6	1.3	4.9	0.3	2.2	2.0	0.5	0.6	0.4	16.6	0.1	1.6

Table 2.- Average concentrations and relative standard deviations of replicate analysis of liquid samples

Column	Leaching cycle	Elements, mg/L												
		Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
ALLUVIUM														
DA2	4	<0.1	14.9	0.4	<0.1	<0.1	4.1	4.8	2.2	8.5	0.2	35.1	7.7	26.7
Conc.			4.6	6.6			15.3	4.6	4.1	7.9	13.5	5.3	4.4	6.5
RSTD ¹														
DA3	3	0.4	56.9	2.1	0.8	<0.1	6.5	17.7	11.3	11.5	2.9	167	18.3	93.4
Conc.			7.2	7.2	3.5		8.5	6.9	7.6	8.9	7.8	7.6	7.5	4.8
RSTD														
DA3	14	0.4	42.4	2.0	0.4	<0.1	5.6	14.1	13.7	3.4	2.8	159	15.8	94.8
Conc.			0.9	0.7	3.6		1.7	0.8	1.0	1.3	0.5	1.3	0.7	0.3
RSTD														
WA2	6	<0.1	6.6	0.1	<0.1	<0.1	1.3	3.5	0.5	1.5	0.4	20.3	3.8	14.0
Conc.			3.1	4.0			1.2	2.1	16.7	0.7	6.2	0.3	0.3	1.3
RSTD ¹														
WA3	2	<0.1	32.1	0.1	<0.1	<0.1	1.4	24.2	4.5	4.7	0.4	54.4	6.1	6.8
Conc.			0.6	0.0			0.5	0.6	0.0	0.5	103.2	0.5	0.1	0.0
RSTD														
WA3	14	<0.1	20.1	<0.1	<0.1	<0.1	1.2	16.2	5.4	3.1	<0.1	38.4	5.0	2.9
Conc.			6.9				<10	0.3	0.4	0.0		0.3	0.7	0.7
RSTD														
WA3	17	<0.1	22.0	0.1	<0.1	<0.1	1.5	16.8	3.0	3.1	<0.1	48.4	5.8	5.9
Conc.			1.9	1.6			0.9	0.6	1.2	1.2		0.9	0.8	0.3
RSTD														
REWORKED														
DR1	17	<0.1	38.2	0.5	<0.1	<0.1	2.6	10.7	<0.1	2.7	2.0	84.1	5.4	58.8
Conc.			1.4	5.4			2.8	3.6		1.0	3.5	5.4	2.2	6.0
RSTD														
FLOOD PLAIN TAILINGS														
WTOS	9	<0.1	3.2	<0.1	<0.1	<0.1	0.7	1.7	1.4	1.1	5.2	14.3	1.6	13.8
Conc.			0.2				0.0	0.0	0.5	1.3	0.3	0.5	0.4	0.7
RSTD														
OM2	8	0.3	27.8	1.3	0.2	<0.1	4.2	9.1	3.0	5.1	2.1	93.8	12.2	57.9
Conc.			5.4	2.0	4.3	66.6	14.4	4.9	1.2	14.0	2.0	2.5	2.7	1.1
RSTD														
DGS1	2	0.3	41.7	1.6	<0.1	0.2	5.5	16.2	28.3	5.4	5.1	220	14.2	138
Conc.			2.1	1.3	0.7	11.5	0.9	0.9	1.1	3.5	0.6	4.0	0.8	3.0
RSTD														
DGS2	12	0.3	54.7	3.1	<0.1	<0.1	5.6	23.2	52.6	3.3	4.9	397	18.7	304
Conc.			0.0	0.1	0.2		0.1	0.2	0.3	1.3	0.1	0.8	0.5	0.5
RSTD ¹														
DG1	5	0.3	34.8	1.5	<0.1	<0.1	4.8	13.4	27.9	3.3	4.2	196	12.0	124
Conc.			2.6	1.7	1.9		1.8	1.5	0.2	1.7	2.4	1.8	2.1	0.6
RSTD														
WF2	0	<0.1	76.6	0.7	<0.1	<0.1	4.9	44.3	57.0	5.4	3.9	232	8.1	77.4
Conc.			3.7	4.8			14.7	4.6	4.3	1.7	1.8	7.9	3.7	4.8
RSTD														
WF2	13	<0.1	90.6	1.2	<0.1	<0.1	4.6	49.3	107	5.0	5.1	310	10.0	126
Conc.			0.9	0.6			0.0	0.0	0.3	0.1	14.1	0.5	0.6	0.1
RSTD														
QUALITY CONTROL SAMPLE														
Conc.		3.3	50.2	4.8	5.1	48.7	47.1	50.0	5.0	52.9	5.0	1.2	0.1	5.2
RSTD ²		31.0	5.0	3.9	2.4	4.4	3.8	2.4	3.6	7.3	9.8	38.5	94.2	4.3

RSTD- Relative standard deviation.

Note- n = 2 unless otherwise noted.

¹n = 3.²n = 21.

Table 3.—Recoveries of metals in blind standards

Element	Recovery, %		No.	Concentration range, mg/L
	Average	Standard deviation		
Al	103.4	2.0	21	2-100
Ca	90.6	2.8	20	10-100
Cd	96.5	2.6	19	2-20
Cu	102.4	6.3	7	10-20
K	102.3	3.4	3	10-20
Mg	96.5		1	10
Mn	100.7	2.3	19	2-20
Na	91.8		1	20
Pb	97.4		1	10
Si	103.4	6.7	6	1-50
Zn	103.2	5.5	7	5-50

Humidity Cell Tests and Total Dissolution Solutions (RERC)

Liquid solutions were analyzed for total metals and S concentrations on an ARL Q137 ICP (modified with an Interface Design analog to a digital converter) at the above wavelengths. One-point calibrations were performed in conjunction with a 2% HNO₃ calibration blank. Total S concentrations were converted to sulfate concentrations using a 1:3 stoichiometry.

DETERMINATION OF SIZE CUTOFFS

Alluvium

Size fractionation data and results of chemical analyses from one sample of alluvium taken from a Canyon Creek site are presented in figure 1 and table 4. S, Fe, and Pb were elevated in the smallest size fraction of the alluvium sample (finer than 0.075 mm, less than 200 mesh). This fraction made up 3% of the mass of the total sample. The slightly high Zn and S concentrations in the largest fraction (+50 mm) may have been a result of the low number of samples of cobbles analyzed in this fraction, allowing one anomalous sample to have a significant effect on the average. Only 12% of the mass of this alluvium sample was contained in the largest fraction. Although the characterization study indicated a cutoff size of 0.2 mm, this size was increased to 2 mm because, from an engineering perspective, it is much more practical to separate material at this size and because the increase in cutoff size did not dramatically increase the amount of the finer fraction. Because material as large as 50 mm was being tested, 153-mm-diam columns were used to give a 3:1 ratio between column diameter and maximum material size.

Reworked Tailings

The reworked tailings exhibited a dramatic change in metal content at 19.5 mm. Fractions smaller than 19.5 mm had

higher elemental concentrations of S, Zn, and Pb, and constituted 50% of the mass of the total sample (figure 1).

Flood Plain Tailings

Two samples of material categorized as flood plain tailings were characterized by size fractionation (figure 2). In one sample (A8), the fraction between 50 and 19.5 mm had relatively low metal concentrations. Below 19.5 mm, Zn and S concentrations changed very little. Pb concentrations increased with decreasing size below 0.43 mm. The other tailings sample (C8 grab) showed enrichment of S and Zn in the fractions between 0.43 and 50 mm, which constituted most of the mass.

Although the flood plain tailings did not meet the criterion of differing composition with size, they were analyzed using column leaching tests to determine if an effect was observed when only the physical factors were changed (i.e., isolating the reactive finer fraction with its higher surface area from the porous coarser fraction). Because the fraction between 50 and 19.5 mm contained little material, the flood plain tailings were oversized at 19.5 mm. The oversized material (-50 +19.5 mm) was screened by both wet and dry methods and leached in 153-mm-diam columns in experiments that were logistically independent from the leaching tests of the -19.5-mm flood plain tailings. This allowed the use of 102-mm-diam columns and better comparisons of results of the column leaching tests with results of leaching tests on Nine Mile Creek material. In the absence of any definitive change in mineral characteristics with size, the medium size for mass (2 mm) was chosen as the size cutoff for the -19.5-mm tailings.

SELECTION AND PREPARATION OF COMPOSITE SAMPLES

Based upon the identification of appropriate size cutoffs and the -80-mesh data from McCulley Frick and Gilman, Inc. (1994), the individual pit samples were selected for possible inclusion in composite samples. Initially, samples representing a wide range of metal content over the geographical extent of the site were chosen for further testing. Because the Nine Mile Creek study suggested that the chemistry of the large-volume sample could be skewed by a single subsample, a cautious approach was taken. One-kilogram samples from selected 30-L pails were sized according to the appropriate cutoff for each material type and analyzed for metals. The results of the analyses were examined for consistency in pattern and to determine if samples had metal contents significantly beyond the range of the other samples. If a sample did not show the same or a similar pattern as other samples, analytical logs, the labels on the pails, and the remaining material in the pails were examined for inconsistencies. Seven samples were analyzed but were not used for a variety of reasons (table A-1). Material greater than 50 mm was rejected by damp

Table 4. Metal concentrations in 10 fractions from alluvium, reworked tailings, and flood plain tailings

Location	Depth range, cm	Size fraction lower size, mm	Elements, wt pct												
			Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
ALLUVIUM															
B24	0-91	50	6.31	0.22			0.97	2.34	0.11	0.03	1.68	0.00	0.09	53.46	0.06
B24	0-91	19.5	6.11	0.06		0.00	1.68	2.17	0.21	0.04	1.83	0.00	0.00	54.67	0.01
B24	0-91	9.5	6.91	0.06		0.00	2.51	2.56	0.23	0.05	3.11	0.02	0.00	66.40	0.02
B24	0-91	4.8	6.25	0.09		0.00	2.24	2.03	0.23	0.04	2.24	0.02	0.00	54.75	0.03
B24	0-91	2.00	6.68	0.08		0.00	2.16	2.37	0.22	0.07	2.89	0.06	0.00	61.56	0.03
B24	0-91	0.85	6.61	0.10		0.00	2.00	2.27	0.20	0.07	2.36	0.06	0.00	58.25	0.03
B24	0-91	0.43	6.56	0.12		0.00	1.94	2.02	0.20	0.08	2.10	0.06	0.00	51.90	0.04
B24	0-91	0.21	6.40	0.19		0.00	1.89	2.37	0.24	0.11	2.35	0.10	0.02	56.70	0.05
B24	0-91	0.15	5.56	0.14		0.01	1.89	1.92	0.19	0.13	1.71	0.15	0.03	48.23	0.07
B24	0-91	0.08	5.41	0.19	0.001	0.01	2.05	1.77	0.23	0.18	1.56	0.19	0.00	46.54	0.11
B24	0-91	<0.075	7.66	0.28	0.001	0.03	3.23	1.99	0.45	0.38	2.42	0.44	0.07	50.69	0.25
B24	0-91	+2.0 wt av	6.25	0.09			1.69	2.23	0.20	0.04	2.00	0.01	0.01	55.82	0.02
B24	0-91	-2.0 wt av	6.01	0.10			1.83	2.00	0.18	0.10	2.06	0.06	0.00	51.17	0.04
REWORKED TAILINGS															
C24	38-152	50	6.68	0.07		0.00	2.78	2.08	0.17	0.02	0.22	0.03	0.03	31.87	0.03
C24	38-152	19.5	5.17	0.08		0.01	1.60	2.09	0.17	0.02	0.92	0.05	0.03	35.44	0.03
C24	38-152	9.5	5.03	0.18		0.01	4.00	1.84	0.21	0.19	0.55	0.74	0.32	32.56	0.13
C24	38-152	4.8	5.16	0.11	0.003	0.01	4.08	1.98	0.19	0.17	0.50	0.56	0.45	34.25	0.68
C24	38-152	2.00	5.17	0.15	0.003	0.01	4.19	1.99	0.20	0.18	0.51	0.75	0.52	33.82	0.73
C24	38-152	0.85	5.09	0.16	0.001	0.02	4.20	2.23	0.18	0.19	0.52	0.70	0.24	33.18	0.37
C24	38-152	0.43	4.93	0.15	0.004	0.02	6.53	2.36	0.19	0.37	0.47	0.77	0.74	31.93	0.60
C24	38-152	0.21	4.06	0.18	0.003	0.02	9.26	1.86	0.21	0.54	0.32	0.95	0.99	31.32	0.67
C24	38-152	0.15	3.57	0.17	0.002	0.04	12.73	1.53	0.23	0.76	0.29	1.17	1.45	30.16	0.55
C24	38-152	0.08	3.37	0.16	0.003	0.03	13.49	1.50	0.24	0.75	0.31	1.75	1.64	29.41	0.53
C24	38-152	<0.075	4.21	0.26	0.004	0.07	9.68	1.72	0.35	0.56	0.54	2.98	1.63	31.31	1.02
C24	38-152	+19.5 wt av	5.17	0.08		0.01	1.60	2.09	0.17	0.02	0.92	0.05	0.03	35.44	0.03
C24	38-152	-19.5 wt av	4.98	0.15		0.01	4.97	2.00	0.20	0.24	0.50	0.76	0.50	32.98	0.48
FLOOD PLAIN TAILINGS															
A8	0-61	19.5	6.78	0.15	0.007	0.01	2.29	3.06	0.24	0.03	1.81	0.02	0.10	33.52	0.03
A8	0-61	9.5	5.31	0.28	0.011	0.02	6.05	2.16	0.30	0.38	1.26	1.37	0.71	39.39	0.69
A8	0-61	4.8	5.71	0.28	0.009	0.03	5.40	2.46	0.27	0.32	1.21	1.24	0.69	39.33	0.59
A8	0-61	2.00	5.60	0.23	0.009	0.04	5.23	2.50	0.25	0.29	0.99	0.95	0.59	37.98	0.39
A8	0-61	0.85	5.27	0.15	0.008	0.01	4.72	2.50	0.18	0.26	0.67	0.95	0.42	32.74	0.44
A8	0-61	0.43	5.83	0.18	0.007	0.01	4.21	2.63	0.20	0.18	1.79	1.05	0.17	43.93	0.23
A8	0-61	0.21	5.33	0.25	0.006	0.02	7.50	2.23	0.22	0.29	1.46	2.13	0.36	39.32	0.38
A8	0-61	0.15	5.12	0.30	0.009	0.03	8.24	1.81	0.24	0.32	1.54	2.61	0.43	38.09	0.46
A8	0-61	0.08	5.01	0.43	0.008	0.05	9.17	1.56	0.28	0.38	1.78	3.07	0.52	38.04	0.51
A8	0-61	<0.075	7.21	0.80	0.008	0.04	7.87	1.54	0.46	0.29	2.63	4.14	0.37	40.30	0.57
A8	0-61	+2.0 wt av	5.65	0.26	0.009	0.03	5.29	2.43	0.27	0.31	1.22	1.10	0.62	38.48	0.52
A8	0-61	-2.0 wt av	5.88	0.35	0.008	0.02	6.00	2.19	0.27	0.26	1.67	2.05	0.33	39.27	0.40
C08	Grab	19.5	5.91	0.20		0.10	10.60	1.79	0.38	0.67		3.35	2.46		2.99
C08	Grab	9.5	6.17	0.17		0.80	9.44	1.86	0.37	0.58		2.02	1.65		1.66
C08	Grab	4.8	6.08	0.15		0.06	9.14	1.86	0.36	0.57		3.25	1.78		2.01
C08	Grab	2.00	5.78	0.16		0.06	8.77	1.70	0.33	0.48		3.10	2.46		3.21
C08	Grab	0.85	5.92	0.13		0.06	7.36	1.89	0.25	0.32		3.47	1.78		2.26
C08	Grab	0.43	6.77	0.15		0.06	6.63	2.03	0.25	0.24		4.27	1.21		0.90
C08	Grab	0.21	6.77	0.18		0.04	6.49	2.08	0.26	0.23		3.80	0.72		0.42
C08	Grab	0.15	7.05	0.16		0.04	6.73	2.01	0.27	0.23		4.00	0.74		0.29
C08	Grab	0.08	6.77	0.28		0.04	6.98	1.84	0.28	0.20		4.52	0.82		0.33
C08	Grab	<0.075	7.12	0.49		0.04	6.75	1.61	0.34	0.15		4.84	0.85		0.36
C08	Grab	+2.0 wt av	5.98	0.16		0.22	9.41	1.80	0.36	0.57		2.97	2.07		2.45
C08	Grab	-2.0 wt av	6.76	0.27		0.04	6.83	1.86	0.28	0.21		4.26	0.99		0.71

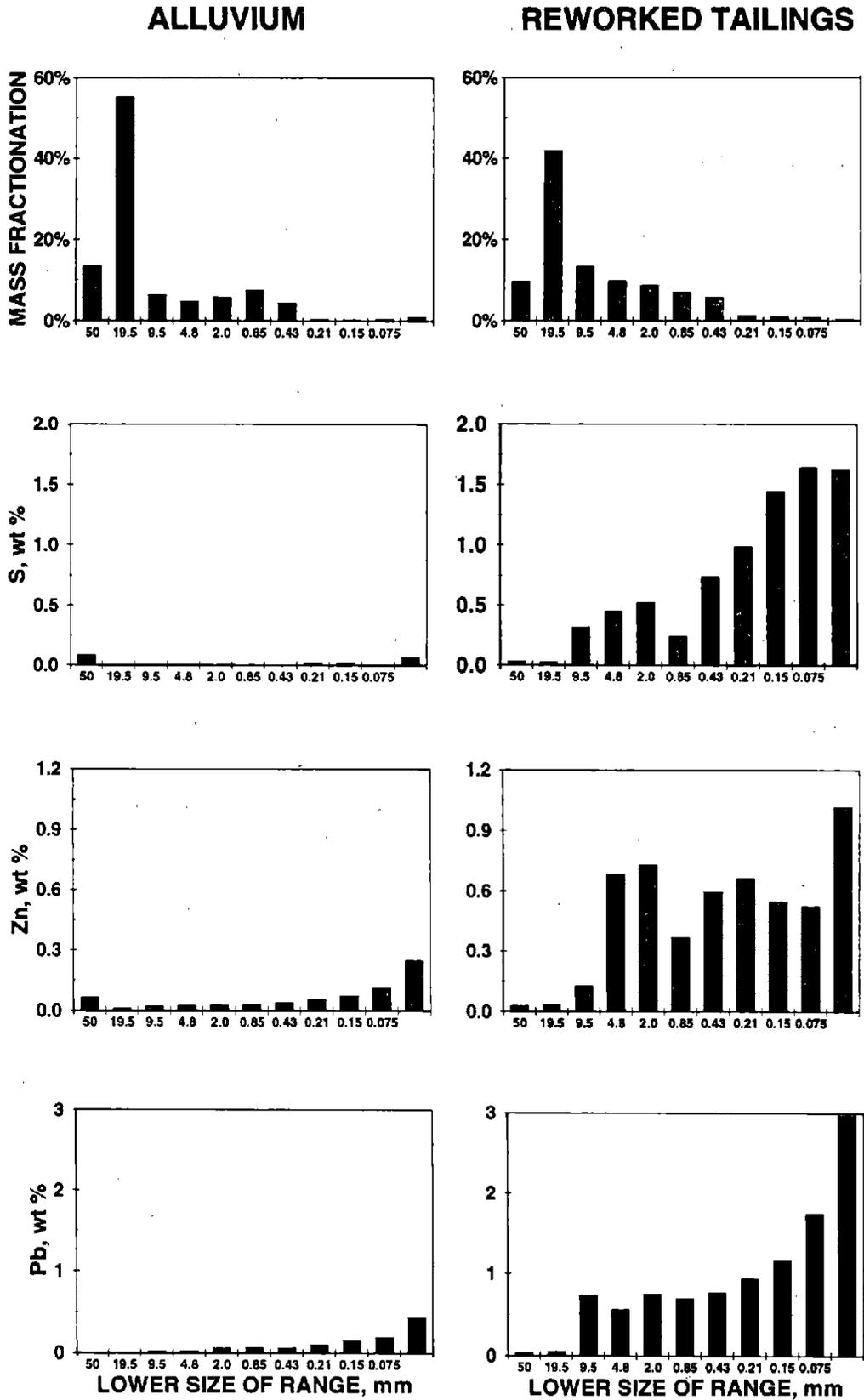


Figure 1.—Mass fraction, S, Zn, and Pb of 10 size fractions separated from alluvium and reworked tailings.

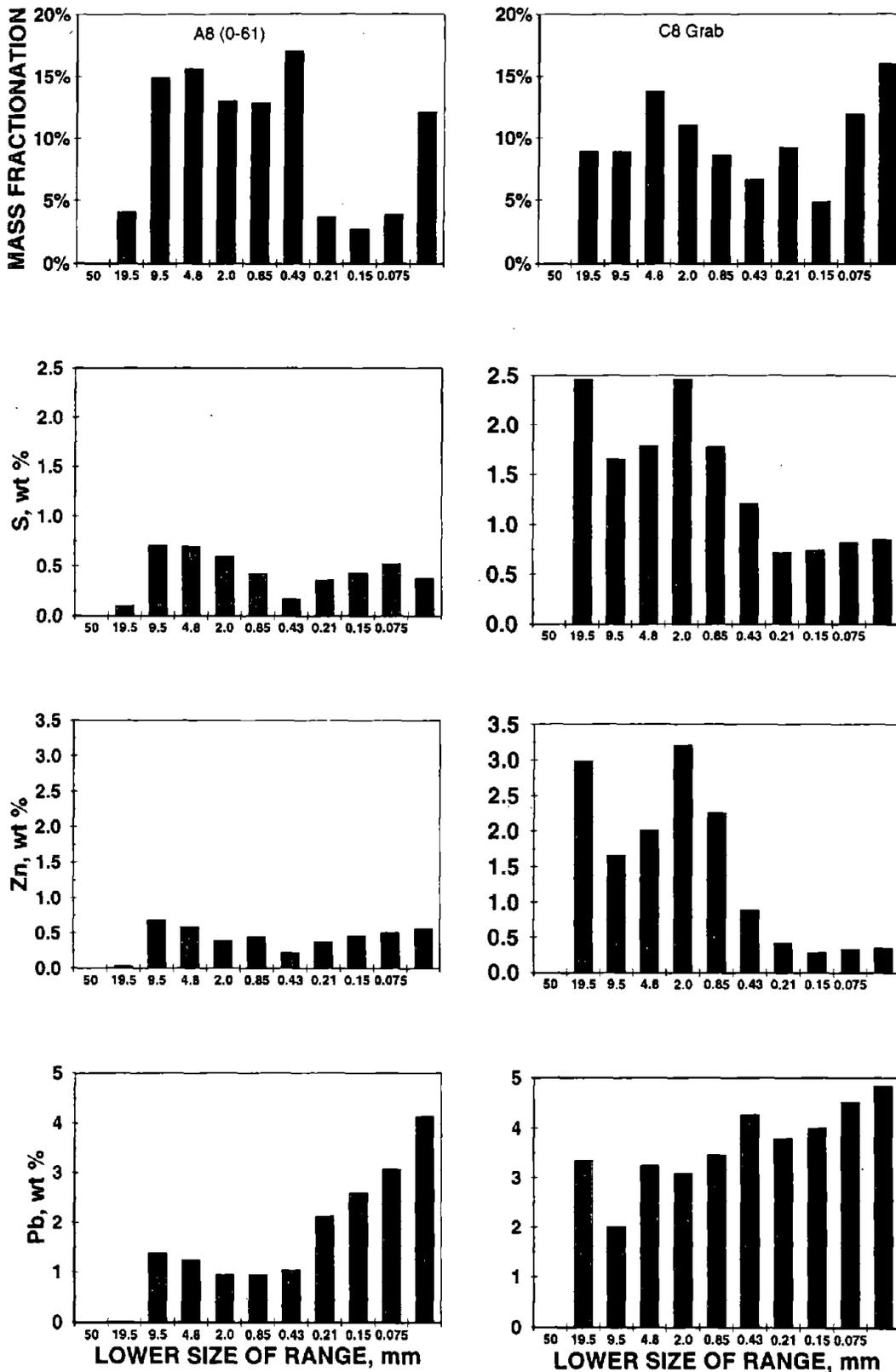


Figure 2.—Mass fraction, S, Zn, and Pb of 10 size fractions separated from flood plain tallings.

screening before the -50-mm material was added to the appropriate composite sample. Material larger than 50 mm constituted 37.5%, 37.5%, and 17% of the dry weight of the alluvium, reworked tailings, and flood plain tailings, respectively. One chunk of cemented flood plain tailings constituted 5.6% of the total flood plain tailings processed. For each of the three types of material, solids less than 50 mm were blended with the contents of other pails of the same material type using the quartering method to form the alluvium and reworked tailings composite and a large volume of flood plain tailings (American Society for Testing Materials [ASTM], 1994). Half of each composite sample was screened without the use of water, while the other half was sent to RORC for size separation by more aggressive wet screening.

SCREENING AND PACKING OF COLUMNS

Damp screening of the material was conducted separately using appropriately sized steel screens enclosed in a Gilson vibrating size separator. To simulate the mechanical force of a full-scale operation, a gloved hand was used to force the moist material through the screens. Wet screening was accomplished with appropriately sized steel screens mounted in a 46-cm gyratory separator. For each material, the weight of solid material processed and the volume of wash water were measured. The pH and conductivity of the wash water and a corresponding sample of tap water used as a blank were also measured. After settling overnight, each sample of wash water was filtered and analyzed for metals and S.

The columns used in this study were 1 m high and made of clear acrylic. The 102-mm-diam columns were connected to white polypropylene Buchner-like funnels loaded with filter paper and a polyethylene screen. The funnels of the 153-mm-diam columns were cut off at the base of the support and glued to white, polyethylene plumbing couplings, which fit snugly over the acrylic columns. A subsample of each composite, the damp- and wet-screened fractions, and the subfractions used in the leaching tests were analyzed for total metals, as described in the section "Solids."

Alluvium

A 2-mm (10-mesh) screen was used to screen the alluvium composite into coarser and finer alluvium samples. Because the alluvium formed clay balls during damp screening, it was partially dried for 1 h at 50 °C. The results of the large-volume separation are listed in table 5 along with moisture content and amount of fines (-1 mm) recovered from the coarser fractions. Approximately 34 kg of -50-mm alluvium composite was separated in the gyratory separator at 2 mm using 148 L of processing water. The use of water increased the recovery of the finer fractions from 22% using damp methods to 36% using wet methods. Approximately 10 kg of

the alluvium composite, the wet- and dry-screened coarser alluvium fractions, and the damp-screened finer alluvium fraction were packed into 153-mm-diam columns (table 5). Because the amount of sample was limited, only 4 kg of the wet-screened, finer fraction was subjected to leaching tests.

Reworked Tailings

A 19.5-mm screen was used to separate the finer fraction from the coarser fraction during both wet and damp screening of the reworked tailings composite. During wet screening, 48 L of processing water was used to separate 33 kg of reworked tailings composite. Between 64% and 77% of the -50-mm material was recovered as the finer fraction. However, when processed material rejected as oversized (+50 mm) was included (37.5% of the total), 19.5 mm was close to the median size for material found in the field. The reworked composite and the damp- and wet-screened coarser and finer fractions were packed into 153-mm-diam columns. Because the filter paper in the column containing the coarser fraction tended to float, the column was emptied after the third leaching (day 6) and repacked after placing a small amount of clean silica sand directly over the filter.

Flood Plain Tailings

The large-volume sample of flood plain tailings was again separated by hand at 19.5 mm because the size fraction data suggested that the +19.5-mm material contained lower amounts of metals. The -50 +19.5-mm size fraction is hereafter called "the oversized flood plain tailings." This second oversizing excluded 15% of the -50-mm material. The oversized flood plain tailings were allowed to air dry and was rescreened on a Gilson vibrating size separator to dislodge the loose finer material, resulting in a recovery of less than 0.1% of the mass as -1-mm fines. Approximately 13 kg of the damp-screened, oversized flood plain tailings was packed into 1-m-high, 153-mm-diam columns.

The -19.5 mm material is referred to hereafter as the "flood plain tailings composite." Passage of most of the flood plain tailings through the 19.5-mm screen allowed 102-mm-diam columns to be used rather than the more cumbersome 153-mm-diam columns. Duplicate 102-mm columns were loaded with an average of 6.35 kg of the flood plain tailings composite sample (-19.5 mm).

During separation of the flood plain tailings composite by damp screening, the 2-mm-mesh screen clogged easily. The screen was washed with water and dried with compressed air between processing of each batch of flood plain tailings. Duplicate columns containing approximately 6 kg of the damp-screened, sand-gravel fraction (-19.5 +2 mm) and the fine fraction (-2 mm) of the flood plain tailings were packed.

Table 5 - Summary of large-volume processing and column packing

Sample	Composite		Fractions and subfractions																
	Col. wt., kg	Moisture content, %	Coarser fraction					Finer fraction											
			Wt. rate, kg	Water used, L	Fraction name	Size, mm	Wt. recovered, kg	Fraction of Moisture content, %	Fines recov- ered, %	Col. wt., kg	Fraction name	Size, mm	Wt. recov- ered, kg	Fraction of composite, %	Moisture content, %	Col. wt., kg			
			DAMP SCREENED																
Alluvium	10.98	8.1	39.1		Coarser	-50 +2	30.29	77.6	0.6	1.7	10.98	Finer		-2	8.77	22.4	0.6	9.36	
Reworked tailings	8.7	9.5	33.3		Coarser	-50 +19.5	7.62	22.9	1.3	1	7.51	Finer		-19.5	25.63	23	13.2	9.35	
Flood plain tailings: -50 mm			62.0		Overized	-50 +19.5	9.2	14.8	1	0.1	12.98	Composite ¹							
Composite	6.35	9.4	38.4		Sand-gravel ²	-19.5 +2	25.98	67.6	11	15	6.28	Fines		-2	12.46	32.4	12.8	5.98	
Sand-gravel, damp-screened			9.7		Gravel sub- fraction	-19.5 +4.8	6.14	63.3	10	17	5.67	Sand sub- fraction		-4.8 +2	3.56	36.7	10	4.7	
Sand-gravel, wet- screened			17.9		Gravel sub- fraction	-19.5 +4.8	9	53	4.63	0.3	5.83	Sand sub- fraction		-4.8 +2	8.6	47	13	4.92	
			WET SCREENED																
Alluvium			31	153	Coarser	-50 +2	20.9	63.6	3.2	1.9	9.56	Finer		-2	10.06	36.4	23.6	3.59	
Reworked tailings			32	48	Coarser	-50 +19.5	11.34	36	1.4	0.1	7.53	Finer		-19.5	20.62	64	24	9.39	
Flood plain tailings: -50 mm			90	370	Overized	-50 +19.5	15.1	16.8	1.4	0.02	13.32	Composite ¹							
Composite					Sand-gravel	-19.5 +2	43.03	48.3	15.6	2.7	5.31	Fines		-1	31	34.9	28	5.87	

¹Composite material further divided into sand-gravel fraction and fines fraction. ²Sand-gravel fraction further divided into gravel subfraction and sand subfraction.

NOTE: - Alluvium, reworked tailings, and overized flood plain tailings processed in 153-mm-diam columns; flood plain tailings processed in 102-mm-diam columns.

Approximately 90 kg (dry weight) of -50-mm flood plain tailings composite was sized with a 2-mm screen using 362 L of water. The wet-screened, coarser fraction was initially oversized at 19.5 mm, resulting in removal of 17% of the -50-mm material. As with the damp-screened, oversized tailings, 13 kg of the wet-screened, oversized tailings was packed in 153-mm-diam columns. After oversizing at 19.5 mm and decanting 4.5 kg of dirty water that contained 0.99 kg of fines, the gravel-sand fraction (-19 +2 mm) constituted 58% of the dry weight of the flood plain tailings composite (-19.5 mm). Duplicate columns each containing approximately 5.5 kg of the wet-screened, sand-gravel fraction (-19.5 +2 mm) and the fine fraction (-2 mm) of the flood plain tailings were packed.

In addition, a portion of both damp-screened and wet-screened, sand-gravel flood plain tailings were damp screened with a 4.8-mm screen (4 mesh) without the use of any water. When the previously damp-screened, sand-gravel fraction was sized, the separation resulted in a ratio of 63%:37% for the gravel (-19.5 +4.8 mm) and sand (-4.8 +2 mm) flood plain tailings subfractions. Damp screening the previously wet-screened, sand-gravel fraction resulted in a 53%:47% separation ratio. The effect of the previous wet screening can be seen in the amount of fines recovered from the coarser gravel subfraction. The result of the separation of the previously dry-screened, sand-gravel fraction was that 17% of the mass of the gravel subfraction was recovered as -1-mm fines (table 5). In contrast, only 0.3% of the mass of the gravel subfraction from the previously wet-screened, sand-gravel fraction was recovered as fines. Between 4.7 and 5.8 kg of the four subfractions were packed into 102-mm-diam columns.

STATIC TESTS

Approximately 500 g of each sample was placed in a 2-L jar and 1,250 mL of artificial rainwater was added (2.5 L/kg). The artificial rainwater contained 0.3, 4.3, 0.15, 0.64, 2.1, and 0.4 mg/L of Cl⁻, NO₃⁻, NH₄⁺, S (in the form of SO₄²⁻), K⁺, and Ca²⁺, respectively, and was adjusted to pH 5.5. The jar was placed on a rotator for 18 h, after which the slurry was allowed to settle. Electrical conductivity (EC) and pH measurements were obtained from an aliquot of unfiltered decant. The remaining decant was filtered through an acid-cleaned, 0.4- μ m, 47-mm, Nuclepore polycarbonate filter and acidified for analysis. The analyses were not corrected for the concentrations in the initial artificial rainwater because the initial concentrations were small, and the adjustments for evaporation in the column leaching tests would require extensive calculations of marginal technical importance.

COLUMN LEACHING TESTS

Aliquots of artificial rainwater (225 mL) were added to each 153-mm-diam column in a manner that would provide a wet period and a dry period every 4 months while still

approximating the annual rainfall of 94 cm found throughout much of the Coeur d'Alene Basin. Initially, leachant was added every 3 days. About day 13, leachant was added for five consecutive days, with double volumes of leachant being added on the three middle days of this wet period. Two more volumes of leachant were added at 3-day intervals followed by two more volumes at 7-day intervals. The leachate was collected and the columns were allowed to air dry for about 35 days. The last three leachings occurred at 3-day intervals. To maintain the proper leachant-to-solids ratio, the 102-mm columns were leached with 100 mL of leachant.

The leachant from each addition was allowed to flow down through the column of material by gravity and leachate was collected in an open 1-L, acid-cleaned, high-density polyethylene (HDPE) bottle designated for a specific column. However, the columns containing the wet-screened alluvium clogged, and water added to the column collected above the fines over many leaching cycles. There was also ponding of water over the column containing the wet-screened, finer reworked tailings, but to a lesser extent.

These columns were designed to simulate the chemistry of leachate from an unconfined surface pile of waste material flowing into an aquifer. Because oxidation of any ferrous Fe in the leachate draining from the columns would be oxidized in the open bottles, these column leaching tests best simulated leachate flowing into an oxygenated aquifer.

The leachate that drained from each aliquot addition was processed before the next aliquot was added or within 4 days, whichever came first. The collection bottle was not cleaned between the collection of leachate from subsequent aliquot additions. The pH was measured using a Ross combination electrode attached to an Orion EA 940 meter that had been calibrated with pH 4 and pH 7 buffers. EC was measured on a YSI model 32 calibrated to 12.85 millimhos/cm with a 0.1 M potassium chloride (KCl) solution. The remaining sample was filtered through an acid-cleaned, 0.4- μ m, 47-mm polycarbonate Nuclepore filter held in an acid-cleaned Nalgene polysulfone filter holder. One fraction for ICP analysis was transferred to an acid-cleaned, 60-mL, HDPE bottle to which Trace Metal Grade HNO₃ (Fischer, Inc.) was added to achieve 0.1 M.

As part of the quality assurance program, the S concentrations of the leachate from individual columns were regressed against EC. Because these two values came from independent subsamples of the leachate, possible instances of misidentification of samples were revealed. The S and critical metal concentrations were then plotted against time. If both the regression and time plots suggested an identification error, other samples collected on that day were examined. If another sample from the same day revealed anomalies in the opposite trend, the identifications of the samples were switched. Of the 442 leachate samples collected in this study, two pairs of samples for ICP analysis and one pair of EC values were switched. In addition, one set of pH measurements was disregarded because all samples from that day returned high

values when plotted against time, indicating an improper calibration.

HUMIDITY CELL TEST

A humidity cell was charged with 300 g of the finer fractions of the alluvium separated by wet screening of the composite. This sample size was chosen to obtain a bed depth of 40 mm in each cell, which allowed the sample to be flooded during leaching without overflowing the air lines. The cell and the sample were weighed at the start of the test, at the end of each leaching step, after the dry-air portion of each cycle, and again after the wet-air portion of each cycle. The first cycle consisted of 1 day of leaching followed by 3 days of dry

air and was used to remove part of the soluble sulfate load from the samples. The entire apparatus was contained in a chamber held at constant temperature.

All subsequent cycles were 7 days long with the pattern of 1 day of leaching, 3 days of purging with dry air, and 3 days of purging with wet air. The leaching cycle was conducted by weighing the required quantity of leachant for each cell into individual wash bottles that could be emptied by squeezing. The leachant was introduced into each cell through a gas dispersion tube. The effluent was collected in a wide-mouth Erlenmeyer flask vented to the constant-temperature atmosphere. The volume, EC, oxidation-reduction potential (ORP), and element concentrations of each effluent were determined.

RESULTS

S measured by ICP, which is assumed to have equal molar concentrations as sulfate, pH, Zn, and Pb will be emphasized in the graphical presentation of the data. Where appropriate, the analysis of other cations listed in the tables will be noted.

PREPARATION OF COMPOSITE SAMPLES

Seven of the ten samples of alluvium were used in the composite sample. Concentrations of Pb and Zn in the finer fraction were generally equal to or greater than concentrations of the coarser fraction, with the exception of Zn in sample A40 (figure 3) (table A-2). The coarser fraction had higher concentrations of S. Six of the seven samples of reworked tailings were used in the composite sample. In all cases, S, Zn, and Pb concentrations in the finer fractions were much greater than those in the coarser fraction.

Ten of the fourteen flood plain tailings samples were used in making the large-volume sample. The four samples excluded had been mismarked, leading to uncertain identification of sample type. The flood plain tailings exhibited much more variability in elemental concentrations than the alluvium or reworked tailings (figure 3). In general, the coarser material had lower element concentrations than the finer material. The concentration of Zn in the coarser fraction of sample C08 was about three times higher than in the coarser sample having the next highest Zn concentration. This sample was not eliminated for inclusion into the large-volume sample because two samples of the fine fraction (A30 and C10) had equally high Zn concentrations, and three other samples (A8, A20, and B24) had nearly equal Zn concentrations in the coarser and finer fractions.

ALLUVIUM COMPOSITE SAMPLE

The alluvium composite was prepared from samples taken in the saturated zone of the flood plain below the organic

layer. As noted earlier, this level is thought to have been the ground surface prior to any disturbances by mining. A summary of the processing of the alluvium composite sample and the rationale for the different tests is given in figure 4.

Pb and Zn solid phase concentrations in the alluvium composite were low, 380 and 774 ppm, respectively (table 6). Metal concentrations were generally higher in the finer fraction of the damp-screened alluvium. The high Pb concentration (1,677 ppm) in the wet-screened, coarser fraction was surprising considering the low Pb concentrations in the alluvium composite. More metals were released from the finer fraction of the damp-screened material during the static tests than from the coarser fractions, whereas intermediate amounts of metals were released from the alluvium composite. Lesser amounts of metals were released from the wet-screened, coarser material during the static test than from the damp-screened material. This was especially true for Zn, where 11.1 mg Zn per kilogram of alluvium (ppm) was released from the damp-screened material and 2.0 ppm was released from the wet-screened material.

The most dramatic difference in the release of metals during the static tests can be seen in the finer fraction of alluvium. The amount of Zn released from the damp-screened, finer fraction during the static tests was 43 ppm while the release from the wet-screened, finer fraction was 5.3 ppm. A large part of this difference can be attributed to flushing of soluble Zn salts during wet separation, which corresponded to a release of 10.2 mg of Zn per kilogram of alluvium composite. Results of the static tests suggest that a major portion of the Zn released during the wet screening originated from the finer fraction. Of note is the observation that Ca and Mg were actually removed from the tap water during screening (table 6). This ion exchange could have provided some buffering of the acidity generated during the column leaching tests.

Alluvium

Reworked tailings

Flood plain tailings

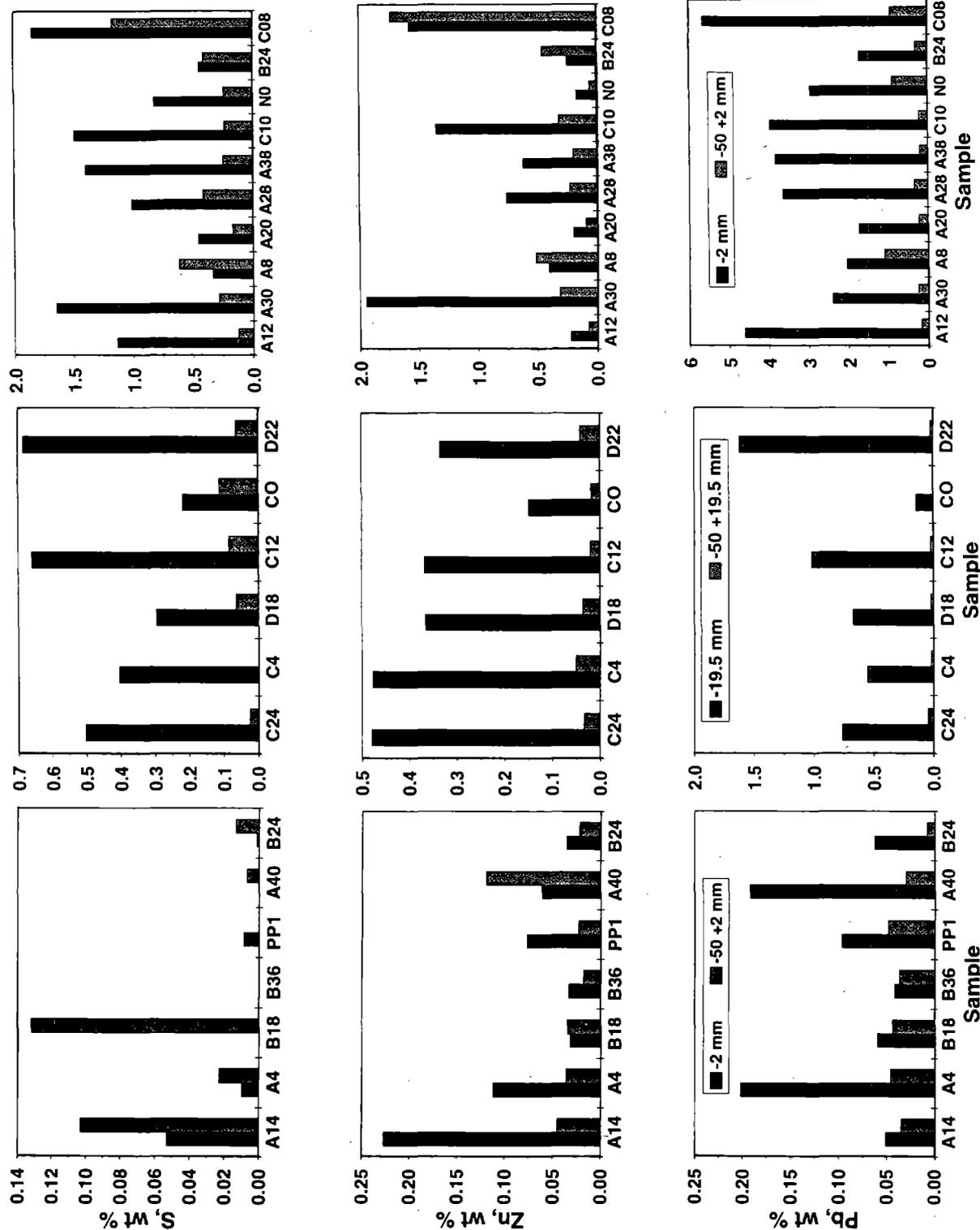


Figure 3.—S, Zn, and Pb from coarser and finer size fractions of alluvium, reworked tailings, and flood plain tailings used in composite samples.

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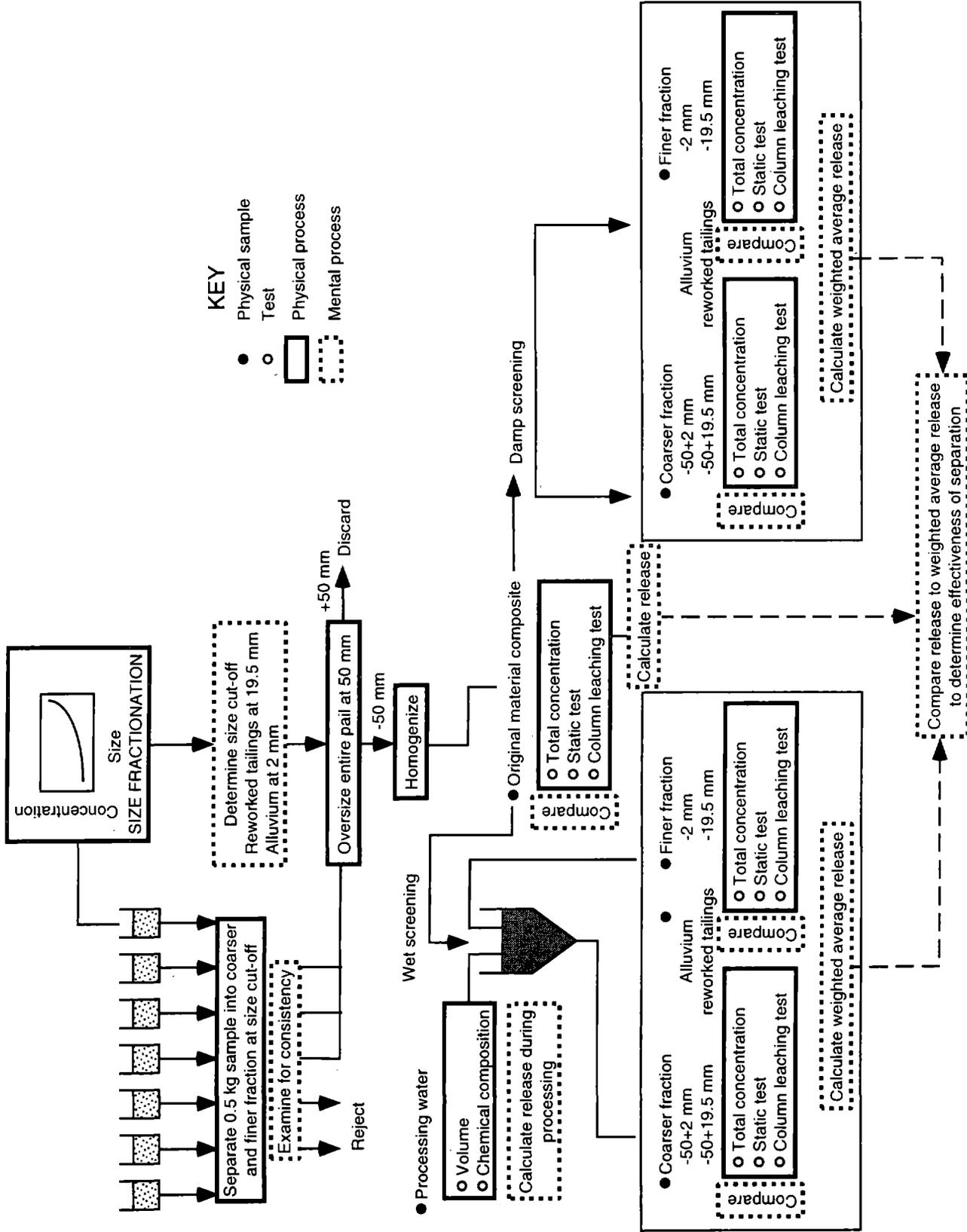


Figure 4.—Schematic of experiments with alluvium and reworked tailings.

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Table 6.—Summary of tests on alluvium

	Liquid:solid ratio, L/kg	pH	EC, milli-mohs/cm	Element, mg/kg												
				Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
COMPOSITE																
Total conc.	68,800	635	9.9	<4	25,800	24,400	2,630	822	8,470	380	NA	293,000	774			
Static test	2.58	5.04	0.18	0.13	12.5	0.41	0.26	0.08	23.7	4.2	15.1	8.4	0.7	48	17.9	22.4
Col. release	0.33	4.85	0.52	0.08	5.9	0.29	0.06	0.07	1.0	2.0	0.6	1.0	0.5	19	2.7	14.2
Dry-screened col. release, wt av		0.05	5.8	0.2	0.03	0.01	1.2	1.9	1.5	0.3	18	2.8	12.7			
Wet-screened:																
Release during separation	4.50	7.38	0.42	-83	0.3			2.2	-21	1.8			0.1	50	10.2	
Col. release, wt av		0.14	6.7	0.05	0.01	0.02	0.6	4.8	1.3	1.2	1.4	2.0	4.1			
COARSER FRACTION (-50 + 2 mm)																
Dry screened:																
Total conc.	50,000	143	11.7	<4	17,300	19,370	1,230	513	3,550	34	NA	278,000	139			
Static test	2.57	6.16	0.09	0.21	8.4	0.21	0.59	0.05	32.1	3.1	8.2	10.5	1.0	23	18.6	11.1
Column test	0.38	5.54	0.21	0.02	3.1	0.10	0.01	1.0	1.0	1.0	0.6	1.3	0.2	9.0	2.1	6.8
Wet screened:																
Total conc.	49,700	321	11.0	3	20,500	22,100	1,410	676	3,360	1,680	NA	267,800	550			
Static test	2.50	6.33	0.073	30.5	3.6	0.22	0.47	0.10	19.0	1.3	2.0	6.0	0.7	17.9	12.9	2.0
Col. test	0.40	5.33	0.15	0.12	2.6	0.06	0.01	<0.01	0.5	1.3	0.2	0.6	0.2	7.0	1.5	5.1
SMALLER FRACTION (-2 mm)																
Dry screened:																
Total conc.	70,900	1,260	17.2	36	24,200	24,800	3,060	1,170	7,350	928	NA	294,000	658			
Static test	2.71	4.96	0.28	0.5	24.7	0.9	0.5	0.1	24.3	8.3	31.4	9.2	2.4	82	26.1	43
Column test	0.31	4.50	0.97	0.2	15.1	0.6	0.1	<0.1	1.8	5.0	3.7	2.1	0.9	48	4.9	32
Wet screened:																
Total conc.	71,700	3,120	16.5	27	27,400	25,000	3,190	711	7,050	861	NA	281,000	958			
Static test	2.50	5.66	0.18	0.02	28.8	0.27	0.45	0.05	6.2	20.9	6.8	6.3	0.5	45	19.0	5.3
Col. test	0.55	7.07	0.39	0.17	14.3	0.04	0.01	0.03	0.8	11.2	3.3	2.2	0.1	26	3.0	2.3
Humidity cell tests	3.05	5.82	0.17	0.85	36.0	0.20	0.06	0.17	3.8	27.0	5.0	12.0	0.4	67	5.7	5.7

NA Not analyzed.

The pH of the leachate from the columns containing the alluvium composite was about 5.0 (table 7) and did not change in a systematic manner during the experiment (figure 5). The pH of damp-screened, coarser material was higher (6.15 on average), while the finer fraction had pH's similar to the alluvium composite sample. In general, the concentrations of S, Zn, and Pb in the damp material followed pH, so that

Coarser fraction < composite < finer fraction.

Since percolation of rainfall through a pile of material would be proportional to the area of ground surface exposed to the weather, the volume of leachate would be proportional to the area of the pile. If piles of equal height were formed from the two sized fractions, the areas of exposed ground would essentially be proportional to their mass fractions. Therefore, the concentration of the two leachates, weighted by their mass fractions, would be the concentration one would expect from two piles of segregated material in the absence of any change in water percolation rate, geochemistry, or biology. Based on the fraction of mass of the composite sample (i.e., 22.4% of the mass for the finer fraction and 77.8% for the coarser fraction), weighted-average concentrations were calculated. In general, the weighted-average concentrations of S, Zn, and Pb were slightly lower than the concentrations of the composite material. The weighted-average concentrations of S and Zn from the damp-screened, segregated material were about 90% those of the alluvium composite.

To relate these leachate concentrations to the results of static tests, an elaborate series of calculations had to be undertaken. The amounts of each element released from the column during each leaching (milligram of element per leaching) were calculated by multiplying the volume of leachate recovered by the concentration of the leachate. The amounts of the element released during the 17 leachings were then summed over the entire wet-dry cycle to obtain the total amount of metals released during the entire test. The milligrams of metals released during the test were divided by the total dry weight of the material in the column. This calculation was repeated for each element. The results of these calculations derived from concentrations, volumes of leachate, and weights of material leached are defined hereafter as the "release" from the column.

Implicit in the comparison of the static tests and the column leaching tests is the assumption that elements released from the columns during the leaching tests were released either through dissolution of soluble salts or through oxidation of sulfide minerals. However, oxidation probably did not play a major role during the static tests because the static tests take very little time. Therefore, the ratio of metal release during the static tests to metal release during the column leaching tests indicates what portion of the release from the columns occurred through dissolution of soluble salts rather than

oxidation. For most of the elements, the release from the alluvium composite during the column leaching tests was considerably lower than the release during the static tests (table 6). For instance, Zn release during the column leaching test was 14 ppm, while it was 22 ppm during the static test. This observation suggests that most of the metal released during the column leaching tests of the alluvium composite occurred through dissolution. This relationship was also observed for both the damp-screened, finer and coarser fractions, except that the Ca and Mg releases from the damp-screened, coarser fraction were comparable to the releases during the static tests.

The concentrations and pH's (figure 5) (table 8) and releases (table 6) from the column containing the wet-screened, coarser fraction were similar to those of the damp-screened, coarser fraction. The amount of fines (-1 mm) dislodged from the damp- and wet-screened, coarser material was similar (1.8%), suggesting that wet screening was no more efficient than damp screening.

The increase of 2.5 pH units between the damp-screened, finer fraction and the wet-screened fraction (tables 7 and 8) was the most dramatic change in this study. Whether this change was a result of washing of acidic soluble salts off the fines, uptake of Ca during the wet-screening process, or submergence of the wet-screened fines under the ponded leachate is not known. The flushing of metals from the finer material during wet screening and the higher pH of the leachate dramatically limited the concentrations of metals in the leachate of the wet-screened, finer fraction (figure 5). For many of the elements, only about half of the amount of the element released during the static test was released during the entire column leaching test. For instance, 5.3 ppm of Zn was released during the static test, while only 2.3 ppm was released during the column leaching test. Because of these factors, metal releases from the wet-screened, finer fraction during the column leaching tests were much lower than releases from the damp-screened, finer fraction (i.e., 32 ppm Zn).

The effects of dissolution during wet screening on metal release during subsequent column leaching tests can be assessed from the available data. First, the release during wet screening was added to the weighted average of the wet-screened, segregated material. Then, this sum was compared to the release from columns containing the alluvium composite. Adding the 10.2 ppm Zn release during wet screening to the weighted-average 4.1 ppm Zn release from the wet-screened, segregated fractions produced a result that was very similar to the Zn release of 14.2 ppm for the column containing the alluvium composite. The high release of S (50 ppm) during wet screening was similar to the S release of the alluvium composite (49 ppm) during the static test. The high liquid-to-solids ratio of the wet screening (4.5) may have facilitated the release of S. Pb releases were low during all tests.

Table 7. - Results from columns containing alluvium composite and damp-screened fractions

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/ cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
ALLUVIUM COMPOSITE (DA1)																		
1	1	225	103.54	4.29	0.470	<0.1	32	1.45	0.34	0.08	5.6	10.0	3.0	6.6	2.87	84	14.0	73
2	3	114	187.24	4.79	0.581	<0.1	27	1.24	0.24	<0.01	4.0	8.8	2.6	4.2	2.01	78	13.4	60
3	6	225	109.74	4.94	0.552	0.3	25	1.06	0.21	<0.01	3.6	7.7	2.3	3.6	1.84	76	11.3	54
4	13	225	¹ 0															
5	20	225	162.84	4.70	0.559	0.8	29	1.40	0.27	0.01	4.0	9.6	3.0	4.2	2.29	90	13.0	69
6	21	225	202.94	4.80	0.516	0.6	22	1.08	0.21	<0.01	3.2	7.5	2.4	3.3	1.85	70	10.2	56
7	22	450	409.84	4.61	0.422	0.2	19	1.00	0.19	0.01	3.2	6.7	2.0	3.0	1.65	61	8.3	52
8	23	450	447.54	5.33	0.373	0.9	14	0.69	0.12	1.62	2.4	5.0	1.5	2.1	1.32	44	7.3	39
9	24	450	423.94	4.51	0.363	0.1	17	0.85	0.16	0.01	2.9	5.7	1.7	2.5	1.40	53	7.1	46
10	28	225	17.54	5.76	NA	<0.1	25	1.10	0.06	0.08	3.9	8.7	2.4	8.6	0.31	82	8.7	49
11	30	225	183.34	4.74	0.710	<0.1	31	1.56	0.32	0.01	5.0	10.2	3.3	7.1	2.43	120	13.3	61
12	34	225	182.84	4.81	0.590	0.2	27	1.37	0.27	0.01	4.6	8.8	3.0	5.6	2.14	92	12.5	57
13	37	225	191.34	4.85	0.571	0.1	26	1.24	0.25	0.01	4.5	8.1	2.7	4.8	2.01	90	12.7	54
14	42	225	195.34	5.09	0.542	0.2	24	1.15	0.24	0.01	4.2	7.5	2.6	4.0	2.00	85	12.3	52
15	72	225	¹ 0															
16	75	225	¹ 0															
17	77	225	80.76	4.69	0.567	0.2	26	1.32	0.29	0.09	4.0	9.1	2.8	3.5	2.39	89	13.9	91
DAMP-SCREENED, COARSER ALLUVIUM (DA2)																		
1	1	450	159.98	4.56	0.211	<0.1	10	0.36	0.07	0.48	2.6	3.2	1.2	2.7	0.89	25	2.4	24
2	3	130	91.44	5.10	0.338	<0.1	17	0.53	0.06	<0.01	4.0	5.3	2.2	5.4	0.65	43	7.2	33
3	6	225	242.34	5.77	0.184	<0.1	7	0.17	<0.01	0.03	2.6	2.4	1.0	7.9	0.02	20	4.0	12
4	13	225	120.34	6.17	0.312	<0.1	15	0.41	0.01	<0.01	4.3	4.9	2.3	8.5	0.19	37	8.0	29
5	20	225	175.84	6.02	0.290	0.3	14	0.47	0.04	<0.01	4.1	4.5	2.8	6.1	0.69	37	8.8	28
6	21	225	207.54	5.16	0.262	0.2	12	0.40	0.05	<0.01	3.6	3.8	2.2	4.9	0.69	34	7.7	25
7	22	450	421.14	5.13	0.193	<0.1	9	0.30	0.05	<0.01	3.2	2.9	1.6	3.8	0.65	26	5.6	20
8	23	450	446.64	5.51	0.154	<0.1	7	0.22	0.03	<0.01	2.4	2.1	1.2	2.8	0.41	20	4.4	15
9	24	450	446.14	5.11	0.145	<0.1	6	0.21	0.03	<0.01	2.4	2.0	1.1	2.6	0.40	19	4.3	15
10	28	225	200.04	5.49	0.190	<0.1	7	0.24	0.03	<0.01	2.5	2.3	1.4	2.6	0.47	25	6.1	17
11	30	225	199.54	5.24	0.171	<0.1	7	0.23	0.03	0.01	2.4	2.2	1.6	2.6	0.47	25	6.2	16
12	34	225	168.84	5.72	0.186	<0.1	8	0.27	0.02	0.05	2.6	2.6	2.3	2.9	0.52	25	6.9	19
13	37	225	190.24	5.79	0.192	<0.1	8	0.25	0.02	0.09	2.5	2.4	2.8	2.5	0.29	26	6.8	17
14	42	225	183.44	5.70	0.181	<0.1	8	0.26	0.01	0.04	2.6	2.5	2.3	2.7	0.38	26	6.9	18
15	72	225	55.53	5.17	NA	<0.1	6	0.05	<0.01	0.01	1.4	1.5	1.7	1.4	0.33	12	10.2	7
16	75	225	151.92	6.59	0.176	<0.1	7	0.22	<0.01	<0.01	2.3	2.5	3.4	2.2	0.34	24	7.2	18
17	77	225	173.84	5.98	0.161	<0.1	7	0.21	<0.01	0.02	2.3	2.3	2.4	2.0	0.32	22	7.0	18
DAMP-SCREENED, FINER ALLUVIUM (DA3)																		
1	1	2200	232.24	4.34	1.266	0.2	75	3.08	0.54	0.03	8.3	24	12.5	18.4	3.89	190	23	124
2	3	0	106.84	3.80	1.137	0.2	61	2.33	0.40	<0.01	6.8	19.4	10.5	13.0	2.95	170	19.8	100
3	6	225	153.24	4.72	1.036	0.8	63	2.36	0.44	<0.01	7.3	19.5	12.6	13.1	3.26	186	20	100
4	13	225	29.54	4.48	NA	1.1	51	2.14	0.39	0.01	5.6	17.1	12.8	10.3	2.88	153	16.7	94
5	20	225	167.04	4.52	1.117	1.9	64	2.56	0.45	<0.01	6.0	22	16.6	10.7	3.60	187	19.5	142
6	21	225	200.94	4.55	1.046	0.9	52	2.17	0.42	<0.01	5.8	17.3	13.9	9.8	3.09	164	16.9	95
7	22	450	428.14	4.50	1.006	0.6	51	2.25	0.42	0.01	6.2	17.7	14.6	9.4	3.11	162	17.7	99
8	23	450	446.04	4.65	0.860	0.4	47	1.97	0.33	0.01	5.0	16.9	13.5	6.2	2.69	150	16.0	117
9	24	450	438.94	4.57	0.804	0.4	41	1.77	0.32	<0.01	5.2	14.3	12.0	5.0	2.39	131	15.3	85
10	28	225	204.24	4.60	0.858	0.2	39	1.92	0.36	0.01	6.2	13.5	12.5	4.9	2.65	164	16.9	66
11	30	225	210.14	4.43	0.871	0.3	39	1.90	0.37	<0.01	6.2	13.3	12.8	4.5	2.67	173	16.7	66
12	34	225	190.14	4.60	0.845	0.5	41	1.99	0.37	<0.01	6.3	13.4	13.3	4.3	2.66	149	16.6	68
13	37	225	140.24	4.55	0.872	0.4	42	1.93	0.35	<0.01	5.6	14.0	13.3	3.5	2.68	152	16.0	93
14	42	225	189.74	4.61	0.866	0.4	42	1.97	0.36	0.02	5.6	14.1	13.7	3.4	2.75	159	15.8	95
15	72	225	¹ 0															
16	75	225	¹ 0															
17	77	225	53.51	4.55	1.098	0.4	56	2.78	0.56	0.02	6.5	19.5	17.1	3.6	3.89	199	18.4	168

NA Not analyzed because of insufficient volume of leachate recovered.

¹ No leachate recovered.

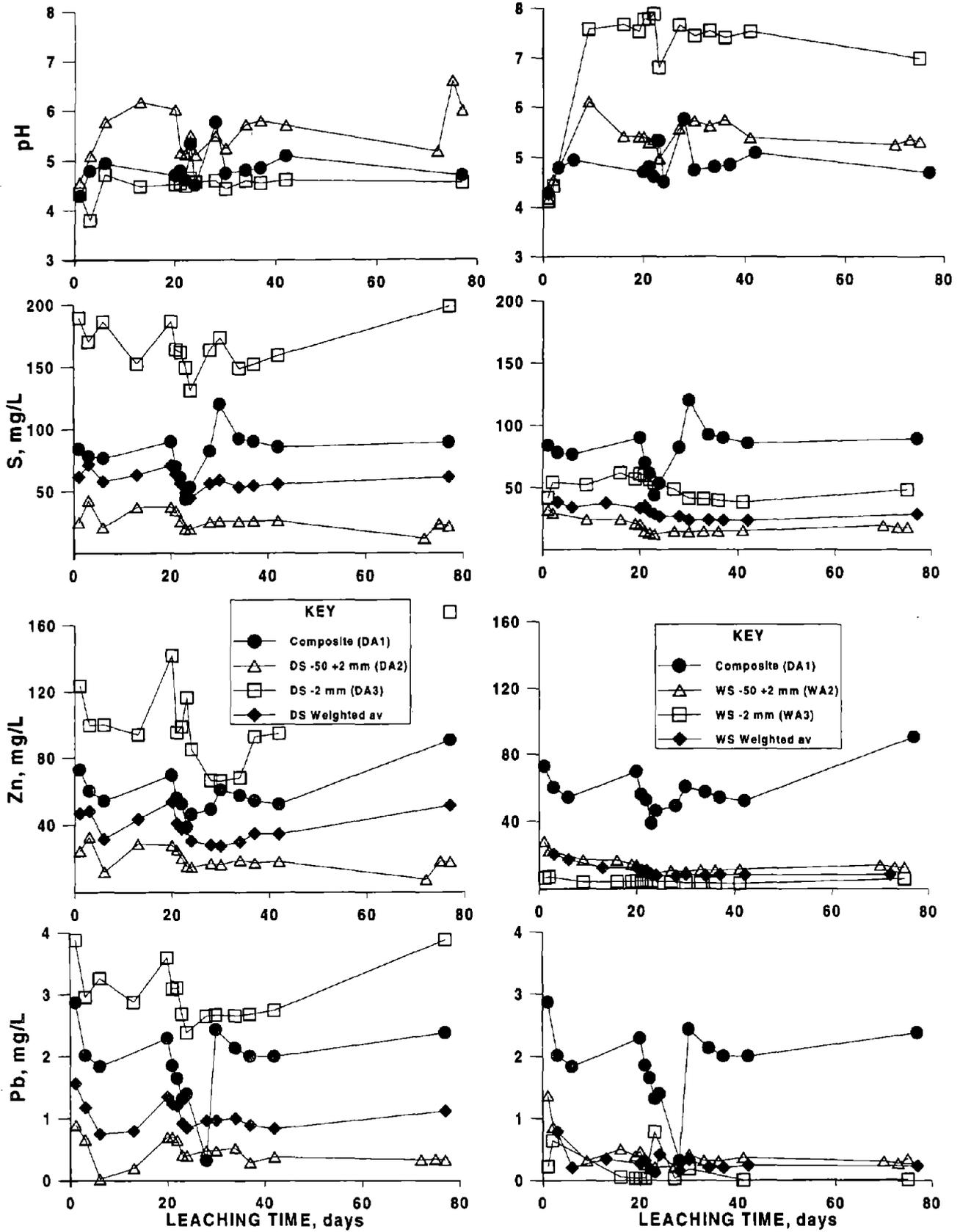


Figure 5.—Results of column leaching tests on alluvium. Damp-screened fractions on left, wet screened fractions on right. Weighted-average concentrations based on mass distribution of the two fractions (22.4%:77.6% for damp-screening process and 36.4%:63.6% for wet-screening process).

Table 8. - Results from columns containing wet-screened alluvium fractions

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
COARSER ALLUVIUM (WA2)																		
1	1	225	182.5	4.17	0.354	0.2	18	0.36	0.08	<0.01	2.1	7.7	1.1	3.5	1.37	32	6.1	28
2	2	225	232.7	4.55	0.259	4.6	12	0.27	0.03	0.01	1.8	6.0	0.9	2.3	0.86	30	5.5	22
3	9	225	182.8	6.11	0.193	<0.1	9	0.20	<0.01	<0.01	1.4	4.6	1.4	1.8	0.31	24	4.7	17
4	16	225	159.1	5.42	0.184	<0.1	8	0.19	0.04	0.04	1.4	4.5	0.8	1.8	0.50	24	4.7	17
5	19	225	156.0	5.41	0.152	<0.1	7	0.15	0.03	0.04	1.3	3.7	0.5	1.5	0.39	21	3.9	14
6	20	225	197.9	5.40	0.144	0.1	7	0.15	0.03	0.02	1.3	3.6	0.5	1.5	0.46	20	3.8	14
7	21	450	440.8	5.29	0.112	0.1	5	0.09	0.02	0.02	1.1	2.6	0.3	1.2	0.25	14	2.6	10
8	22	450	411.2	5.35	0.105	<0.1	4	0.08	0.01	<0.01	1.1	2.4	0.3	1.2	0.19	13	2.5	9
9	23	450	444.2	4.97	0.103	<0.1	4	0.07	0.01	<0.01	1.1	2.2	0.2	1.1	0.21	12	2.5	9
10	27	225	182.3	5.57	0.111	<0.1	5	0.10	0.01	0.02	1.2	2.6	0.3	1.2	0.22	15	3.5	11
11	30	225	181.4	5.72	0.114	<0.1	5	0.18	0.18	0.02	1.2	2.5	0.3	1.3	0.41	14	3.6	10
12	33	225	177.3	5.62	0.133	<0.1	5	0.12	0.02	0.02	1.1	2.6	0.3	1.2	0.32	14	3.5	11
13	36	225	186.6	5.75	0.119	<0.1	6	0.12	0.01	0.01	1.1	2.7	0.2	1.2	0.31	15	3.5	11
14	41	225	177.5	5.39	0.155	<0.1	7	0.12	0.02	0.04	1.1	2.8	0.2	1.3	0.36	15	3.7	11
15	70	225	110.9	5.25	0.141	<0.1	6	0.15	<0.01	<0.01	1.2	3.1	0.3	1.4	0.31	19	5.4	14
16	73	225	172.4	5.35	0.125	<0.1	6	0.14	<0.01	<0.01	1.2	2.9	0.2	1.3	0.28	18	6.9	13
17	75	225	188.9	5.31	0.124	<0.1	5	0.14	<0.01	<0.01	1.2	2.8	0.2	1.3	0.35	18	5.3	13
FINER ALLUVIUM (WA3)																		
1	1	225	114.5	4.13	0.494	0.5	34	0.09	0.02	0.14	1.7	22	2.5	5.5	0.22	42	6.0	6
2	2	225	116.3	4.43	0.530	4.4	32	0.10	0.01	0.20	1.4	24	4.5	4.7	0.64	54	6.2	7
3	9	225	206.5	7.58	0.429	<0.1	29	0.05	<0.01	<0.01	1.3	23	8.6	4.8	<0.01	52	5.0	4
4	16	225	128.6	7.67	0.448	0.1	31	0.07	0.01	0.08	1.5	25	8.5	5.0	0.05	62	5.6	4
5	19	225	30.6	7.53	NA	0.1	29	0.06	0.02	0.01	1.4	23	7.5	4.6	0.03	57	5.3	4
6	20	225	47.6	7.77	NA	0.1	30	0.07	0.01	0.01	1.5	24	7.5	4.7	0.03	61	5.5	4
7	21	450	54.3	7.78	NA	0.1	29	0.07	0.02	<0.01	1.5	24	7.0	4.6	0.03	60	5.5	4
8	22	450	52.2	7.88	NA	<0.1	29	0.07	<0.01	<0.01	1.6	23	7.0	4.8	<0.01	56	5.7	4
9	23	450	252.5	6.80	0.408	<0.1	28	0.06	0.02	0.13	1.5	22	6.5	4.4	0.78	54	5.7	4
10	27	225	168.2	7.66	0.351	<0.1	25	0.05	0.01	0.16	1.4	20	6.0	4.0	0.03	49	5.6	4
11	30	225	165.0	7.44	0.335	<0.1	23	0.13	0.17	0.02	1.4	18.0	5.4	3.7	0.18	41	5.3	3
12	33	225	199.6	7.54	0.317	<0.1	21	0.05	0.00	0.01	1.3	17.5	5.5	3.4	<0.01	41	5.1	3
13	36	225	154.9	7.41	0.400	<0.1	20	0.05	<0.01	0.01	1.3	16.8	5.4	3.2	<0.01	40	5.2	3
14	41	225	186.2	7.53	0.298	<0.1	21	0.05	0.00	0.03	1.2	16.1	5.4	3.1	<0.01	38	5.1	3
15	70	225 ¹⁰																
16	73	225 ¹⁰																
17	75	225	87.4	6.98	0.324	<0.1	22	0.09	<.01	<.01	1.5	16.7	3.0	3.1	0.02	48	5.8	6

NA Not analyzed because of insufficient volume of leachate recovered.

¹ No leachate recovered.

The concentrations of metals in the leachate from the humidity cell containing the wet-screened, finer fraction were generally less than the concentrations in the column leachates (table 9). However, metal release was higher as a result of the larger volumes of leachate recovered. For S and Zn, releases from the humidity cell during nine leachings was 2.5 times higher than releases during the column leaching tests, in which five times less leachant was added during the 17 leachings. For Cd, Cu, and Pb, the ratio of release during the humidity cell test relative to release during the column leaching tests was closer to the ratio of leachate recovered during the tests. This level of metal release during the humidity cell tests was less than the metal release from the damp-screened, finer material.

REWORKED TAILINGS COMPOSITE SAMPLE

The reworked tailings composite was prepared from material taken from the gravel beds of the stream. The processing of the reworked tailings and the tests undertaken are summarized in figure 4.

The metal distribution suggests that the coarser fraction was alluvial cobbles and gravels, while the finer fraction was mine waste physically trapped by the coarser material (table 10). As expected from the distribution of metals in the samples mixed to form the reworked tailings composite, the metals were concentrated in the finer fraction (-19.5 mm). For instance, Zn concentration in the wet-screened, finer fraction was 2,473 ppm, while in the coarser fraction, Zn concentration was 422 ppm.

The static tests indicated that only a small portion of the metals in all fractions was easily dissolvable. The results of the static test mimic total concentrations—high values in the finer fraction and very low values in the coarser fraction. This would suggest that most of the metals released from the reworked tailings composite during the static test were released from the finer fraction. In both size fractions, releases from the wet-screened fractions during the static test were equal to or slightly lower than releases from the damp-screened material. While significant amounts of S were released into the wet-screening processing water, very little Zn

Table 9. — Weights, field parameters, and concentrations of leachates from humidity cell containing alluvium composite

Cycle	Day leachant added	Weight of cell and sample, g	Leachant vol. added, mL	pH	Vol. of cell and sample after leaching, g	Leachate		Acidity titration to pH 8.3, M	Element, mg/L										
						SO ₄	ORP, mV		Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	Zn
1	0	981.2	200	6.85	110	0.374	0.000042	156	0.09	28	0.10	0.019	<0.01	1.59	19.7	2.44	15.1	0.17	3.57
2	8	1003.4	172	5.47	1063.1	0.210	0.000034	81	0.33	15.7	0.06	0.022	0.05	0.28	10.9	1.93	2.64	0.14	2.34
3	15	1004.2	167	5.74	1060.0	0.178	0.000016	78	0.03	13.5	0.04	0.004	0.04	1.36	9.5	1.86	1.88	0.02	2.19
4	22	999.5	166	5.45	1060.6	0.140	0.000016	57	0.13	10.0	0.06	0.004	0.04	1.54	7.6	1.51	1.90	0.19	1.49
5	29	1006.3	161	5.69	1056.6	0.142	0.000016	54	0.24	9.8	0.05	0.014	0.12	0.92	7.1	1.56	2.00	0.05	1.70
6	36	1003.4	161	5.90	1059.2	0.127	0.000017	45	0.49	8.6	0.04	0.019	0.14	1.26	6.4	1.38	2.23	0.03	1.57
7	43	981.9	175	5.91	1057.9	0.123	0.000017	45	0.24	8.4	0.04	0.043	0.08	1.23	6.3	1.39	2.14	0.04	1.42
8	50	997.7	167	5.60	1056.1	0.109	0.000016	36	0.73	6.7	0.15	0.041	0.02	1.74	5.1	1.36	3.80	0.46	1.00
9	57	990.7	170	5.83	1056.6	0.105	0.000013	36	0.24	6.6	0.04	0.005	0.04	1.48	4.5	1.30	2.96	0.02	1.33

ORO Oxidation reduction potential.

Table 10. — Summary of tests on reworked tailings

Liquid-solid ratio, L/kg	pH	EC, milli-mohs/cm	Element, mg/kg													
			Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn	
COMPOSITE																
Total conc.	58,800	1,770	27.8	41	39,300	22,400	2,600	2,150	5,220	3,157	NA	284,000	4,730			
Static tests	2.57	6.42	0.27	0.08	31.7	0.41	0.05	0.15	46.5	8.1	27.3	10.1	4.3	96	15.1	30.9
Col. release	0.35	6.02	0.47	0.04	11.3	0.20	0.02	0.02	0.9	3.1	0.6	1.3	0.6	25.5	6.7	15.0
Dry-screened col. release, wt av	0.02	15.0	0.16	0.01	0.01	1.5	3.7	0.2	1.4	0.8	30.6	1.8	15.0			
Wet-screened:																
Release during separation	1.48	7.78	0.53	0.01	-5.0	0.02	<0.01	<0.01	0.7	-1.4	2.2	0.2	0.1	17.9	<0.1	1.6
Col. release, wt av	0.16	16.8	0.09	<0.01	0.01	1.1	7.1	3.4	1.1	0.3	33.2	1.5	9.9			
COARSER FRACTION (-50 + 19.5 mm)																
Dry screened:																
Total conc.	49,000	115	10.4	508	14,000	21,500	1,460	402	3,240	397	NA	297,000	226			
Static test	2.77	7.29	0.073	0.4	13.8	<0.01	0.08	0.33	49.4	3.9	0.7	19.8	1.2	18.7	12.4	0.7
Column test	0.03	6.22	0.120	0.0	3.1	0.02	0.01	0.02	0.8	0.8	0.7	1.1	0.4	5.5	1.7	3.0
Wet screened:																
Total conc.	66,000	774	12.2	8	21,400	25,200	1,920	491	7,830	346	NA	276,000	422			
Static test	2.63	7.29	0.074	0.1	3.4	0.21	0.45	0.05	17.5	1.5	3.0	7.6	0.6	13.6	9.6	0.7
Col. test	0.49	5.95	0.067	0.1	1.7	0.01	0.01	0.01	0.4	0.5	0.1	0.5	0.3	2.6	0.8	1.6
FINER FRACTION (-19.5 mm)																
Dry screened:																
Total conc.	55,800	1,070	26.9	206	34,900	22,900	2,180	1,920	4,640	6,280	NA	292,000	3,800			
Static test	2.57	6.46	0.39	0.0	46.1	0.6	0.1	0.1	35.5	9.5	38.0	7.6	3.7	122	13.7	43
Column test	0.35	6.27	0.74	0.0	19.5	0.2	<0.1	<0.1	1.7	4.9	0.1	1.6	0.9	40.1	2.0	19.6
Wet screened:																
Total conc.	48,300	1,610	20.5	98	35,400	19,300	2,020	1,890	4,610	6,030	NA	264,000	2,470			
Static test	2.50	6.54	0.67	30.2	55.2	0.6	0.4	0.1	27.0	19.4	42.9	5.7	3.4	125	14.0	34.1
Col. test	0.29	7.14	0.96	0.2	26.5	0.14	<0.1	<0.1	1.64	11.3	5.5	1.5	0.3	53	2.0	15.2

NA Not analyzed.

and Pb were released. The amounts of Ca and Mg removed from the tap water by the reworked tailings during the wet-screening process was much less than that observed for the alluvial material.

The pH's of the reworked tailings composite and the damp-screened fractions were generally between 5.5 and 6.5

(table 11). The effects of emptying the column containing the damp-screened, coarser reworked tailings fraction (day 6) and repacking the column were a dramatic decrease in pH and an increase in Pb concentrations (figure 6). This action did not affect S concentrations and affected Zn concentrations in a minor way.

Table 11. - Results from columns containing reworked tailings composite and damp-screened fractions

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
REWORKED COMPOSITE (DR1)																		
0	Draining		26.34	4.20	NA	<0.01	74.0	0.7	<0.01	0.08	6.7	18.9	3.3	8.5	2.9	142	6.8	66
1	1	225	174.14	5.67	0.525	<0.01	42.8	0.4	<0.01	0.03	5.1	11.1	1.7	5.7	3.1	82	4.2	43
2	3	225	186.04	NA	NA	<0.01	39.8	0.3	<0.01	<0.01	3.5	10.1	0.9	3.9	1.0	76	4.5	36
3	6	225	150.84	5.73	0.488	0.03	37.1	0.3	<0.01	<0.01	3.3	9.3	0.2	3.6	1.3	75	4.2	35
4	13	225	30.84	5.65	NA	<0.01	53.1	0.5	<0.01	<0.01	4.4	13.6	0.1	4.8	1.9	105	5.9	53
5	20	225	167.54	6.04	0.562	0.54	42.7	0.5	<0.01	<0.01	3.5	11.5	0.1	3.9	1.8	85	5.1	47
6	21	225	190.44	5.82	0.514	0.40	36.1	0.4	<0.01	<0.01	3.0	9.8	0.1	3.4	1.6	71	4.6	40
7	22	450	411.04	5.84	0.412	0.37	26.5	0.3	<0.01	<0.01	2.4	7.1	<0.1	2.5	1.3	52	3.7	31
8	23	450	438.34	5.96	0.339	0.05	24.3	0.3	<0.01	0.10	2.5	6.2	<0.1	2.7	1.2	51	3.7	29
9	24	450	424.94	6.19	0.352	0.02	25.8	0.3	<0.01	<0.01	2.6	6.6	<0.1	2.7	1.2	55	3.9	31
10	28	225	198.54	5.65	0.438	0.01	29.3	0.4	<0.01	<0.01	3.1	7.7	<0.1	3.0	1.5	71	5.0	36
11	30	225	186.84	6.40	0.445	<0.01	28.9	0.4	<0.01	<0.01	2.9	7.6	<0.1	2.8	1.6	74	4.8	36
12	34	225	192.24	6.48	0.472	0.04	33.8	0.5	<0.01	<0.01	3.4	8.6	<0.1	3.3	1.8	74	5.3	40
13	37	225	199.14	6.20	0.486	0.01	33.0	0.4	<0.01	<0.01	3.1	8.2	<0.1	3.0	1.0	76	5.3	39
14	42	225	205.14	5.77	0.497	0.01	34.5	0.5	<0.01	<0.01	3.1	8.5	<0.1	3.0	1.9	81	5.3	41
15	72	225	¹ 0															
16	75	225	79.42	6.70	0.571	<0.01	41.9	0.6	<0.01	<0.01	2.6	11.8	0.1	2.9	2.0	90	5.7	63
17	77	225	158.10	6.16	0.499	<0.01	37.8	0.5	<0.01	<0.01	2.5	10.4	<0.1	2.7	2.0	81	5.3	56
DAMP-SCREENED, COARSER REWORKED TAILING (DR2)																		
1	1	225	176.44	5.65	0.199	<0.01	13.7	0.1	0.24	0.70	6.7	3.4	3.2	6.2	3.0	17.5	1.9	16
2	3	212	196.94	6.71	0.172	<0.01	12.3	<0.1	0.01	<0.01	3.0	3.5	1.0	5.7	0.1	16.1	1.6	3.4
3	6	225	171.14	6.33	0.132	0.01	6.1	<0.1	<0.01	<0.01	2.8	1.4	0.8	2.4	0.2	11.4	1.4	4.3
4	13	225	64.54	4.34	NA	0.06	16.0	0.2	0.12	0.05	3.1	3.6	3.2	5.2	10.0	16.1	7.8	20
5	20	225	162.14	4.67	0.193	0.31	12.2	0.2	0.05	0.03	2.6	3.0	3.5	2.7	6.4	18.0	7.9	18
6	21	225	210.04	6.22	0.122	0.21	8.1	0.1	0.01	<0.01	1.9	2.1	1.6	2.3	1.2	16.5	5.6	8.1
7	22	450	434.04	6.14	0.093	0.34	4.4	<0.1	<0.01	<0.01	1.1	1.2	0.9	1.6	0.4	8.7	2.8	3.9
8	23	450	447.24	6.44	0.113	<0.01	4.0	<0.1	<0.01	0.04	1.1	1.1	0.7	1.6	0.4	7.9	2.5	3.6
9	24	450	442.74	6.62	0.074	<0.01	3.8	<0.1	<0.01	<0.01	1.0	1.0	0.7	1.6	0.3	7.6	2.2	3.6
10	28	225	196.24	6.09	0.107	<0.01	5.7	<0.1	<0.01	<0.01	1.3	1.5	1.3	1.8	0.3	12.5	3.9	5.1
11	30	225	192.14	6.75	0.103	<0.01	5.8	<0.1	<0.01	<0.01	1.4	1.5	1.4	1.7	0.3	12.7	3.8	5.1
12	34	225	179.04	6.69	0.121	0.02	6.6	<0.1	<0.01	<0.01	1.4	1.6	1.6	1.8	0.4	12.5	4.1	5.9
13	37	225	207.84	6.72	0.107	<0.01	6.2	<0.1	<0.01	<0.01	1.3	1.5	1.4	1.7	0.1	12.3	4.1	5.6
14	42	225	104.74	6.35	0.112	<0.01	6.6	0.1	<0.01	<0.01	1.3	1.6	1.6	1.7	0.4	13.7	4.1	6.7
15	72	225	106.04	6.36	0.109	<0.01	6.7	0.2	<0.01	<0.01	2.2	2.2	4.1	2.1	0.3	20.9	5.9	16
16	75	225	170.38	7.07	0.083	<0.01	4.8	<0.1	<0.01	0.02	0.9	1.2	1.0	1.3	0.3	8.7	7.1	5.7
17	77	225	186.30	6.56	0.076	<0.01	4.7	<0.1	0.03	0.01	1.0	1.1	0.9	1.2	0.4	7.6	4.9	5.2
DAMP-SCREENED, FINER REWORKED TAILINGS (DR3)																		
0	Draining		73.10	5.14	NA	<0.01	67.3	0.6	0.02	<0.01	7.2	18.0	1.9	7.9	3.8	135	6.4	63
1	1	225	182.54	6.38	0.778	<0.01	63.0	0.6	0.04	0.01	7.3	17.1	1.5	7.8	2.9	129	6.2	62
2	3	187	184.04	6.68	NA	<0.01	60.6	0.5	<0.01	<0.01	6.0	15.8	1.2	6.1	2.4	119	6.0	54
3	6	225	144.24	6.11	0.620	0.07	47.7	0.4	<0.01	<0.01	4.6	12.0	0.3	4.4	2.1	100	4.8	44
4	13	225	42.84	5.82	NA	<0.01	52.0	0.6	<0.01	<0.01	4.7	13.7	0.1	4.6	2.4	107	5.7	55
5	20	225	169.34	6.00	0.716	0.56	54.5	0.6	<0.01	<0.01	4.9	14.9	0.1	4.8	2.7	113	5.8	58
6	21	225	201.74	6.36	0.736	0.37	53.4	0.6	<0.01	<0.01	4.6	14.4	0.1	4.6	2.3	108	5.5	55
7	22	450	422.04	6.32	0.564	<0.01	45.4	0.5	<0.01	<0.01	4.2	12.5	0.1	4.1	2.3	90	4.7	51
8	23	450	447.64	6.15	0.645	0.01	46.1	0.5	<0.01	<0.01	4.2	12.6	0.1	3.8	2.3	93	5.1	52
9	24	450	435.64	6.38	0.563	<0.01	42.0	0.5	<0.01	<0.01	3.8	11.4	0.1	3.2	2.2	86	4.8	49
10	28	225	193.14	6.10	0.736	<0.01	65.0	0.7	<0.01	<0.01	5.4	13.6	0.1	4.4	2.8	134	6.4	52
11	30	225	193.94	6.58	0.801	<0.01	69.5	0.7	0.02	<0.01	5.7	14.4	0.1	4.6	3.1	154	6.6	55
12	34	225	194.94	6.53	0.797	0.04	72.6	0.8	<0.01	<0.01	5.7	14.6	0.1	4.6	3.0	138	6.6	57
13	37	225	148.84	6.29	0.807	0.02	72.0	0.8	<0.01	<0.01	5.6	13.9	<0.1	4.3	2.8	140	6.3	55
14	42	225	195.64	5.99	0.787	<0.01	58.3	0.7	<0.01	<0.01	4.8	14.7	0.1	3.6	3.0	137	6.0	72
15	72	225	¹ 0															
16	75	225	67.25	6.34	0.942	<0.01	76.1	1.0	<0.01	0.03	4.5	20.4	<0.1	3.9	3.8	166	6.8	105
17	77	225	142.96	6.28	0.843	<0.01	71.0	0.9	<0.01	<0.01	4.4	18.8	0.1	3.8	3.8	155	6.5	99

NA Not analyzed

¹ No leachate recovered.

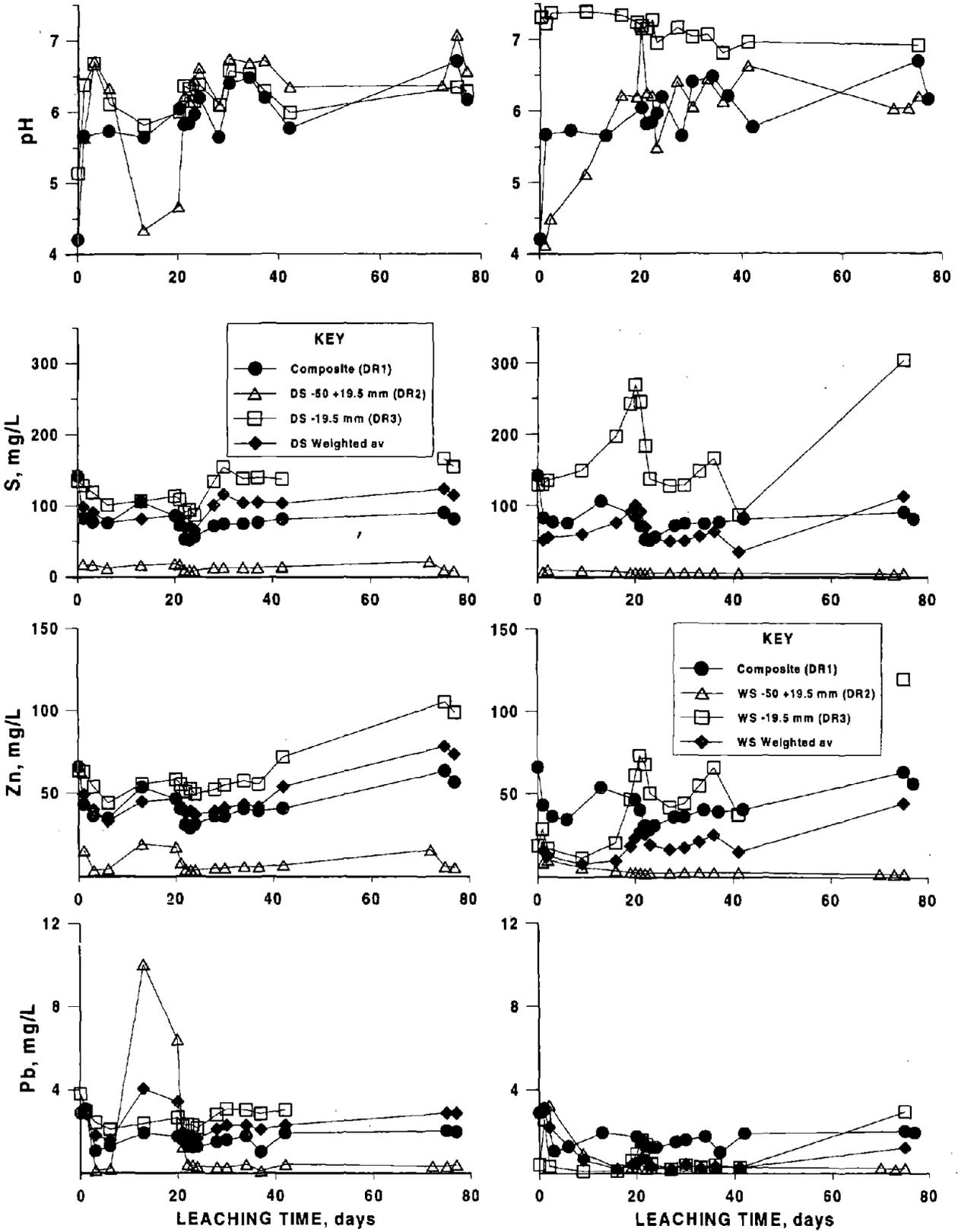


Figure 6.—Results of column leaching tests on reworked tailings. Damp-screened fractions on left, wet screened on right. Weighted-average concentrations based on mass distribution of coarser and finer fractions (23%:77% for damp-screening process and 36%:64% for wet-screening process).

The release of most elements from the reworked tailings composite during the column leaching tests was less than half of what was released during the static tests (table 10). This finding would suggest that soluble salts present at the beginning of the experiment were not completely flushed from the column during the 17 leachings. In general, metal releases from the damp-screened, coarser fraction were low. Releases from the damp-screened, finer fraction were slightly higher than releases from the reworked tailings composite. As with the reworked tailings composite, releases of metals from the damp-screened fractions during the column leaching tests were less than releases during the static tests (table 10). One notable exception was the greater release of Zn from the damp-screened, coarser fraction during the column leaching tests (3.0 ppm) relative to Zn release during the static tests (0.7 ppm). This result could be either because of the higher pH during the static test, which could cause precipitation of Zn carbonate minerals, or because of oxidation of sphalerite (ZnS) during the column leaching test.

Since the finer fraction (-19.5 mm) dominated the mass of the -50-mm reworked tailings composite, the weighted-average concentrations of the two fractions for most elements were similar to that of the reworked tailings composite. When the amounts of metals released throughout the experiment were summed and normalized to the dry weight of the material in the columns, damp screening did not reduce releases of S and Pb.

The pH of the wet-screened, coarser fraction started at 4 and increased to about 6 after the fourth leaching (table 12). Perhaps some reaction occurred during transport of the wet-screened material from RORC that was activated by the presence of water. This change in pH had no effect on Zn and S release, but Pb decreased as pH increased. The increase in pH would tend to enhance the adsorption of Pb onto Fe oxides. As with releases from the damp-screened, coarser fraction, concentrations of the leachate from the wet-screened, coarser fraction were low throughout the rest of the experiment.

Table 12. - Results from columns containing wet-screened fractions of reworked tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
COARSER REWORKED TAILINGS (WR2)																		
1	1	225	139.50	4.12	0.163	<0.01	8.1	<0.1	<0.01	0.04	0.9	2.1	0.8	2.4	3.2	6	1.0	8.5
2	2	225	206.31	4.49	0.159	4.49	7.9	<0.1	<0.01	0.01	1.0	2.2	1.0	1.4	3.3	9	1.7	10.3
3	9	225	188.35	5.12	0.114	<0.01	5.2	<0.1	<0.01	<0.01	0.7	1.5	0.6	1.2	0.9	8	1.5	5.8
4	16	225	152.87	6.21	0.064	0.04	3.6	<0.1	0.02	0.03	0.5	1.0	0.3	1.1	0.2	7	1.4	3.6
5	19	225	168.31	6.20	0.050	0.07	2.8	<0.1	0.02	0.14	0.5	0.8	0.2	1.0	0.3	5	1.1	2.7
6	20	225	191.07	7.14	0.054	0.09	2.8	<0.1	<0.01	0.05	0.5	0.9	0.2	1.1	0.2	5	1.4	2.7
7	21	450	423.51	6.25	0.056	0.15	2.8	<0.1	<0.01	<0.01	0.7	0.9	0.2	1.0	0.2	5	1.1	2.4
8	22	450	415.65	6.21	0.047	<0.01	2.2	<0.1	<0.01	<0.01	0.8	0.7	0.2	1.0	0.2	4	1.0	2.2
9	23	450	431.37	5.49	0.051	<0.01	2.4	<0.1	<0.01	0.04	0.8	0.8	0.2	1.0	0.2	5	1.2	2.4
10	27	225	171.17	6.41	0.054	<0.01	2.6	<0.1	<0.01	<0.01	0.8	0.8	0.2	1.0	0.2	5	1.3	2.5
11	30	225	175.75	6.05	0.050	0.02	2.7	0.1	0.18	0.05	0.9	0.8	0.2	1.1	0.4	5	1.4	2.5
12	33	225	163.81	6.45	0.054	<0.01	2.7	<0.1	<0.01	0.01	0.8	0.9	0.2	1.0	0.2	5	1.3	2.8
13	36	225	193.58	6.13	0.055	<0.01	4.4	<0.1	<0.01	0.01	0.9	0.9	0.2	1.1	0.3	5	1.5	2.7
14	41	225	175.24	6.63	0.050	<0.01	4.6	<0.1	<0.01	0.01	1.0	0.8	0.1	1.1	0.3	5	1.2	2.7
15	70	225	129.14	6.03	0.046	0.03	2.6	<0.1	<0.01	<0.01	0.5	0.6	0.2	1.0	0.2	4	1.4	1.9
16	73	225	168.09	6.04	0.038	0.03	1.6	<0.1	<0.01	<0.01	0.4	0.5	0.2	1.0	0.2	3	2.8	1.5
17	75	225	190.90	6.21	0.045	0.03	1.9	<0.1	<0.01	<0.01	0.4	0.8	0.3	1.0	0.2	5	5.9	1.9
FINER REWORKED TAILINGS (WR3)																		
0	Draining		395.57	7.31	0.825	<0.01	62	0.2	0.02	0.03	4.9	29.9	18	6.0	0.4	129	5.3	19
1	1	225	256.09	7.22	0.891	<0.01	72	0.2	<0.01	<0.01	5.4	34.1	22	6.2	2.6	130	6.7	29
2	2	225	206.14	7.37	0.899	7.37	74	0.2	<0.01	<0.01	5.4	35.4	27	6.3	0.3	136	5.5	17
3	9	225	120.38	7.39	0.926	<0.01	82	0.2	<0.01	<0.01	5.4	38.7	39	6.7	0.1	149	4.6	12
4	16	225	77.82	7.33	1.086	0.09	97	0.3	0.02	0.03	5.5	45.8	39	7.3	0.1	197	4.8	20
5	19	225	126.16	7.24	1.236	0.06	118	0.5	<0.01	0.02	6.1	52.9	39	8.0	0.6	243	7.0	47
6	20	225	186.15	7.19	1.317	0.23	130	0.6	<0.01	<0.01	6.6	56.0	32	8.2	0.9	270	7.6	61
7	21	450	420.46	7.15	1.229	0.20	116	0.7	0.02	<0.01	6.5	49.7	18	6.7	1.6	246	8.1	73
8	22	450	404.51	7.27	0.997	0.11	95	0.6	<0.01	<0.01	5.9	39.3	11.4	4.8	1.4	184	7.9	68
9	23	450	413.33	6.95	0.800	<0.01	72	0.4	0.00	<0.01	5.0	28.9	7.7	3.2	0.5	137	6.5	50
10	27	225	117.32	7.16	0.716	<0.01	65	0.4	<0.01	0.24	4.8	26.3	11.2	2.8	0.2	128	6.0	42
11	30	225	128.73	7.03	0.784	<0.01	69	0.5	0.17	0.01	4.7	27.1	11.9	2.8	0.4	128	5.9	44
12	33	225	98.04	7.07	0.839	<0.01	75	0.5	<0.01	0.09	4.7	29.7	14.5	2.8	0.3	148	5.9	55
13	36	225	146.10	6.81	0.890	<0.01	80	0.6	<0.01	0.01	4.9	31.3	13.2	2.9	0.4	166	6.1	66
14	41	225	106.39	6.96	0.944	<0.01	41	0.3	<0.01	0.02	2.3	16.4	7.0	1.3	0.3	87	3.1	38
15	70	225	10															
16	73	225	10															
17	75	225	39.81	6.92	NA	0.03	127	1.2	<0.01	<0.01	7.0	49.3	1.9	4.8	3.0	304	8.6	120

NA Not analyzed because of insufficient volume of leachate recovered.

¹ No leachate recovered.

Comparisons of the releases from the wet-screened, coarser fraction during the static tests with releases from the damp-screened, coarser fraction indicated that wet screening washed both soluble salts and fine material from the coarser fraction. For instance, release of S during the static test from the damp-screened, coarser fraction, which contained 1.0% fines, was 19 ppm, while release of S from the wet-screened, coarser fraction, which contained 0.1% fines, was 15 ppm. While releases of S and Pb from both columns containing the coarser fractions were lower than the respective releases during the static tests, the opposite was found for Zn. This observation may have been a result of oxidation of sphalerite during the column leaching tests or the suppression of dissolved Zn during the static tests. The higher pH in the static test (7.29) could have led to the precipitation of Zn carbonate.

S concentrations in leachates from the wet-screened, finer fraction were higher than concentrations from the damp-screened, finer fraction, resulting in a higher cumulative release (53 ppm for wet-screened fines versus 40 ppm for the damp-screened fines) (table 10). Again, note that both of these values were less than S releases during their respective static tests. In contrast, Zn and Pb concentrations of leachate from the wet-screened, finer fraction were slightly less than concentrations from the damp-screened, finer fraction. Noteworthy are the higher concentrations of S, Zn, and Pb in the leachate recovered from the column containing the wet-screened, finer fraction after the dry period (figure 6). Perhaps the low amounts of metals released during the earlier leachings were a result of water saturation of this column, which was caused by the high initial water content (23.6%) of the fines. The 40-day dry period may have allowed oxygen to penetrate into the column.

The weighted-average releases of Zn and Pb from the wet-screened fractions were less than the releases from the reworked tailings composite. After adding the release during wet-screening, Zn and Pb releases from the wet-screened fractions were 23% and 33% less than releases from the composite material. Because of the high release of S from the wet-screened, finer fraction, the weighted-average release of S from the wet-screened fractions was twice that of the composite sample when release from the wet-screening process was included.

FLOOD PLAIN TAILINGS

Three experiments were conducted with the flood plain tailings. The static and column leaching tests on the oversized material (-50 +19.5 mm) were conducted as separate experiments (figure 7). In the main experiment using -19.5-mm tailings, releases from the damp- and wet-screened fractions were compared to releases from the flood plain tailings composite. In the third coordinated experiment, the damp- and wet-screened, gravel-sand fractions were separated into gravel and sand subfractions, and releases from these four subfractions

were compared to releases from their respective gravel-sand fractions. The results of these three experiments are discussed separately.

Oversized Fraction Equipment

The cobble-sized material from the flood plain was very heterogeneous. Therefore, single determinations from 500-g samples make comparisons of total metal concentrations with metal releases during static tests ambiguous. For instance, total concentrations of Pb and Zn in the wet-screened, oversized flood plain tailings were much higher than concentrations in the damp-screened fraction, but Pb and Zn releases from the wet-screened, oversized flood plain tailings during the static tests were much less than releases from the damp-screened material (table 13). Because the column leaching tests were conducted with much larger samples (approximately 13 kg), only the column leaching tests are discussed in detail.

The pH of the leachate from both the damp- and wet-screened materials increased during the initial stages of the leaching experiment, with the pH of leachates from the wet-screened material being slightly higher (figure 8). The initial increases in S and Zn concentrations from the two columns were similar, as were the decreases during the wet cycle (table 14). During the dry periods, the damp-screened, oversized material released slightly more S and Zn. After the 40-day dry period, S and Zn concentrations from both columns increased by varying magnitudes. Pb release from the damp-screened material was greater than the release from the wet-screened material throughout the experiment. When the S and Zn released during the entire experiment were summed and normalized to the weight of the sample leached, the releases from the wet-screened, oversized flood plain tailings were similar to the releases from the damp-screened material (table 13). Pb release from the wet-screened material was about half that from the damp-screened material.

Composite Sample Experiment

A summary of processing of the flood plain tailings is shown in figure 7. The flood plain tailings composite had higher total metal concentrations (table 13) compared to the alluvium and reworked tailings composites. As with the other composites, only a small fraction of the metals was released during the static tests.

The pH's of the duplicate samples of the flood plain tailings composite averaged about 4.6 during the early leachings and increased to pH 5.0 during the wet cycle when the volume of leachant was doubled (table 15). At day 24, the pH's of the duplicate composite samples diverged, leading to the largest difference of 0.35 at day 20 (figure 9). The pH's were again very similar after the dry period.

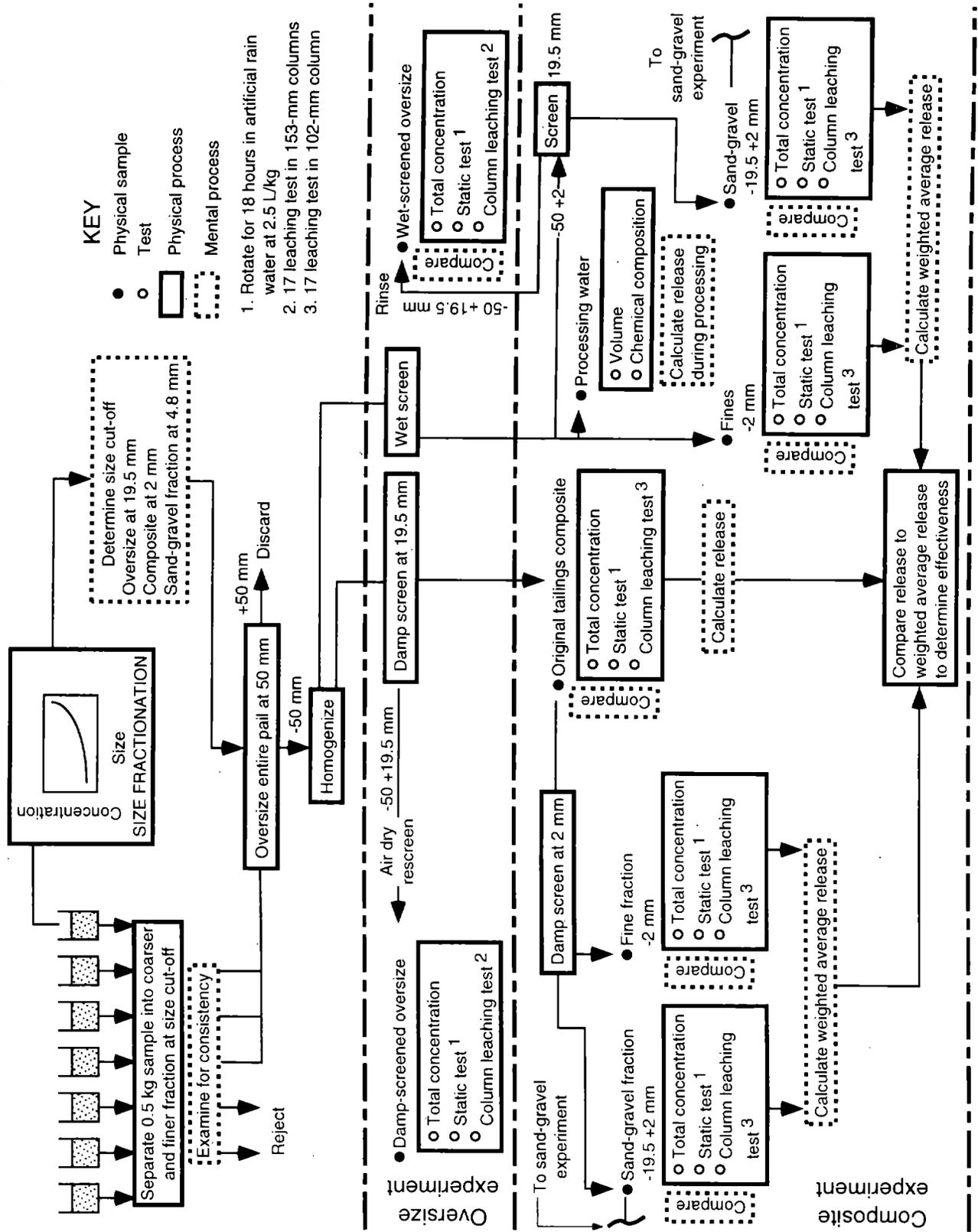


Figure 7.—Schematic of experiments with flood plain tailings.

Table 13.—Summary of tests on flood plain tailings

	Liquid:solid ratio, L/kg	pH	EC, milli-mohs/cm	Element, mg/kg													
				Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn	
OVERSIZED MATERIAL (-50 + 19.5 mm)																	
Dry screened:																	
Total conc.				56,500	37	8.2	<4	15,900	23,500	1,340	372	5,120	465	<4	317,000	49	
Static tests	2.62	5.87	0.21	0.03	3.8	0.05	0.42	<0.001	86.6	2.2	4.2	17.40	8.81	75	28.1	12.1	
Col. release	0.52	4.75	0.27	0.06	2.3	0.05	0.02	0.005	0.41	0.8	0.7	0.50	2.21	7.7	0.9	8.6	
Wet screened:																	
Total conc.				64,300	1,780	12.6	29	23,600	23,800	5,140	958	8,590	1,850	<3	288,000	1,180	
Static tests	2.50	6.44	0.09	0.02	2.0	0.20	0.45	0.10	24.6	1.87	4.1	6.4	0.72	22	8.6	2.2	
Col. release	0.26	4.98	0.18	0.04	1.3	0.03	0.01	0.009	0.26	0.7	0.6	0.35	1.28	5.4	0.6	5.3	
COMPOSITE (-19.5 mm)																	
Total conc.				50,300	1,150	34.9	235	51,800	19,900	2,190	1,900	2,970	20,000	5,900	279,000	8,410	
Static tests	2.57	4.69	0.62	0.39	30	1.44	0.54	0.10	37	11.3	105	7.3	13.2	244	22.4	120	
Col. release	0.27	4.64	1.88	0.46	16.4	0.72	0.07	0.009	1.36	6.3	10.8	1.20	1.26	103	4.3	73	
Dry-screened col. release, wt av				0.40	13.9	0.62	0.07	0.040	1.41	5.7	12.6	1.16	1.17	89	4.0	62	
Wet-screened:																	
Release during separation	4.06	6.70	0.33	<0.01	-315	0.36	<0.01	-0.040	1.11	-20	4.78	3.47	1.03	179	-3	41	
Col. release, wt av				0.39	21.2	0.37	0.03	0.009	1.69	11.9	17.7	1.51	1.60	74	3.5	43	
GRAVEL-SAND FRACTION (-19.5 mm + 2 mm)																	
Dry screened:																	
Total conc.				52,300	1,110	36.4	305	46,900	20,500	2,150	1,990	2,610	12,500	2,740	278,000	6,770	
Static tests	2.66	5.15	0.64	0.16	49	1.17	0.13	0.56	71	13.0	99	11.1	12.3	269	22.9	110	
Col. release	0.26	4.50	1.67	0.37	12.4	0.61	0.08	0.036	1.42	5.0	10.9	1.03	1.14	83	4.1	59	
Wet-screened:																	
Total conc.				54,300	1,120	51.8	286	46,000	21,400	2,160	2,000	2,230	13,700	9,520	268,000	13,000	
Static tests	2.50	5.61	0.41	0.03	64	0.75	0.45	0.80	39.6	14.3	38	5.4	12.5	158	16.4	64	
Col. release	0.39	4.75	0.86	0.33	13.4	0.43	0.05	0.008	1.78	7.1	6.8	1.15	1.70	60	4.0	55	
FINER FRACTION (-19.5 mm)																	
Dry-screened:																	
Total conc.				50,100	2,860	30.5	331	65,000	18,600	2,390	2,400	3,360	28,700	8,620	258,000	7,660	
Static tests	2.67	4.54	0.72	0.94	40	1.92	1.28	0.16	35	12.7	118	7.5	15.0	305	29.5	145	
Col. release	0.27	4.65	1.99	0.45	17.0	0.64	0.05	0.050	1.37	7.0	16.4	1.43	1.24	102	3.9	69	
Wet screened:																	
Total conc.				47,200	1,520	37.7	258	69,400	17,100	2,330	3,140	2,980	32,600	11,400	246,000	5,970	
Static tests	2.53	6.39	0.64	0.03	88	1.74	1.01	5.66	14.7	40	104	6.1	44	278	21.6	135	
Col. release	0.38	6.31	1.25	0.45	28.4	0.31	0.01	0.011	1.60	16.4	27.8	1.84	1.50	88	3.1	32	

Table 13.—Summary of tests on flood plain tailings (continued)

	Liquid:solid ratio, L/kg	pH	EC, milli-mohs/cm	Element, mg/kg												
				Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
GRAVEL AND SAND SUBFRACTIONS																
Dry screened:																
Col. release	0.26	4.50	1.67	0.37	12.4	0.61	0.08	0.036	1.42	5.0	10.9	1.03	1.14	83	4.1	59
Col. release, wt av				0.38	11.7	0.60	0.09	0.018	1.16	4.7	11.5	1.09	1.41	79	4.1	60
Gravel fraction:																
Total conc.				51,900	616	25.0	51	37,600	20,700	1,890	2,280	3,290	8,300	<4	300,000	4,030
Static test	2.63	5.70	0.77	<0.01	154	1.13	0.03	0.05	7.3	11.9	75	12.3	7.9	327	18.0	98
Col. release	0.30	4.49	1.02	0.29	8.6	0.42	0.08	0.020	1.23	3.5	7.3	0.84	1.33	52	3.3	42
Sand fraction:																
Total conc.				50,000	990	35.5	140	49,000	19,700	2,270	2,190	2,540	16,700	4,060	286,000	7,700
Static test	2.83	4.97	0.69	0.28	41	1.42	0.37	0.37	72	15.8	141	12.5	13.3	309	27.8	118
Col. release	0.36	4.54	1.73	0.55	17.1	0.91	0.10	0.014	2.25	6.8	18.6	1.51	1.56	125	5.5	92
Wet screened:																
Col. release	0.39	4.75	0.86	0.33	13.4	0.43	0.05	0.008	1.78	7.1	6.8	1.15	1.70	60	4.0	55
Col. release, wt av				0.29	11.3	0.33	0.03	0.007	1.78	5.8	6.9	1.00	1.55	48	3.2	42
Gravel fraction:																
Total conc.				59,000	975	26.4	46	43,000	23,100	2,560	2,750	3,260	9,410	4,490	282,000	3,730
Static test	2.50	5.59	0.51	0.02	54	1.25	0.42	0.27	38.3	14.4	67	5.6	12.9	204	18.1	125
Col. release	0.28	4.95	0.50	0.14	5.2	0.14	0.02	0.007	0.85	2.8	2.4	0.58	1.28	21	1.9	20
Sand fraction:																
Total conc.				62,000	872	32.5	265	34,800	23,700	2,120	1,460	2,510	5,060	3,300	291,000	5,070
Static test	2.50	5.65	0.54	29.4	36	1.40	0.62	0.62	29.9	16.4	99	5.1	15.3	229	24.5	142
Col. release	0.44	4.64	1.09	0.45	18.3	0.54	0.04	0.008	2.85	9.4	12.2	1.48	1.88	80	4.8	68

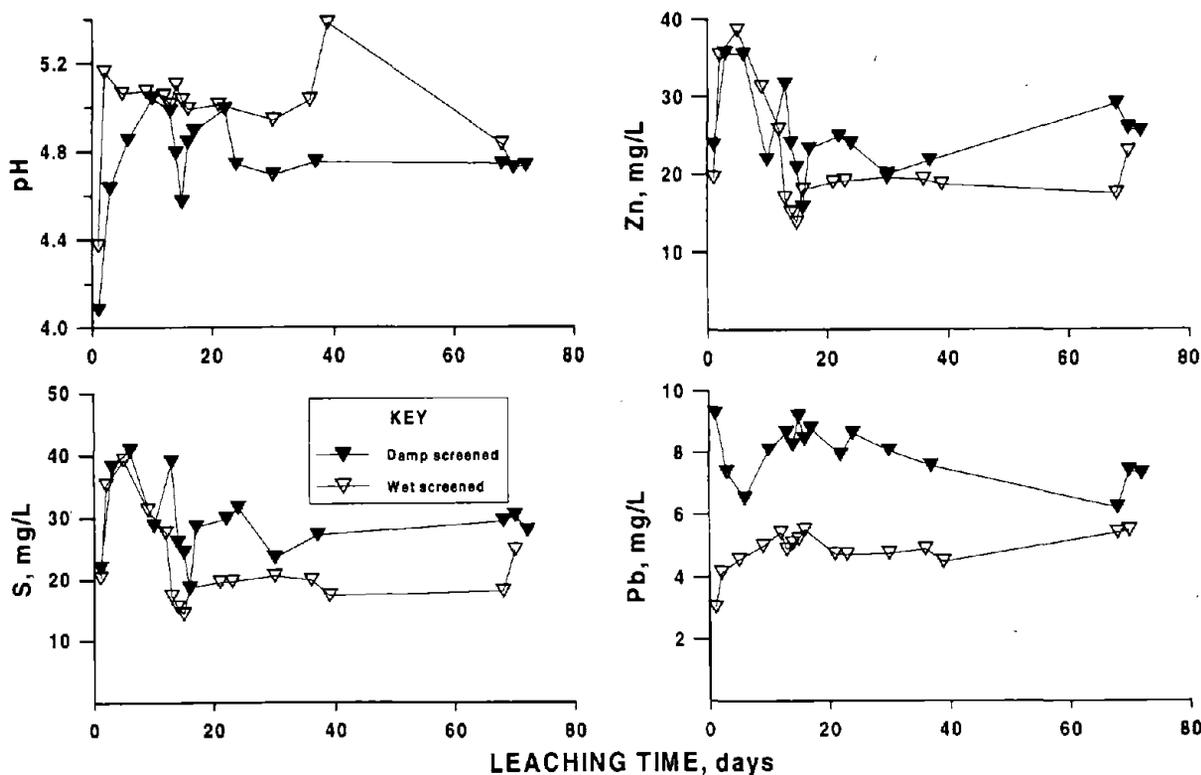


Figure 8.—Results of column leaching tests on oversized material from flood plain tailings.

Table 14. - Results from columns containing oversized flood plain tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L													
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn	
DAMP SCREENED (DTOS)																			
1	1	225	82.63	4.08	0.220	<0.01	7.8	0.15	0.10	0.41	3.03	1.70	2.11	3.0	9.3	22	1.3	24	
2	3	225	186.04	4.63	0.326	<0.01	12.9	0.26	0.08	<0.01	2.42	2.87	4.28	2.3	7.4	38	3.6	36	
3	6	225	205.04	4.85	0.291	0.07	13.0	0.26	0.05	0.02	2.08	2.92	4.33	2.3	6.5	41	3.8	35	
5	10	225	162.94	5.04	0.199	0.14	8.4	0.17	0.06	<0.01	1.50	1.81	2.92	1.7	8.1	29	2.6	22	
6	13	225	218.84	4.98	0.248	<0.01	11.5	0.24	0.07	<0.01	1.97	2.67	3.39	2.1	8.6	39	3.8	32	
7	14	450	415.04	4.79	0.202	0.07	7.3	0.12	0.05	0.02	1.37	2.35	2.55	2.2	8.2	26	3.2	24	
8	15	450	407.64	4.57	0.188	0.01	6.5	0.16	0.08	<0.01	1.44	1.76	2.12	1.8	9.2	24	3.2	21	
9	16	450	433.34	4.84	0.163	<0.01	4.8	0.10	0.05	<0.01	1.07	1.31	1.58	1.4	8.4	18	2.3	16	
10	17	225	210.94	4.89	0.211	0.24	8.2	0.18	0.08	<0.01	1.52	2.15	2.42	1.9	8.8	28	3.8	23	
11	22	225	150.64	4.99	0.214	0.06	8.3	0.20	0.08	<0.01	1.69	2.18	3.08	1.8	7.9	30	4.1	25	
12	24	225	207.34	4.74	0.215	0.03	8.9	0.19	0.08	<0.01	1.51	2.19	2.62	1.8	8.6	32	4.0	24	
13	30	225	171.24	4.69	0.180	0.06	6.8	0.16	0.07	<0.01	1.27	1.60	2.29	1.6	8.0	23	2.9	20	
14	37	225	149.64	4.75	0.220	0.03	7.6	0.17	0.08	<0.01	1.30	1.79	2.59	1.6	7.5	27	3.7	22	
15	68	225	121.26	4.74	0.208	<0.01	7.6	0.17	0.04	<0.01	1.02	1.84	3.27	1.2	6.2	29	3.6	29	
16	70	225	200.24	4.72	0.193	<0.01	9.4	0.17	0.04	<0.01	1.02	2.22	2.54	1.4	7.4	30	3.8	26	
17	72	225	196.34	4.73	0.204	<0.01	8.8	0.16	0.06	<0.01	1.14	2.37	2.78	1.5	7.3	28	3.9	26	
WET SCREENED (WTOS)																			
1	1	225	152.9	4.37	0.209	<0.01	8.1	0.09	0.02	0.05	1.23	3.24	2.15	2.2	3.0	20	1.9	19	
2	2	225	206.3	5.16	0.292	5.16	10.1	0.19	0.03	<0.01	1.60	4.86	4.06	1.9	4.1	35	3.1	35	
3	5	225	85.2	5.06	0.313	<0.01	10.3	0.23	0.02	<0.01	1.66	5.19	4.31	1.9	4.5	39	3.8	39	
5	9	225	184.4	5.07	0.230	<0.01	7.8	0.18	0.01	<0.01	1.35	4.08	3.42	1.5	5.0	31	3.3	31	
6	12	225	181.0	5.05	0.218	0.01	6.8	0.22	0.19	0.09	1.26	3.35	2.79	1.4	5.4	28	3.2	26	
7	13	450	417.8	5.01	0.133	<0.01	4.0	0.08	0.02	<0.01	0.80	2.01	1.70	1.2	4.9	17	1.8	17	
8	14	450	417.6	5.10	0.119	0.25	3.6	0.07	0.02	0.09	0.77	1.85	1.50	1.2	5.1	15	1.6	15	
9	15	450	436.9	5.03	0.114	<0.01	3.2	0.06	0.02	<0.01	0.66	1.67	1.41	1.1	5.2	14	1.6	14	
10	16	225	214.8	4.99	0.152	0.06	4.1	0.08	0.03	0.04	0.78	2.26	1.86	1.2	5.5	19	2.2	18	
11	21	225	164.3	5.01	0.149	0.05	4.3	0.08	0.03	<0.01	1.13	2.33	1.97	1.3	4.7	20	2.6	19	
12	23	225	182.9	NA	0.162	<0.01	4.3	0.09	0.03	<0.01	1.15	2.33	1.98	1.2	4.7	20	2.6	19	
13	30	225	144.5	4.94	0.168	0.02	4.8	0.18	0.22	0.02	1.24	2.49	2.13	1.3	4.7	21	3.1	19	
14	36	225	140.2	5.03	0.155	<.01	4.7	0.11	0.04	0.02	1.32	2.33	2.00	1.3	4.9	20	2.7	19	
15	39	225	135.1	5.38	NA	0.07	3.8	0.10	0.03	0.08	0.91	2.14	1.95	1.3	4.5	17	3.3	19	
16	68	225	196.8	4.83	0.139	0.07	4.9	0.09	0.02	0.11	0.81	2.14	1.85	1.3	5.4	18	3.0	17	
17	70	225	212.8	4.72	0.173	0.07	4.8	0.13	0.01	<0.01	0.99	2.78	2.45	1.4	5.5	25	4.0	23	

NA Not analyzed.

Table 15. - Results from columns containing flood plain tailings composite

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
OM1																		
1	1	500	152.24	4.67	0.890	<0.01	37	1.25	0.20	0.02	3.8	14	15	4.9	5.3	168	11.6	124
2	3	55	33.54	4.49	NA	<0.01	36	1.29	0.19	0.02	3.8	14	18	4.7	5.2	180	12.1	127
3	6	100	67.64	4.74	1.236	<0.01	41	1.39	0.20	<0.01	3.8	15	22	4.5	5.0	195	12.6	128
4	8	100	88.54	4.66	1.305	0.25	56	1.96	0.27	<0.01	4.7	20	28	5.6	5.3	276	15.3	167
5	10	100	89.74	4.50	1.458	<0.01	53	1.81	0.24	<0.01	4.2	19	27	4.6	4.3	273	13.5	150
6	13	100	84.14	4.56	1.669	0.21	66	2.46	0.29	<0.01	4.8	26	38	5.8	5.2	364	17.6	299
7	14	200	180.94	4.51	1.675	<0.01	63	2.38	0.26	<0.01	4.5	24	36	5.2	4.8	369	16.2	296
8	15	200	185.34	4.72	1.589	0.21	58	2.35	0.26	0.03	4.4	22	33	4.5	4.5	325	15.9	299
9	16	200	190.84	4.58	1.476	0.13	53	2.26	0.25	0.03	4.6	20	30	4.1	4.3	319	16.1	291
10	17	100	104.04	4.91	1.443	1.31	50	2.20	0.25	0.04	4.3	19	29	3.2	4.2	297	15.0	260
11	22	100	67.04	4.66	1.665	0.13	54	2.45	0.18	0.15	4.7	21	41	3.2	4.6	334	15.3	283
12	24	100	88.04	4.52	1.929	0.10	63	2.95	0.21	0.05	5.4	24	43	3.6	4.9	406	16.9	311
13	30	100	77.04	4.18	2.140	<0.01	68	3.09	0.15	0.03	5.9	26	53	3.6	4.5	537	17.4	316
14	37	100	79.64	4.38	2.299	0.39	76	3.50	0.22	0.10	6.5	27	55	3.9	4.5	502	18.0	341
15	68	100	46.11	4.61	2.915	<0.01	100	4.98	0.44	<0.01	7.8	37	73	4.5	4.2	715	25	394
16	70	100	73.13	4.66	2.840	<0.01	93	5.13	0.46	<0.01	7.7	36	71	4.2	4.5	764	20	401
17	72	100	78.83	4.67	2.782	0.20	107	5.02	0.08	0.11	8.7	46	186	5.5	3.8	789	15.8	384
OM2																		
1	1	500	144.04	4.65	0.913	<0.01	36	1.22	0.20	0.03	4.1	14	15	5.4	5.2	163	11.4	122
2	3	63	45.04	4.56	NA	<0.01	40	1.26	0.20	0.02	3.9	14	17	4.7	5.0	182	11.8	126
3	6	100	63.44	4.77	1.143	0.20	35	1.25	0.17	<0.01	3.2	14	20	4.1	4.4	165	10.9	129
4	8	100	84.24	4.63	1.270	0.17	49	1.81	0.23	<0.01	4.2	19	28	5.3	5.2	257	14.0	159
5	10	100	84.74	4.64	1.925	<0.01	54	1.91	0.24	<0.01	4.3	20	30	5.0	4.7	289	14.0	154
6	13	100	27.74	4.65	1.654	0.19	66	2.42	0.26	0.02	4.7	26	38	6.0	5.4	363	17.4	295
7	14	200	184.64	4.61	1.710	<0.01	64	2.47	0.26	0.05	4.6	25	36	5.4	4.9	378	16.6	302
8	15	200	198.04	4.73	1.680	0.26	59	2.47	0.26	0.03	4.5	23	33	4.7	4.6	337	16.6	306
9	16	200	197.34	4.66	1.634	0.10	56	2.48	0.25	0.04	4.6	22	32	4.3	4.5	344	16.7	305
10	17	100	117.54	5.03	1.655	1.28	54	2.48	0.26	0.05	4.4	22	32	3.4	4.5	330	15.8	276
11	22	100	85.14	4.89	1.752	0.18	59	2.80	0.24	0.11	5.2	24	45	3.6	4.9	376	16.5	301
12	24	100	98.44	4.64	2.023	0.11	67	3.28	0.30	0.04	5.7	26	45	3.8	5.1	444	17.7	323
13	30	100	88.04	4.55	2.195	<0.01	70	3.46	0.27	0.04	6.3	28	54	3.7	5.1	585	18.5	330
14	37	100	84.94	4.56	2.394	0.32	76	3.89	0.30	0.04	6.6	29	54	3.8	4.9	535	18.8	352
15	68	100	52.72	4.58	3.076	<0.01	98	5.69	0.52	0.03	8.2	40	75	4.7	4.5	783	24	411
16	70	100	73.09	4.59	3.030	<0.01	97	5.81	0.51	0.02	7.8	39	71	4.3	4.7	835	22	414
17	72	100	77.83	4.64	2.944	0.11	101	5.69	0.56	0.02	8.0	37	65	4.3	4.6	747	22	398

NA Not analyzed because of insufficient volume of leachate recovered.

S concentrations in duplicate columns of the composite were similar and averaged about 180 mg/L until day 8, when S concentrations from both columns increased to about 350 mg/L. S concentrations decreased to 250 mg/L during the wet period and increased to 600 mg/L during the period when leachant was added at 3-day intervals. Following the 45-day-long dry period, S concentrations averaged 775 mg/L. Zn concentrations in the leachate were very similar and increased from 160 to 300 mg/L at day 13. Note that the increases in Zn occurred before the effects of the wettest period could have been manifested. Pb concentrations for all columns containing any flood plain tailings ranged between 4 and 6 mg/L and generally decreased slightly during the wet cycle.

Releases of S and Zn during this 72-day column test were 60% and 40% less, respectively, than releases during the static tests. The releases of Pb during the column leaching tests were much lower than releases during the static tests, even though the pH's of the leachate from the two tests were very similar.

Total metal concentrations in the damp-screened, gravel-sand fractions of the flood plain tailings composite (analogous

to the coarser fraction of the alluvium and reworked tailings composite) were less than those in the composite. However, releases of S, Zn, and Pb during the static test were similar to releases from the composite (table 13). During the first two leachings, the pH's of the duplicate samples of the damp-screened, gravel-sand fraction were different, but both averaged about 4.6 throughout the entire experiment and both increased during the wet period (table 16). During the dry period, pH's decreased to an average of 4.1, then increased to 4.6 at the end of the dry period.

S concentrations in leachates from the damp-screened, gravel-sand fraction of the flood plain tailings did not show the lag observed in the flood plain tailings composite and immediately increased to about 350 mg/L. S decreased to 240 mg/L during the wet cycle. After the wet cycle, S concentrations diverged, although both columns still had lower S concentrations than the flood plain tailings composite. Zn concentrations in the leachate paralleled those from the composite sample until the beginning of the wet cycle, when Zn decreases were greater than those observed from the

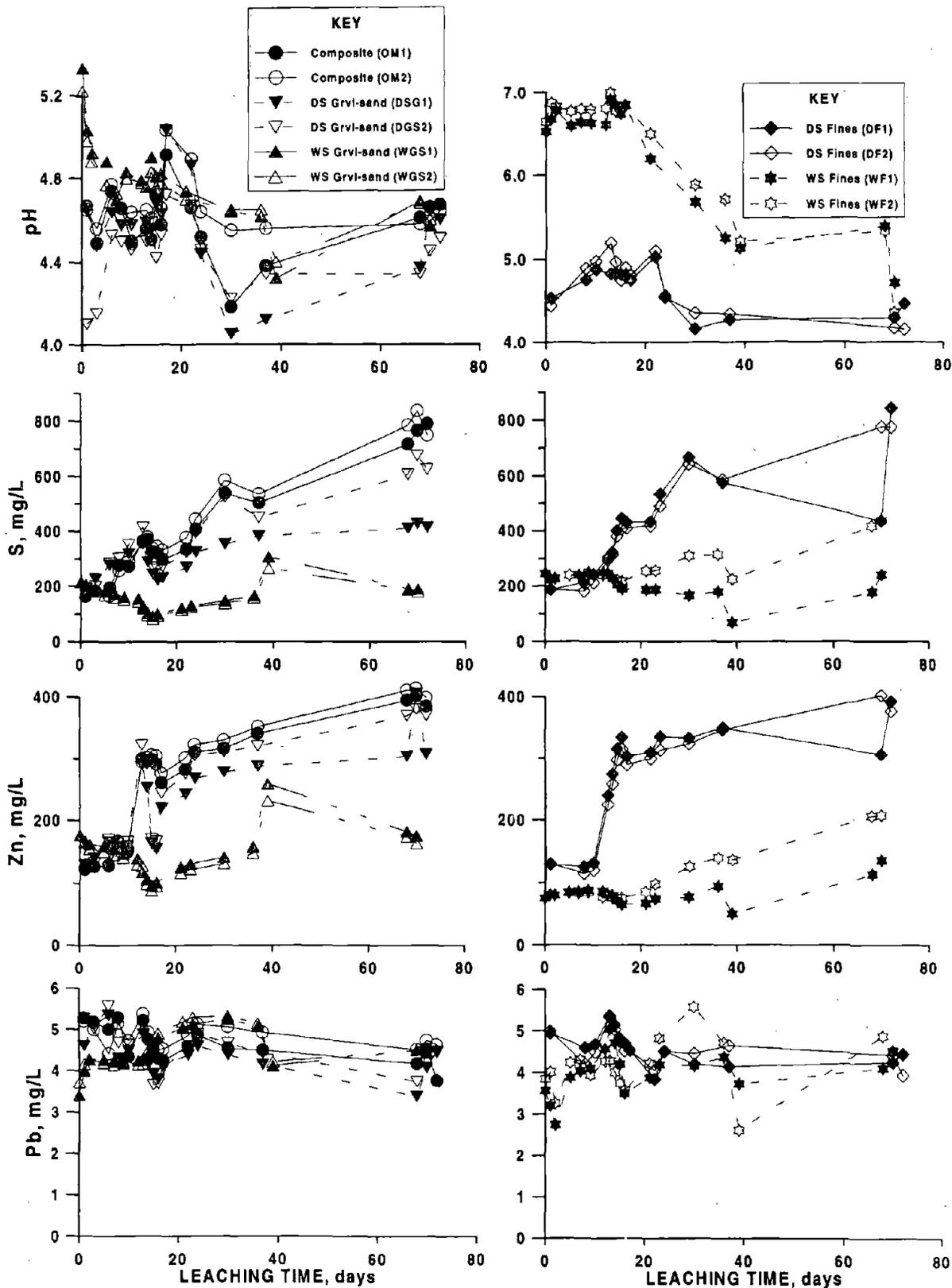


Figure 9.—Results of column leaching tests on flood plain tailings. Columns containing composite, damp-screened, gravel-sand fraction, and wet-screened, gravel-sand fraction on left. Damp-screened, fine fraction and wet-screened, fine fraction on right. Duplicate samples are shown as filled and open symbols.

Table 16. - Results from columns containing damp-screened, gravel-sand fraction of flood plain tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
DGS1																		
1	1	200	107.24	4.65	0.939	<0.01	37	1.37	0.25	0.06	5.3	15	24	5.8	4.6	181	12.8	127
2	3	100	83.74	4.48	1.166	<0.01	41	1.63	0.28	0.16	5.6	16	29	5.6	5.1	226	14.3	140
3	6	100	62.34	4.64	1.347	0.37	52	2.09	0.34	0.29	6.3	20	38	6.0	5.4	277	16.7	166
4	8	100	79.74	4.58	1.468	0.21	48	1.98	0.30	0.00	5.4	19	37	4.9	4.3	275	14.5	163
5	10	100	81.54	4.58	1.528	<0.01	55	2.19	0.32	0.02	6.1	20	42	4.8	4.5	319	15.6	160
6	13	100	81.34	4.59	1.592	0.27	58	2.52	0.31	0.05	6.1	23	50	5.0	4.9	355	18.1	292
7	14	200	167.54	4.56	1.641	<0.01	43	2.01	0.24	0.03	5.0	17	37	3.8	4.2	289	14.4	253
8	15	200	191.14	4.68	1.191	0.17	38	1.92	0.26	0.05	5.3	14	31	3.1	3.9	243	13.6	164
9	16	200	193.24	4.63	1.131	0.12	33	1.74	0.23	0.07	4.8	12	28	2.7	3.8	222	12.7	155
10	17	100	124.84	5.03	1.239	1.29	36	1.84	0.16	0.35	4.3	14	33	2.6	4.1	230	13.8	220
11	22	100	66.04	4.86	1.389	0.16	41	2.10	0.09	1.06	4.7	16	47	2.7	4.4	268	14.6	243
12	24	100	92.14	4.44	1.597	0.03	47	2.48	0.10	1.09	5.2	19	54	3.1	4.6	324	15.4	268
13	30	100	69.34	4.05	NA	<0.01	50	2.60	0.10	0.59	5.6	20	62	3.2	4.4	353	15.5	278
14	37	100	51.24	4.12	1.877	0.13	53	2.72	0.11	0.09	6.0	21	70	3.3	4.2	382	15.6	287
15	68	100	19.37	4.37	NA	<0.01	51	3.08	0.26	0.04	6.7	23	71	3.3	3.4	409	15.7	304
16	70	100	60.40	4.64	1.801	<0.01	52	3.04	0.23	0.06	5.8	24	65	2.8	4.1	427	15.7	405
17	72	100	74.83	4.60	1.758	<0.01	56	3.20	0.26	0.09	6.6	24	66	3.2	4.5	413	16.3	307
DGS2																		
1	1	200	109.44	4.10	0.972	<0.01	37	1.38	0.26	0.02	5.0	15	23	5.5	5.3	192	13.7	129
2	3	100	89.44	4.15	1.158	0.11	41	1.52	0.28	0.02	4.9	16	25	5.1	5.0	200	14.3	132
3	6	100	60.84	4.53	1.383	0.40	52	2.14	0.38	0.12	6.0	21	36	6.4	5.6	284	17.9	170
4	8	100	84.14	4.50	1.493	<0.01	53	2.08	0.36	<0.01	5.5	21	36	5.4	4.7	302	16.8	158
5	10	100	73.34	4.46	1.647	<0.01	57	2.38	0.39	<0.01	6.0	22	41	5.4	4.6	352	17.4	166
6	13	100	74.74	4.50	1.828	0.32	66	2.91	0.41	0.02	5.9	28	52	5.9	5.1	414	20.5	323
7	14	200	182.54	4.59	1.333	0.05	54	2.48	0.37	0.08	5.3	22	42	4.6	4.2	359	17.4	292
8	15	200	192.04	4.42	1.392	0.20	42	2.07	0.33	0.02	5.0	17	32	3.4	3.7	268	14.4	170
9	16	200	192.44	4.53	1.309	0.19	40	2.01	0.32	0.04	5.0	15	30	3.1	3.7	260	14.3	166
10	17	100	122.64	4.72	1.421	1.32	41	2.14	0.28	0.12	4.4	17	35	2.7	4.1	270	16.0	244
11	22	100	70.24	4.67	1.607	0.23	48	2.55	0.25	0.40	5.0	20	48	3.0	4.6	323	17.1	276
12	24	100	104.24	4.46	1.843	0.06	55	3.06	0.33	0.06	5.6	23	53	3.3	4.9	394	18.6	305
13	30	100	69.24	4.22	NA	<0.01	58	3.22	0.31	0.07	6.1	25	59	3.3	4.7	524	19.6	311
14	37	100	54.84	4.34	2.127	0.23	58	3.37	0.31	0.13	6.3	25	60	3.4	4.4	449	19.2	321
15	68	100	36.70	4.34	2.663	<0.01	70	4.52	0.59	0.10	7.6	34	75	4.0	3.7	606	20.7	370
16	70	100	69.76	4.45	2.580	<0.01	70	4.77	0.65	0.03	7.3	35	76	3.8	4.4	674	21.6	380
17	72	100	83.08	4.51	2.459	<0.01	73	4.80	0.69	0.02	7.8	35	75	4.0	4.4	624	21.7	370

NA Not analyzed because of insufficient volume of leachate recovered.

flood plain tailings composite. After the wet cycle, Zn concentrations in one of the duplicate columns were slightly less than Zn concentrations in the other duplicate and both composite samples. The cumulative releases of S, Zn, and Pb during the entire column leaching tests were 31%, 54%, and 12%, respectively, of the releases during the static tests.

The sample of the wet-screened, gravel-sand fraction had higher concentrations of elements than did the damp-screened fraction. In comparison, releases of S, Zn, and Pb during the static tests were lower, probably as a result of soluble salts being flushed during the wet-screening process (table 13). The pH's of the leachates from columns containing the wet-screened fraction were initially higher than the pH's of leachates from the damp-screened fraction, but decreased to about 4.4 after the long dry period (table 17). S concentrations in the initial leachates from the columns containing the wet-screened, gravel-sand fraction (200 mg/L) were similar to those of the damp-screened, gravel-sand fraction and the flood plain tailings composite. In comparison with columns containing the composite and damp-screened, gravel-sand

fraction, S concentrations of the leachates from the wet-screened, gravel-sand fraction not only did not increase before the wetter sequence, but decreased to 90 mg/L by the end of the sequence. Only the leachate sample collected immediately after the long dry interval had S concentrations greater than 200 mg/L. The average release of S from the columns containing the wet-screened, gravel-sand fraction was much lower than S release from the columns containing the flood plain tailings composite, as previously discussed, and was significantly less than S release during the static test.

Zn concentrations in the leachate from the wet-screened, gravel-sand fraction mimicked those of S, and the average cumulative Zn release was only slightly less than Zn release during the static test. Although Zn concentrations in leachates from the wet-screened, gravel-sand fraction were significantly less than those from the damp-screened fraction, the average cumulative Zn release was only slightly less (55 ppm from the wet-screened fraction versus 59 ppm from the damp-screened fraction). The higher liquid-to-solids ratio (0.39 L/kg for the wet-screened fraction versus 0.26 L/kg for the damp-screened

fraction) explains this apparent discrepancy. Three factors were responsible. (1) Initial draining of the columns containing wet-screened material provided leachate, (2) the retention of moisture by the fines adhering to the damp-screened, gravel-sand fraction enhanced eventual evaporation of the moisture in the columns relative to the amount of moisture evaporated from the wet-screened, gravel-sand fraction, where most of the leachant was immediately collected as leachate, and (3) most importantly, the dry weight (5.31 kg) of the columns containing the wet-screened fraction was less than the dry weight (6.29 kg) of the columns containing the damp-screened fraction.

Total concentrations of S and Pb in the damp-screened, fine fraction were higher than those in the composite sample (table 13). Zn concentrations were slightly lower. Releases of S, Zn, and Pb from the fine fraction during the static test

were slightly higher than releases from the composite. Initially, the pH of the leachate from the damp-screened, fine fraction increased to 5.0 before decreasing to 4.3 after the dry interval (table 18). S concentrations in the damp-screened, fine fraction did not exhibit a decrease during the wet cycle and were slightly higher than S concentrations from the flood plain tailings composite throughout much of the column leaching test. Zn concentrations from this fine fraction were similar to those from the flood plain tailings composite. The cumulative releases of S, Zn, and Pb from the damp-screened, fine fraction were 33%, 47%, and 8.2% of the releases measured during the static test, respectively.

The wet-screened, fine fraction also contained high concentrations of the elements of interest (table 13). Zn release during the static test was similar to Zn release from the damp-screened, fine fraction, despite the fact that the Zn release

Table 17. - Results from columns containing wet-screened, gravel-sand fraction of flood plain tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
WGS1																		
0	Draining		228.9	5.33	1.176	<0.01	53	1.42	0.09	0.02	5.7	28	24	5.9	3.4	215	11.2	176
1	1	100	93.6	5.03	1.163	<0.01	48	1.32	0.11	<0.01	5.3	25	22	4.7	4.0	203	10.9	165
2	2	100	109.4	4.92	1.116	4.92	45	1.29	0.13	0.06	5.4	24	21	4.3	4.3	190	11.3	162
3	5	100	74.0	4.88	1.085	<0.01	42	1.27	0.14	<0.01	5.0	23	21	3.9	4.3	180	11.2	159
4	7	100	87.8	4.70	1.060	<0.01	40	1.24	0.14	<0.01	4.8	21	19.6	3.4	4.2	172	10.8	156
5	9	100	96.5	4.83	0.909	<0.01	38	1.16	0.14	<0.01	4.7	19.5	18.3	3.0	4.2	161	10.6	147
6	12	100	64.1	4.79	0.952	<0.01	36	1.18	0.32	0.02	4.6	18.3	17.3	2.8	4.3	155	10.5	139
7	13	200	181.1	4.76	0.664	0.32	26	0.87	0.10	0.02	4.0	13.6	13.6	2.0	4.3	119	8.5	118
8	14	200	189.1	4.90	0.573	<0.01	22	0.77	0.09	0.02	3.5	11.3	11.1	1.7	4.4	102	7.7	106
9	15	200	195.9	4.81	0.528	<0.01	20	0.71	0.09	<0.01	3.3	9.7	9.7	1.5	4.6	91	7.3	96
10	16	100	110.2	4.82	0.588	0.06	20	0.76	0.12	0.07	3.3	10.7	10.6	1.5	4.8	99	8.4	101
11	21	100	67.9	4.74	0.704	0.02	25	0.97	0.13	<0.01	4.0	13.2	13.7	1.7	5.0	121	10.6	125
12	23	100	95.8	NA	0.741	<0.01	26	1.01	0.14	<0.01	4.1	13.6	14.3	1.7	5.1	129	10.8	130
13	30	100	65.0	4.64	0.851	<0.01	30	1.22	0.33	0.02	4.6	15.6	16.8	2.0	5.3	146	12.1	141
14	36	100	70.8	4.62	0.917	<0.01	32	1.29	0.15	<0.01	4.6	16.9	18.6	2.0	5.1	165	12.4	158
15	39	100	22.8	4.32	NA	0.13	61	2.58	0.31	0.11	8.7	33	38	3.8	4.1	306	12.7	259
16	68	100	96.9	4.69	NA	0.07	34	1.50	0.17	0.10	4.6	20	22	2.0	4.5	190	13.0	182
17	70	100	98.0	4.57	0.958	0.06	32	1.42	0.13	<0.01	4.4	18.6	20	1.9	4.5	188	12.6	175
WGS2																		
0	Draining		495.4	5.22	1.272	0.03	52	1.42	0.10	<0.01	5.7	28	24	5.5	3.7	213	11.2	176
1	1	100	93.1	4.98	1.139	<0.01	49	1.34	0.11	<0.01	5.6	26	23	4.8	4.2	206	11.1	167
2	2	100	108.1	4.88	1.075	4.88	43	1.22	0.12	<0.01	5.4	23	21	4.1	4.3	181	10.9	155
3	5	100	72.0	4.77	1.053	<0.01	39	1.17	0.14	<0.01	5.0	21	19.8	3.7	4.2	167	10.7	150
4	7	100	88.7	4.73	0.987	<0.01	38	1.13	0.13	<0.01	4.8	19.8	18.8	3.2	4.1	159	10.5	145
5	9	100	91.5	4.80	0.855	<0.01	36	1.10	0.13	<0.01	4.9	18.7	18.0	2.9	4.2	151	10.4	140
6	12	100	64.6	4.78	0.892	0.02	34	1.07	0.30	<0.01	4.6	16.9	16.6	2.6	4.2	144	10.2	130
7	13	200	187.7	4.76	0.732	<0.01	28	0.95	0.11	0.02	4.1	14.6	14.1	2.1	4.2	127	8.8	127
8	14	200	184.0	4.83	0.542	<0.01	21	0.71	0.09	0.02	3.4	10.4	10.7	1.6	4.5	95	7.5	98
9	15	200	194.4	4.76	0.493	<0.01	18	0.64	0.08	0.02	3.1	8.9	9.3	1.4	4.7	83	7.0	88
10	16	100	106.4	4.78	0.554	0.06	19	0.71	0.11	0.07	3.3	10.1	10.5	1.5	4.9	93	8.2	94
11	21	100	66.9	4.70	0.668	0.05	25	0.88	0.12	<0.01	4.1	12.4	13.5	1.7	5.2	115	10.3	116
12	23	100	91.5	NA	0.696	0.03	26	0.94	0.13	<0.01	4.2	13.2	14.5	1.8	5.3	124	10.8	122
13	30	100	64.9	4.65	0.816	0.02	29	1.13	0.32	0.03	4.8	14.9	16.8	2.0	5.3	137	11.8	131
14	36	100	67.4	4.65	0.869	<0.01	31	1.19	0.14	<0.01	4.8	16.2	18.7	1.9	5.1	157	12.1	148
15	39	100	23.5	4.40	0.146	0.11	56	2.17	0.25	0.11	8.2	29	35	3.4	4.2	264	12.4	231
16	68	100	95.5	4.68	0.980	0.07	36	1.43	0.12	0.09	5.0	19.7	23	2.1	4.5	187	12.8	174
17	70	100	95.6	4.60	0.891	0.06	32	1.32	0.12	<0.01	4.7	18.0	21	1.9	4.4	179	12.3	163

NA Not analyzed.

Table 18. - Results from columns containing damp-screened, fine fraction of flood plain tailings

Cycle	Day leachant added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
DF1																		
1	1	400	311.34	4.53	0.958	<0.01	38	1.41	0.24	0.13	4.2	15	21	5.3	4.9	186	11.5	129
2	3	¹ 0																
3	6	¹ 0																
4	8	100	30.44	4.75	NA	<0.01	43	1.45	0.19	0.00	4.7	17	31	5.5	4.6	210	13.0	125
5	10	100	60.04	4.88	1.167	0.18	48	1.52	0.19	0.04	4.8	18	40	5.5	4.7	242	13.2	131
6	13	100	61.74	4.83	1.374	<0.01	56	1.90	0.19	0.05	4.8	23	52	6.3	5.4	302	15.4	240
7	14	200	188.64	4.83	1.567	0.32	62	2.19	0.21	0.06	4.8	26	55	6.3	5.1	322	15.5	275
8	15	200	194.04	4.82	1.857	0.11	71	2.60	0.23	0.04	5.0	29	58	6.2	4.8	400	16.0	316
9	16	200	186.74	4.79	1.950	0.12	74	2.82	0.23	0.07	5.1	30	58	6.0	4.7	446	16.5	335
10	17	100	112.64	4.75	2.054	1.21	73	2.87	0.22	0.08	5.0	30	59	4.8	4.5	431	15.7	303
11	22	100	48.04	5.03	2.060	0.19	69	2.83	0.04	0.60	5.1	29	73	4.2	3.8	432	14.3	310
12	24	100	96.84	4.56	2.317	0.49	77	3.36	0.06	1.23	6.1	33	84	4.7	4.5	534	16.4	336
13	30	100	68.84	4.16	2.506	<0.01	79	3.38	0.02	0.24	6.3	33	95	4.3	4.2	666	16.3	333
14	37	100	45.04	4.27	2.718	0.18	83	3.63	0.01	2.46	6.6	34	103	4.4	4.1	575	16.0	349
15	68	100	² 0															
16	70	100	12.69	4.29	NA	<0.01	48	3.05	0.27	0.03	6.2	23	64	3.0	4.2	436	15.4	306
17	72	100	73.63	4.46	3.288	<0.01	109	5.46	0.28	0.12	9.3	47	170	5.4	4.4	842	19.3	392
DF2																		
1	1	500	309.54	4.44	0.999	<0.01	39	1.36	0.22	0.06	4.5	15	20	5.7	5.0	187	11.6	130
2	3	¹ 0																
3	6	¹ 0																
4	8	100	60.74	4.89	NA	<0.01	37	1.20	0.17	<0.01	3.9	14	26	4.7	4.2	180	11.0	114
5	10	100	82.54	4.98	1.131	0.15	42	1.30	0.17	<0.01	4.3	16	38	5.1	4.5	211	11.8	120
6	13	100	76.94	5.20	1.366	<0.01	58	1.75	0.18	0.04	4.9	24	59	6.7	5.3	295	15.1	224
7	14	200	188.34	4.97	1.530	0.24	64	1.98	0.20	0.04	4.8	27	63	6.6	5.0	314	15.0	258
8	15	200	175.94	4.75	1.787	0.10	72	2.33	0.20	0.06	4.8	29	64	6.3	4.7	380	15.2	298
9	16	200	201.14	4.90	1.872	0.05	72	2.48	0.20	0.07	4.8	29	61	5.2	4.5	407	14.9	316
10	17	100	118.14	4.81	1.941	1.11	71	2.55	0.20	0.13	4.8	29	61	4.8	4.5	410	15.0	290
11	22	100	62.94	5.10	1.930	0.12	71	2.59	0.04	0.22	5.0	29	81	4.3	4.1	418	14.6	300
12	24	100	112.74	4.54	2.089	0.25	75	2.84	0.06	0.50	5.6	31	90	4.3	4.5	490	15.4	314
13	30	100	92.34	4.35	2.333	<0.01	79	3.07	0.03	0.02	5.9	32	101	4.0	4.5	642	15.9	324
14	37	100	78.14	4.34	2.498	0.21	83	3.46	0.02	0.89	6.4	33	111	4.4	4.6	586	16.4	347
15	68	100	² 0															
16	70	100	54.31	4.17	3.340	<0.01	85	5.06	0.44	0.10	7.5	34	64	4.1	4.4	775	20.3	402
17	72	100	77.48	4.15	3.126	<0.01	103	4.78	0.01	0.09	8.1	43	180	4.9	3.9	774	17.2	377

NA Not analyzed because of insufficient volume of leachate recovered.

¹ No leachant added to equalized the volume of leachate recovered.

² No leachate recovered.

during the wet-screening process was 41 ppm. A dramatic decrease in Zn release (110 ppm versus 64 ppm) in the coarser fraction occurred as a result of wet screening. This would suggest that the Zn released during wet screening was probably associated with material attached to the surfaces of the gravel-sand fraction. S releases during the static tests from the two fine fractions were similar, while the Pb release from the wet-screened, fine fraction during the static test was higher. There was a significant increase in the release of Ca and Mg from the finer fraction during the static test as a result of wet screening.

The most dramatic change observed as a result of wet screening the flood plain tailings was a significant increase in leachate pH from the finer fraction (from 4.7 to 7). This increase (figure 9) probably resulted from a combination of (1) washing off soluble acidic salts, (2) uptake of Ca and Mg onto the fines, which would buffer the release of acid, and (3) saturation of the column, which would limit the diffusion of

oxygen. However, the effect of wet screening on pH was only temporary. After the wet period, the pH of the wet-screened finer fraction started to drop dramatically. At the same time, Ca concentrations in the leachate started to decrease (table 19). Therefore, the uptake of Ca during wet screening and the ion exchange of H⁺ with Ca²⁺ on the surfaces of the fine particles temporarily buffered the solution from the effects of any acid production.

Even though pH started to decrease at day 13, significant increases in the releases of S and Zn did not occur until after the long dry period. Although metal analyses were not performed following the dry period (leachings 18 through 22), five additional leachates continued to exhibit lower pH and higher EC values (table A-8). The column probably dried out enough to allow greater penetration of oxygen into the column. The cumulative releases of S, Zn, and Pb during the column leaching tests were substantially below the amounts released during the static tests.

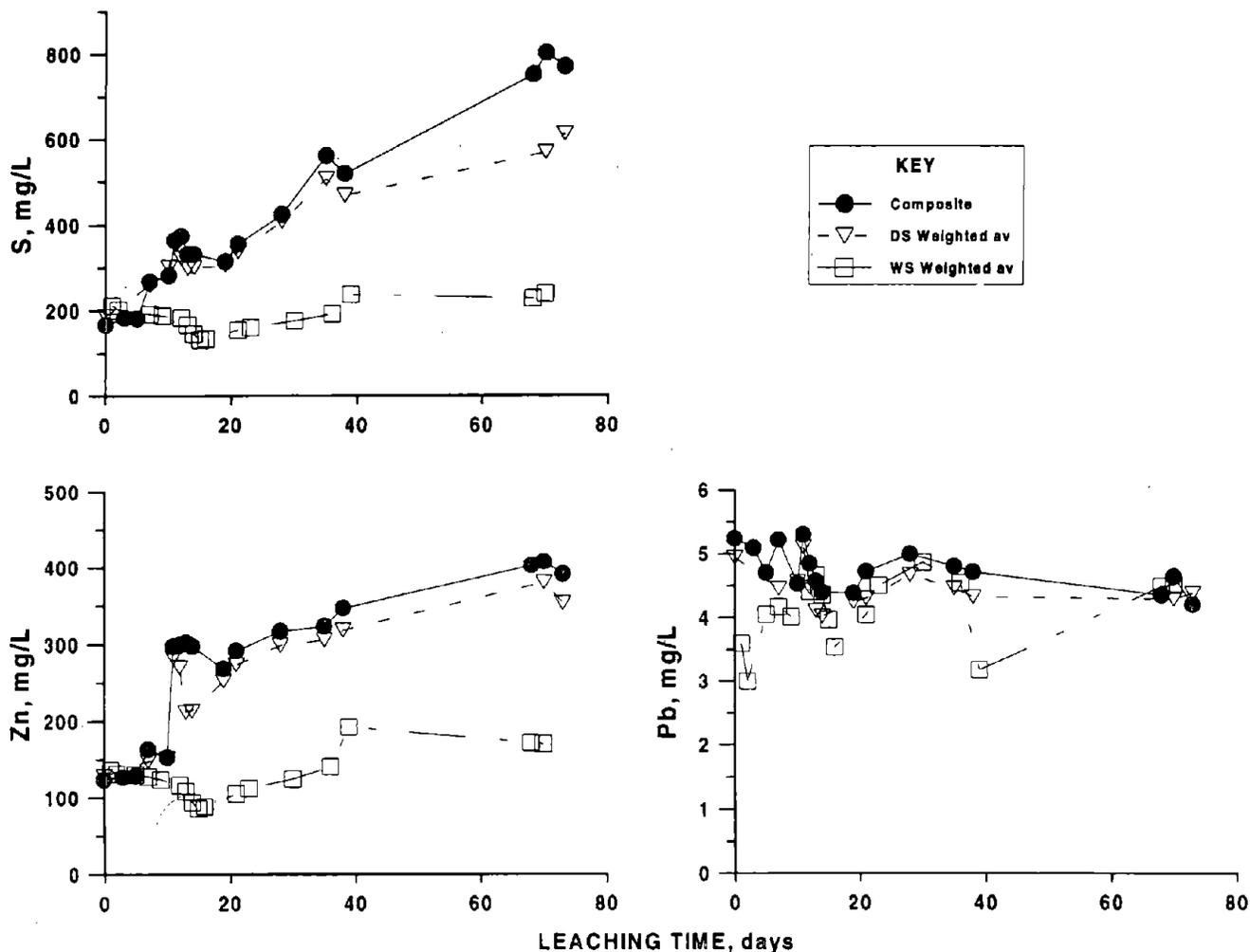


Figure 10.—Concentrations of S, Zn, and Pb as a result of damp and wet screening. Average of original tailings composite. Weighted-average concentrations based on mass distribution of coarser and finer fractions (32%:68% for damp-screening process and 48%:52% for wet-screening process).

Having examined the geochemical behavior of each column type, we can now examine the effect that separating the flood plain tailings had on metal release. With damp screening, only the differences in particle size and porosity of column solids between the sized fractions and the flood plain tailings composite controlled any changes in metal release. The porosity differences were minimized also because damp separation was ineffective (i.e., the dry-screened, coarser fraction contained 15% fines [-1 mm] by weight). By contrast, the effects of wet screening were numerous. Removal of soluble salts by the washing action of the wet screening was calculated from analyses of the processing water. Ion exchange and water saturation of the columns would also limit release. In addition, wet screening could have a dramatic effect on geochemistry at the interface of the solids or on biological activity in the flood plain tailings.

As described above in the section on "Alluvium," concentrations in the leachate from the flood plain tailings composite were compared to average concentrations in the leachates

from the segregated fractions, weighted by their mass fraction. There were very few effects of damp screening on concentrations of S, Zn, and Pb in flood plain tailings (figure 10). When the amounts of metal released during each leaching were summed and normalized to the weight of material leached, the weighted-average releases of the damp-screened fractions were only 14%, 16%, and 7% less, respectively, than the cumulative releases from the column containing the composite. In contrast, releases of S and Zn from the wet-screened fractions were much lower than releases from the composite.

To determine the effects of flushing soluble salts from the system on releases from the columns, releases during both the wet-screening process and the column leaching tests were examined (table 13). Weighted-average releases for S and Pb from the wet-screened fractions were 72% of releases from the flood plain tailings composite. However, when the S released during the wet-screening process was included, the release of S was 2.5 times greater than release from the composite. The sum of S release from the wet screening plus column leaching

Table 19. - Results from columns containing wet-screened, fine fraction of flood plain tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L													
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn	
WF1																			
0	Draining		584.5	6.52	1.207	<0.01	75	0.70	0.02	0.03	4.2	43	55	5.4	3.6	244	7.9	75	
1	1	100	154.9	6.67	1.234	0.10	79	0.77	<0.01	0.25	4.4	46	62	5.4	3.2	222	8.5	80	
2	2	100	103.9	6.78	1.325	6.78	81	0.79	<0.01	0.01	4.6	48	67	5.6	2.7	226	8.4	80	
3	5	100	83.8	6.59	1.360	<0.01	83	0.86	0.01	<0.01	4.6	49	74	5.9	3.9	NA	8.6	85	
4	7	100	83.8	6.63	1.431	<0.01	82	0.84	0.02	<0.01	4.5	49	76	5.7	4.0	237	8.5	86	
5	9	100	81.6	6.63	1.302	<0.01	83	0.86	0.02	<0.01	4.6	49	80	5.8	4.1	243	8.7	87	
6	12	100	77.1	6.61	1.419	0.01	85	0.94	0.21	0.01	4.6	49	83	5.8	4.6	249	8.7	86	
7	13	200	186.2	6.91	1.293	0.01	85	0.90	0.21	0.01	4.6	48	85	5.5	5.1	246	9.3	82	
8	14	200	184.6	6.85	1.170	0.20	76	0.76	0.04	0.01	4.5	45	83	4.5	4.7	229	9.0	79	
9	15	200	188.0	6.74	1.067	<0.01	67	0.68	0.03	0.01	4.2	39	75	3.7	4.2	205	8.4	71	
10	16	100	87.1	6.84	1.038	0.19	61	0.63	0.04	0.01	3.9	37	71	3.4	3.5	189	7.9	65	
11	21	100	58.4	6.19	0.962	0.14	54	0.64	0.05	0.02	3.5	30	64	2.8	3.9	185	7.3	67	
12	23	100	69.2	NA	1.027	<0.01	59	0.69	0.04	<0.01	3.7	33	72	3.1	4.2	186	8.0	74	
13	30	100	46.9	5.68	0.957	<0.01	48	0.70	0.05	<0.01	2.8	26	62	2.6	4.2	164	6.6	77	
14	36	100	40.7	5.25	NA	<0.01	52	0.83	0.08	0.04	2.9	27	68	2.8	4.4	178	6.8	94	
15	39	100	35.4	5.13	NA	0.04	20	0.36	0.01	0.10	1.5	11	26	1.7	3.7	67	2.0	50	
16	68	100	77.6	5.39	1.011	0.05	44	0.89	0.03	0.12	2.9	25	68	2.6	4.1	177	6.6	113	
17	70	100	83.4	4.71	1.233	0.05	55	1.13	0.05	<0.01	3.6	32	89	3.0	4.5	240	8.1	136	
WF2																			
0	Draining		570.5	6.64	1.202	<0.01	75	0.71	0.02	0.02	4.1	43	55	5.3	3.9	245	7.9	75	
1	1	100	161.8	6.87	1.228	0.01	80	0.78	<0.01	0.02	4.5	47	63	5.5	4.0	225	8.5	81	
2	2	100	99.6	6.82	1.329	6.82	81	0.79	<0.01	0.01	4.6	48	66	5.6	3.3	228	8.3	80	
3	5	100	88.3	6.77	1.370	<0.01	83	0.84	0.02	<0.01	4.6	49	74	5.9	4.2	238	8.5	83	
4	7	100	87.1	6.79	1.416	<0.01	83	0.82	0.01	<0.01	4.6	49	77	5.8	4.3	238	8.6	83	
5	9	100	82.6	6.79	1.307	<0.01	86	0.85	<0.01	<0.01	4.7	51	83	5.9	3.9	248	8.8	84	
6	12	100	74.9	6.81	1.375	0.01	83	0.84	0.18	0.01	4.5	48	83	5.6	4.3	240	8.5	77	
7	13	200	183.3	7.00	1.237	0.42	82	0.78	0.02	0.01	4.6	48	87	5.3	4.3	245	8.8	81	
8	14	200	190.5	6.78	1.145	0.34	76	0.72	0.01	0.03	4.4	44	82	4.7	4.0	229	8.3	76	
9	15	200	185.8	6.81	1.141	<0.01	73	0.71	0.01	0.05	4.1	42	79	4.4	3.8	220	8.1	76	
10	16	100	86.8	6.85	1.152	<0.01	71	0.73	0.02	0.07	4.0	42	79	4.3	3.6	217	7.9	76	
11	21	100	60.9	6.49	1.272	0.03	75	0.84	0.03	0.03	4.2	43	85	4.4	4.2	253	8.3	85	
12	23	100	65.8	NA	1.351	0.05	81	0.96	0.02	<0.01	4.4	45	92	4.7	4.8	256	9.0	98	
13	30	100	40.2	5.88	NA	<0.01	91	1.23	0.04	<0.01	4.6	49	108	5.0	5.6	309	10.0	126	
14	36	100	30.4	5.71	NA	<0.01	89	1.32	0.05	0.02	4.0	49	113	4.8	4.7	313	9.1	140	
15	39	100	10.6	5.21	NA	0.05	64	1.11	0.03	0.12	3.2	37	89	3.5	2.6	224	5.8	137	
16	68	100	74.2	5.33	2.013	0.09	106	1.93	0.06	0.11	5.1	59	152	5.3	4.9	417	11.2	206	
17	70	100	84.8	4.35	1.961	0.10	102	1.93	0.05	<0.01	5.4	58	148	5.0	4.5	436	11.3	207	

NA Not analyzed.

(253 ppm) was very similar to S release during the static tests (244 ppm). Perhaps the high liquid-to-solids ratio of the wet screening (4.06 L/kg) maximized flushing of soluble salts present as measured by the static tests.

Weighted-average Zn release from the wet-screened fractions was 56% of Zn release from the flood plain tailings composite. However, when release during wet separation was included, Zn release during wet screening was 15% higher than Zn release from the flood plain tailings composite.

Gravel-Sand Fraction Experiment

The damp- and wet-screened, gravel-sand fractions were further separated by a 4-mesh screen (4.8 mm) without the use of water into gravel and sand subfractions, resulting in four subfractions. The damp-screened and wet-screened, sand

subfractions contained 31% and 13% fines (-1 mm), respectively (table 5). An overview of the experiments with the gravel-sand fraction is shown in figure 11.

The pH's of the two wet-screened subfractions were similar to each other, as were the pH's of the two damp-screened subfractions (tables 20 and 21). The pH's of the two wet-screened subfractions were higher than the pH's of the two damp-screened fractions initially, but differences diminished after the long dry period (figure 12). These higher pH's were consistent with the concept that biogeochemical effects, brought about by initial contact with processing water, controlled subsequent release to a much greater degree than did physical factors. S concentrations from the two sand subfractions were greater than those from the two gravel subfractions. Damp-screened subfractions had higher S concentrations than wet-screened subfractions. A similar trend was found for Zn.

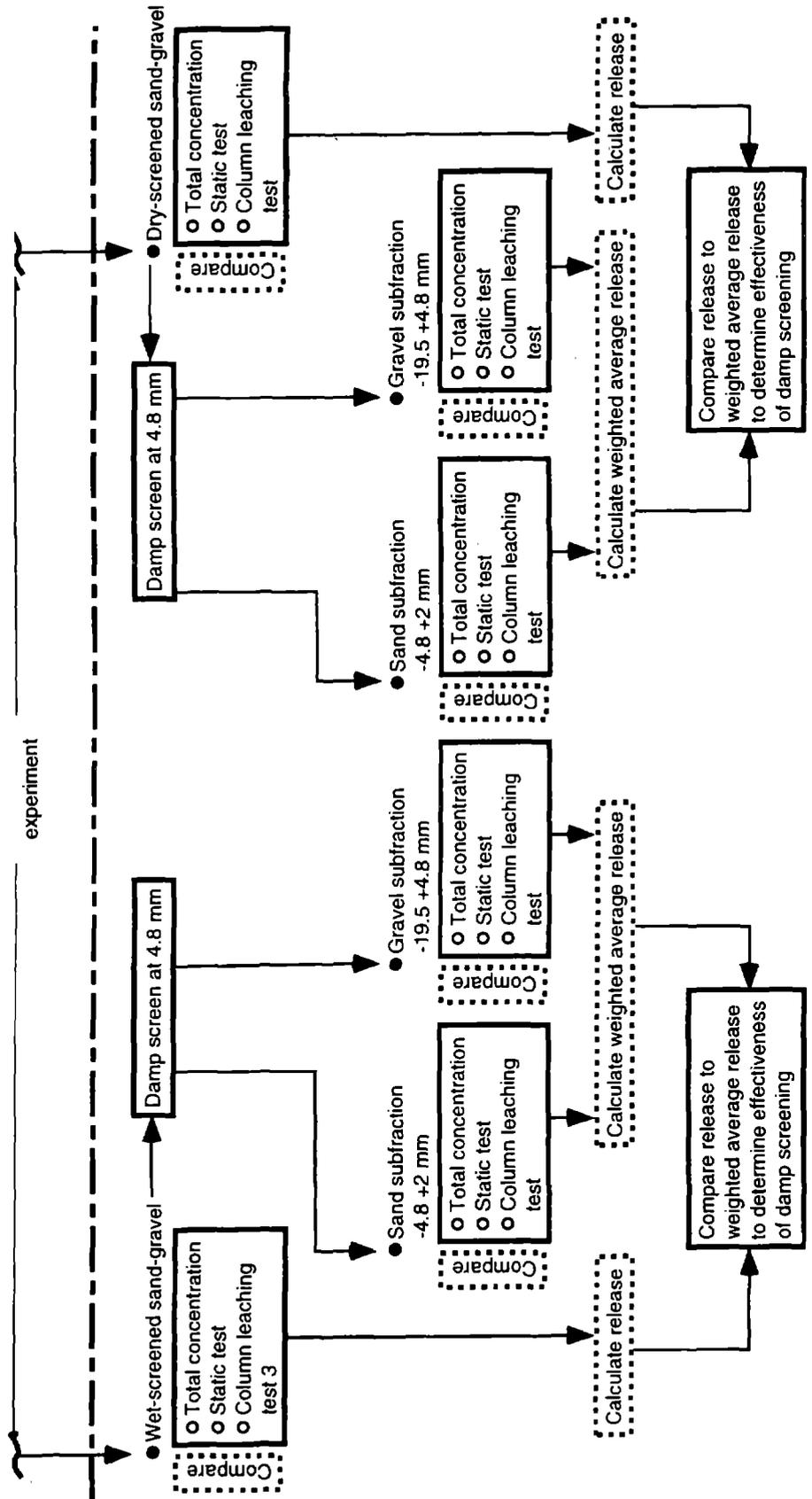


Figure 11.--Schematic of experiments with gravel-sand fractions.

The geochemical effects of tap water on the wet-screened, gravel-sand fraction were different than effects on the damp-screened, gravel-sand fraction. Therefore, weighted-average releases of elements from the sand and gravel subfractions can only be compared to releases from the corresponding gravel-sand fraction (table 13) (figure 13). Weighted-average S and Zn releases from the damp-screened, gravel and sand

subfractions were very similar to the releases from the damp-screened, gravel-sand fraction. When the cumulative releases from the wet-screened fractions were normalized by sample weight, the weighted-average S and Zn releases from the subfractions were 80% and 76%, respectively, of the releases from the wet-screened, gravel-sand fraction.

Table 20. - Results from columns containing damp-screened, gravel and sand subfractions of flood plain tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
GRAVEL SUBFRACTION (DG)																		
1	1	200	107.14	4.17	0.864	<0.01	31	1.17	0.22	0.04	5.7	12.7	26	5.1	5.0	153	10.6	110
2	3	100	84.44	4.46	0.941	0.06	34	1.31	0.22	<0.01	5.6	13.8	28	4.6	4.9	165	12.5	113
3	6	100	68.34	4.56	1.100	<0.01	40	1.74	0.31	0.04	6.0	16.3	35	5.1	5.4	213	15.1	144
2	8	100	79.94	4.49	1.100	<0.01	35	1.50	0.27	<0.01	5.1	13.9	29	3.7	4.3	191	12.8	123
5	10	100	83.44	4.50	1.086	<0.01	34	1.49	0.27	<0.01	4.7	13.2	27	3.2	4.1	194	11.8	124
6	13	100	80.24	4.47	1.148	0.10	21	1.00	0.19	0.00	3.1	8.2	17	2.1	2.6	125	7.7	78
7	14	200	180.64	4.52	0.804	0.07	25	1.23	0.23	0.00	3.9	9.6	20	2.5	4.4	157	9.2	119
8	15	200	193.44	4.57	0.711	0.10	19	0.99	0.19	0.01	3.1	7.4	16	2.0	4.0	111	7.8	103
9	16	200	190.24	4.55	0.631	0.10	17	0.90	0.19	0.24	2.8	6.6	14	1.9	4.1	103	7.3	96
10	17	100	104.24	4.63	0.839	1.23	23	1.23	0.24	0.36	3.3	9.8	21	2.2	5.0	140	10.8	150
11	22	100	69.54	4.55	0.922	0.19	27	1.42	0.25	0.21	3.6	11.3	26	2.3	4.7	164	11.9	170
12	24	100	100.34	4.56	1.048	0.42	29	1.64	0.29	0.03	4.2	11.9	26	2.5	4.8	191	12.5	129
13	30	100	81.14	4.42	1.163	<0.01	33	1.74	0.29	0.01	4.1	13.9	31	2.3	4.9	258	13.4	201
14	37	100	79.44	4.47	1.157	0.19	33	1.73	0.31	0.01	4.1	13.4	30	2.4	4.6	215	12.9	204
15	68	100	56.06	4.43	1.413	<0.01	44	2.35	0.43	0.02	5.1	19.0	41	2.9	4.2	302	16.1	249
16	70	100	55.22	4.46	1.261	<0.01	44	2.13	0.37	0.02	4.5	17.6	36	2.5	4.2	284	14.1	235
17	72	100	87.77	4.51	1.286	<0.01	41	2.12	0.38	0.02	4.6	18.0	35	2.6	4.3	263	13.8	232
SAND SUBFRACTION (DS)																		
1	1	200	113.64	4.46	NA	<0.01	32	1.20	0.21	0.05	5.7	12.6	22	5.4	4.3	158	10.9	116
2	3	90	81.04	4.29	1.137	0.02	38	1.48	0.24	<0.01	5.8	15.1	29	5.1	4.8	195	13.3	128
3	6	100	65.74	4.61	1.450	0.24	49	2.03	0.30	0.03	6.6	19.1	41	6.0	4.9	273	15.6	163
4	8	100	82.04	4.56	1.620	<0.01	55	2.26	0.32	<0.01	7.0	20	46	5.7	4.5	327	16.0	161
5	10	100	77.94	4.53	1.703	0.33	59	2.55	0.37	0.01	7.4	22	51	5.7	4.6	371	16.7	170
6	13	100	84.74	4.54	1.775	0.11	65	2.95	0.36	0.02	7.2	25	62	5.9	4.9	423	19.0	322
7	14	200	176.24	4.57	1.536	<0.01	49	2.35	0.28	0.03	5.8	18.6	47	4.4	4.1	342	14.9	282
8	15	200	188.44	4.62	1.481	0.19	42	2.18	0.26	0.03	5.4	16.0	41	3.8	4.0	285	14.4	272
9	16	200	191.34	4.63	1.361	0.13	40	2.15	0.26	0.04	5.3	14.9	40	3.6	3.9	283	14.2	267
10	17	100	120.34	4.63	1.440	1.28	40	2.27	0.27	0.06	5.3	15.6	43	3.0	4.2	289	15.2	254
11	22	100	72.44	4.66	1.635	0.24	47	2.77	0.25	0.10	5.7	18.5	61	3.3	4.7	350	16.3	288
12	24	100	97.84	4.53	1.981	0.60	54	3.33	0.28	0.04	6.5	22	72	3.6	5.0	442	18.0	318
13	30	100	75.24	4.49	2.082	<0.01	54	3.25	0.24	0.04	7.1	22	78	3.4	4.5	542	17.2	315
14	37	100	77.14	4.52	2.097	0.19	55	3.44	0.20	0.07	7.6	22	82	3.5	4.5	471	17.3	327
15	68	100	20.60	4.42	NA	<0.01	54	4.04	0.40	0.06	8.5	24	84	3.6	3.3	532	14.7	346
16	70	100	78.04	4.57	2.170	<0.01	50	3.80	0.34	0.06	7.6	24	77	3.2	3.9	534	16.3	343
17	72	100	78.75	4.54	2.368	<0.01	60	4.29	0.36	0.04	8.4	27	84	3.6	4.4	561	18.5	353

NA Not analyzed.

Table 21. - Results from columns containing wet-screened, gravel and sand subfractions of flood plain tailings

Cycle	Day leachant, added	Volume added, mL	Volume recovered, mL	pH	EC millimohs/ cm	Elements, mg/L												
						Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn
GRAVEL SUBFRACTION (WG)																		
1	1	100	1 ⁰															
2	2	100	127.6	5.57	0.692	5.57	28	0.65	0.04	<0.01	4.2	15.1	11.7	4.3	4.1	106	7.6	93
3	5	100	66.5	5.20	0.673	<0.01	25	0.63	0.07	<0.01	3.7	13.6	11.0	3.2	4.2	96	7.2	88
4	7	100	87.4	4.88	0.655	<0.01	24	0.62	0.08	<0.01	3.5	12.9	10.5	2.8	4.3	92	7.1	86
5	9	100	99.5	5.02	0.570	<0.01	24	0.62	0.08	<0.01	3.6	12.5	10.5	2.6	4.5	91	7.5	85
6	12	100	47.4	5.00	0.568	0.01	21	0.59	0.26	0.11	3.2	10.6	8.9	2.2	4.1	79	6.7	72
7	13	200	175.2	4.89	0.369	0.28	13.6	0.37	0.04	0.01	2.3	7.3	6.3	1.6	3.6	56	4.7	55
8	14	200	175.5	5.21	0.324	<0.01	12.3	0.34	0.05	0.02	2.2	6.5	5.6	1.4	4.0	51	4.6	50
9	15	200	192.9	5.01	0.308	<0.01	11.5	0.32	0.04	0.05	2.2	6.1	5.3	1.4	4.4	48	4.7	48
10	16	100	128.1	4.89	0.425	0.05	15.7	0.44	0.08	0.05	2.8	8.6	7.4	1.7	5.7	66	6.7	63
11	21	100	66.5	4.87	0.457	<0.01	17.3	0.48	0.10	<0.01	3.0	9.1	8.2	1.7	5.4	71	7.3	69
12	23	100	104.4	NA	0.484	<0.01	18.6	0.51	0.10	<0.01	3.3	9.7	8.8	1.7	5.7	78	8.1	74
13	30	100	62.0	4.91	0.541	0.20	21	0.63	0.31	0.03	3.6	10.6	9.7	2.1	5.4	82	8.6	77
14	36	100	71.8	4.67	0.548	<0.01	21	0.60	0.11	0.01	3.5	11.0	10.2	1.8	5.1	88	8.6	82
15	39	100	28.0	4.55	NA	0.05	39	1.15	0.22	0.09	6.2	20.2	19.3	3.3	4.2	150	8.8	140
16	68	100	90.3	4.86	0.509	0.04	20	0.57	0.07	0.08	3.0	10.3	9.9	1.7	4.5	82	8.0	79
17	70	100	103.5	4.66	0.548	0.04	20	0.64	0.07	<0.01	3.1	11.3	11.0	1.7	4.9	95	8.7	88
SAND SUBFRACTION (WS)																		
0	Draining		546.4	5.63	0.954	0.02	41	0.98	0.05	<0.01	6.6	22	19.4	4.9	3.9	156	8.5	130
1	1	100	90.5	5.13	1.045	0.02	45	1.12	0.07	0.07	7.0	23	24	4.9	4.6	179	10.4	143
2	2	100	105.7	5.01	1.180	5.01	49	1.26	0.06	0.02	7.5	25	29	5.1	4.7	196	11.5	158
3	5	100	69.1	5.09	1.239	<0.01	50	1.33	0.06	<0.01	7.2	26	34	5.0	4.4	203	11.6	164
4	7	100	80.7	4.77	1.306	<0.01	53	1.41	0.08	<0.01	7.4	27	36	4.9	4.6	215	12.1	173
5	9	100	86.0	4.98	1.195	<0.01	54	1.47	0.08	<0.01	7.7	28	38	4.6	4.6	223	12.6	177
6	12	100	55.6	4.90	1.263	0.02	52	1.42	0.27	0.07	7.0	26	37	3.7	4.3	214	11.8	165
7	13	200	178.6	4.89	0.998	0.36	44	1.29	0.12	0.01	6.6	22	31	2.7	4.2	192	11.2	165
8	14	200	181.6	5.32	0.828	0.29	35	1.11	0.09	0.01	5.9	17.5	24	2.0	4.2	157	10.5	144
9	15	200	192.6	4.93	0.750	<0.01	30	1.01	0.09	0.04	5.4	14.7	21	1.7	4.4	140	10.1	133
10	16	100	106.0	4.87	0.817	<0.01	31	1.08	0.11	0.05	5.4	16.0	22	1.9	5.2	150	11.0	137
11	21	100	61.8	4.84	0.944	0.04	37	1.28	0.09	<0.01	6.3	18.5	31	2.0	5.5	176	13.1	158
12	23	100	86.6	NA	0.999	0.01	41	1.36	0.09	<0.01	6.6	19.8	32	2.1	5.4	193	13.4	169
13	30	100	55.5	4.82	1.169	<0.01	43	1.44	0.06	<0.01	7.0	21	36	2.1	4.9	198	13.7	175
14	36	100	61.7	5.04	1.256	<0.01	50	1.65	0.08	0.04	7.5	24	42	2.3	5.0	243	14.9	200
15	39	100	18.5	4.44	NA	0.10	67	2.55	0.10	0.11	10.1	35	63	3.1	3.7	326	13.4	267
16	68	100	99.6	4.78	1.441	0.10	56	2.22	0.09	0.09	7.7	29	50	2.4	4.4	293	15.8	241
17	70	100	96.9	4.48	1.386	0.09	51	2.17	0.10	<0.01	7.4	27	46	2.2	4.3	295	15.7	236

NA Not analyzed.

¹ No leachate recovered.

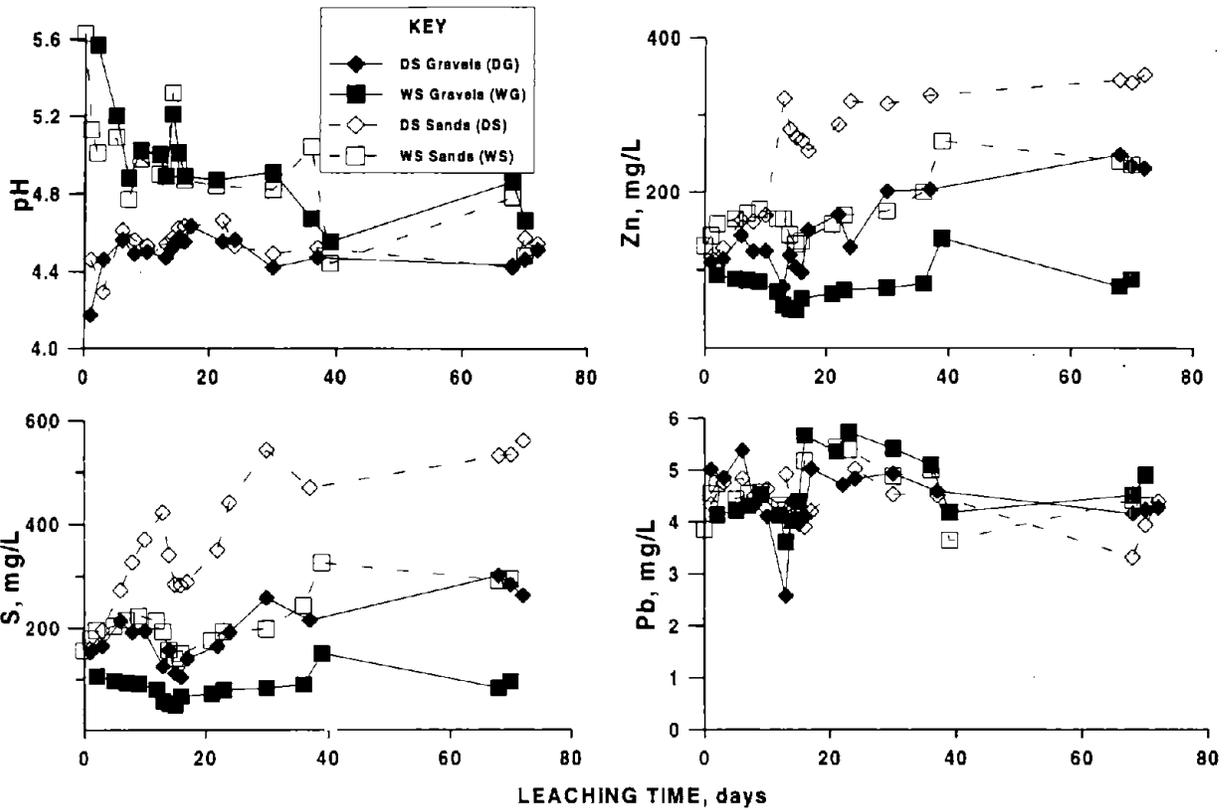


Figure 12.—Results of column leaching tests on gravel and sand subfractions of flood plain tailings.

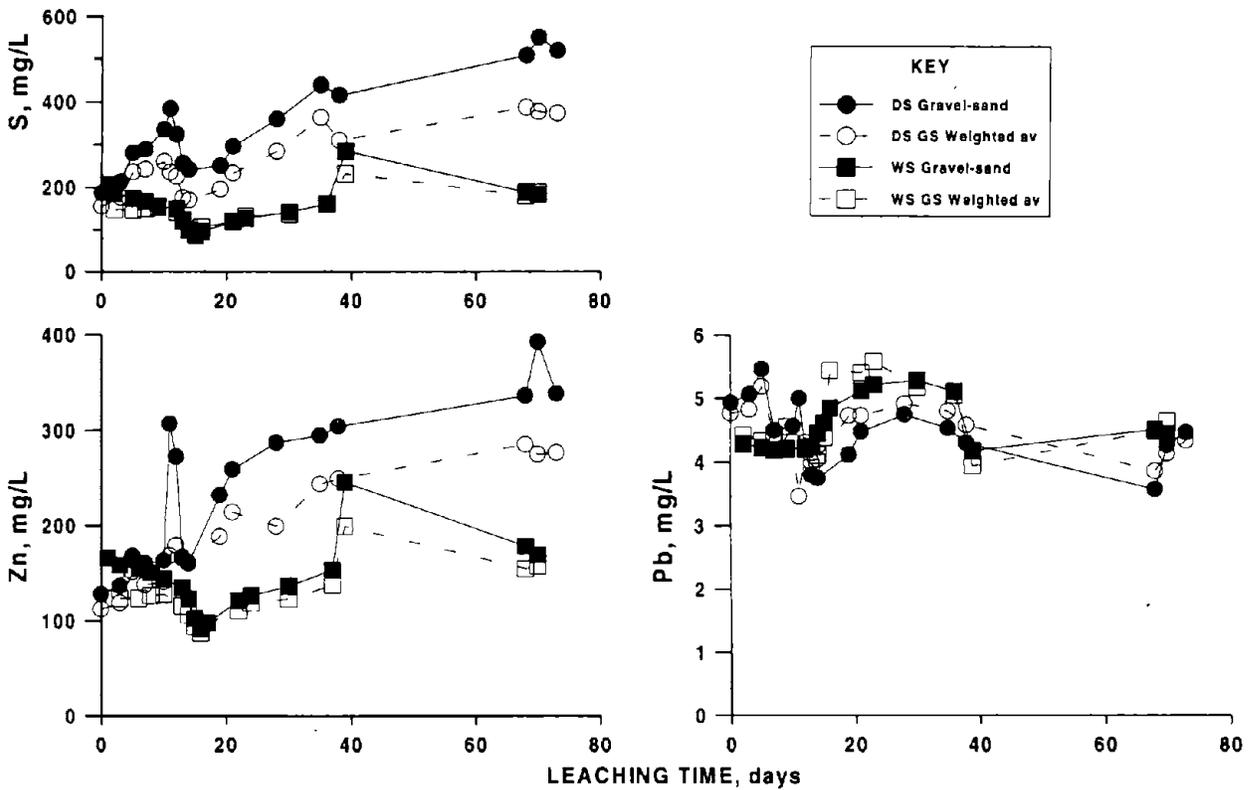


Figure 13.—Effect of damp screening on column release of damp- and wet-screened, gravel-sand fractions of flood plain tailings. Weighted-average concentrations of gravel and sand subfractions based on mass distribution (63%:37% for damp-screened subfractions and 54%:46% for wet-screened subfractions).

DISCUSSION

How metal release is affected by physically separating mine-waste-contaminated soils is the result of complex interactions between physical and biogeochemical factors. Consider a column of pure mineral that has been ground into a spectra of particle sizes. The overall retention of water in the column will depend not only on the retention of water around each individual particle, but the distribution of particle sizes, which will affect the retention of water between particles. If the mineral is a sulfide, the overall oxidation kinetics within the column can be calculated based on particle-size spectra, and an oxygen-diffusion- and surface-area-specific rate equation (Scharer and others, 1994) given ideal conditions. Now consider separating a large amount of this sample into fractions based on size ranges and placing these fractions into columns equal in height to the original sample. In the column containing the coarsest fraction, oxygen diffusion will be maximized because of the air spaces between particles, but water retention will be minimized. In the finest fraction, water retention will be maximized and oxygen diffusion will be minimized. Given ideal conditions, one could estimate the effect that separation will have on the overall rate of oxidation in the fractions compared to the rate of oxidation in the original sample.

However, fluvially deposited tailings are not ideal particles, nor are they single minerals. Different separation processes break up conglomerates to different extents, which makes predicting the resulting size distribution difficult. If these conglomerates are not separated efficiently, fine particles may stick to the surfaces of the coarsest particles. Fine particles in the column containing the coarsest material will increase the retention of water. In addition, different minerals may be concentrated in different size fractions. If the products of reaction from one size fraction are attacking different minerals in other fractions, separating the fractions may reduce the overall release of critical elements. It is probable that the reactivity of a component within a size fraction is not ideally additive and affected by the presence, size, and reactivity of other minerals. The following discussion will highlight instances where the nonadditive behavior of metal release after size separation can be utilized for remediation purposes. Bulk physical factors, such as retention of fines on the coarsest fraction, will be correlated with nonadditive behavior. More detailed geochemical modeling of the behavior of metal release observed in these experiments is beyond the scope of this report.

EXTENT AND MODE OF RELEASE

Prior to examining the effects of physical separation on metal release, the extent and mode of release from different materials should be examined. For the alluvium and reworked tailings, which seemed to contain a large fraction of alluvial cobbles and gravel, the extent of metal release (in milligrams of metal per kilogram of solid) was much less than metal release from the flood plain tailings (table 22). This observation cannot be attributed solely to the effects of pH because the pH of the leachate from the Canyon Creek alluvium was similar to the pH of the flood plain tailings. The low amounts of Al and Si released from the Canyon Creek material suggest that dissolution of gangue minerals did not occur, probably because of the pH of the leachate (>4.5).

Release of metals from columns occurs either through dissolution of secondary minerals present in the material collected from the field or through oxidation of sulfide minerals. Releases during the static tests provided some indication of the amounts of readily dissolvable metals since sulfide mineral oxidation is relatively slow. Therefore, the ratio of release during column experiments to release during static tests provides some information about which process dominates in a column leaching experiment. If the ratio is less than 1, then all the soluble salts have not have been washed from the column at the end of the experiment. On the other hand, if the ratio is greater than 1, then oxidation of sulfide minerals must be responsible for some of the release. This simplistic approach is somewhat complicated when the pH of the static and column leachates is dramatically different (i.e., the one pH unit difference for the wet-screened, coarser fraction of alluvium).

The ratio was much less than 1 for all three types of Canyon Creek material (table 23). This finding would suggest that flushing of soluble salts was the primary process controlling metal release from the Canyon Creek material. The ratio of column release to static release for the damp-screened, gravel-sand fraction was the closest to unity (0.85). The increases in Zn and S concentrations following drier periods, which is characteristic of sulfide oxidation (Doepker, 1991), were most apparent for the column containing the damp-screened, gravel-sand fraction. The Ca:Zn ratio of the leachates from the static and column leaching tests was similar for most columns. This would suggest that ion exchange between Ca and Zn did not dramatically affect the above interpretation.

Table 22.—Summary of metals release from column leaching tests

Sample type	Screening process	Size fraction, mm	Liquid:solid ratio, L/kg	Average pH	Element, mg/kg													
					Al	Ca	Cd	Cu	Fe	K	Mg	Mn	Na	Pb	S	Si	Zn	
Alluvium	None	-50	0.33	4.85	0.08	5.9	0.29	0.06	0.07	1.0	2.0	0.6	1.0	0.5	19	2.7	14	
Reworked tailings	None	-50	0.35	6.02	0.04	11	0.20	0.02	0.02	0.9	3.1	0.6	1.3	0.6	26	6.7	15	
Flood plain tailings:																		
Composite	None	-19.5	0.27	4.75	0.5	16	0.72	0.07	0.01	1.4	6.3	10.8	1.2	1.3	103	4.3	73	
Gravel-sand	Damp	-19.5 + 2	0.26	5.15	0.4	12	0.61	0.08	0.04	1.4	5.0	10.9	1.0	1.1	83	4.1	59	
Gravel-sand	Wet	-19.5 + 2	0.39	5.61	0.3	13	0.43	0.05	0.01	1.8	7.1	6.8	1.1	1.7	60	4.0	55	

Table 23.—Ratios of column release to static release

Sample type	Element			
	Cd	Pb	S	Zn
Alluvium	0.70	0.72	0.40	0.64
Reworked tailings	0.49	0.13	0.27	0.49
Flood plain tailings:				
Composite	0.50	0.10	0.42	0.61
Wet-screened gravel-sand	0.52	0.09	0.31	0.53
Damp-screened gravel-sand	0.58	0.14	0.38	0.86

EFFECTS OF ALTERING PHYSICAL PROCESSES

In the first part of the following discussion on the effects of size separation, factors affecting metal release are reviewed by comparing releases between the material and its sized fraction *having the same solid mass*. Reductions in metal release from a site resulting from size fractionation are examined conceptually without requiring the removal of any solid material from the site. Damp screening of material allows the effects of altering physical processes on metal release to be examined. Such processes include the flow of water through the column (i.e., residence time). However, the effects of physical factors are minimized if damp-screened separation is ineffective. The presence of a significant amount of fines on the coarser fractions leads to water retention. While the 1% to 2% of the fines retained by the alluvium and reworked coarser fraction probably did not affect physical factors to any appreciable extent, the 15% of the fines found in the gravel-sand fraction of the flood plain tailings fraction probably did influence physical factors.

Metal release from the segregated fractions was compared to the release from the composite sample.

$$\text{Percentage of reduction} = \left\{ \frac{(X_c R_c + X_f R_f)}{R_{com}} - 1.0 \right\} \times 100, \quad (1)$$

where R is metal release during the experiment in milligrams per kilogram, X is the mass fraction, and the subscripts c, f, and com represent the coarser fraction, the finer fraction, and the composite, respectively. A 0% reduction indicates no change and 100% reduction is no on-site metal release. Since both the wet-screened and the dry-screened gravel-sand fraction were further separated into the sand and gravel subfractions by damp screening, a similar calculation in the reduction of metal release can be made.

$$\text{Percentage of reduction} = \left\{ \frac{(X_g R_g + X_s R_s)}{R_{gs}} - 1.0 \right\} \times 100, \quad (2)$$

where the subscripts g, s, and gs represent the gravel subfraction, and sand subfraction, and the gravel-sand fraction, respectively.

When the releases of Cd, Pb, S, and Zn from the alluvium and flood plain tailings composites and the two gravel-sand

fractions of flood plain tailings were compared to the weighted-average release from columns containing their damp-screened, size-segregated components (table 24), only marginal reductions in metal release were observed (up to 25% for Cd, S, and Zn). For the reworked tailings, damp screening resulted in increases in Pb and S releases of 33% and 20%, respectively. The results of these comparisons of metal releases of several different types of material with the damp-screened fractions of the same material indicate that changes in physical processes associated with particle size did not significantly control metal release in the column leaching experiments.

GEOCHEMICAL EFFECTS OF WET SCREENING

The effects of separating the finer fractions of the alluvium and reworked tailings after wet screening were estimated by calculating the weighted average of metal release from the wet-screened, segregated fractions.

When releases from the columns containing materials were compared to the weighted-average releases from columns containing their wet-screened components, there were generally significant reductions. These reductions were a result of changes in physical processes associated with particle size (the same as those observed with the damp-screened fractions), flushing of soluble salts during the wet-screening process, and the biogeochemical nature of the interactions between the solution and the solids. The weighted-average Zn release from the segregated columns was between 34% and 71% lower than the release from the material from which it was segregated (table 24).

Although column leaching experiments cannot predict the absolute values of metal release under field conditions, column experiments can predict trends. Examination of the possible causes of these reductions may provide some insight into how far into the future these reductions will continue. The effect of flushing soluble salts during the wet-screening process (i.e., soil washing) has been presented. When releases during the wet-screening process were added to the releases during column leaching, releases of Zn from the wet-screened fractions of Canyon Creek flood plain tailings and alluvium were within 15% of those of the respective composites (equation 3).

$$\text{Percentage of reduction} = \left\{ \frac{(X_c R_c + X_f R_f + R_p)}{R_{com}} - 1.0 \right\} \times 100. \quad (3)$$

The same trend held true for the reworked tailings from Canyon Creek. As shown above, the results of damp screening suggest that physical processes associated with particle size reduce metal releases by only marginal amounts.

Results from the columns containing the wet-screened, fine fraction of Canyon Creek flood plain tailings illustrate two factors associated with wet screening that tend to reduce metal

Table 24.—Reductions in metal release from columns with and without removing finer fraction, percent

Process	Solids removed	Element				Equation
		Cd	Pb	S	Zn	
PROCESSED BY DAMP SCREENING						
Alluvium		-22	-32	-4	-11	1
Reworked tailings		-20	33	20	-0	1
Flood plain tailings:						
Composite		-13	-7	-14	-15	1
Wet-screened gravel-sand		-2	24	-4	3	2
Damp-screened gravel-sand		-24	-9	-20	-24	2
PROCESSED BY WET SCREENING¹						
Alluvium		-83	-72	-27	-71	1
Reworked tailings		-55	-52	30	-34	1
Flood plain tailings composite		-49	27	-28	-41	1
PROCESSED BY WET SCREENING²						
Alluvium		11	-45	234	1	3
Reworked tailings		-45	-35	100	-24	3
Flood plain tailings composite		2	108	146	15	3
FINER FRACTION REMOVED BY DAMP SCREENING						
Alluvium	14	-50	-47	-47	-43	4,5
Reworked tailings	53	-88	-65	-87	-85	4,5
Flood plain tailings:						
Composite	23	-33	-24	-37	-36	6,7
Damp-screened gravel-sand	37	-56	-41	-59	-56	8
Wet-screened gravel-sand	46	-77	-57	-77	-75	8
FINER FRACTION REMOVED BY WET SCREENING						
Alluvium	23	-81	-48	-88	-64	9,10
Reworked tailings	53	-92	-50	-95	-87	9,10
Flood plain tailings composite	35	-69	-60	-88	-66	7,11

¹Does not include metals released during wet-screening separation.

²Includes metals released during wet-screening separation.

release (figure 9). The uptake of Ca^{2+} and Mg^{2+} during the wet-screening process buffered the pH of the tailings by augmenting subsequent ion exchange between the divalent cations and H^+ during the column leaching tests. The significant increases in Zn releases after the long dry period suggest that saturation of the soils (a result of loading the columns as a slurry) may have prevented penetration of oxygen into the columns. These same results suggest that these factors will affect metal releases only for a short time after remediation of a site. The ion-exchange capacity of the wet-screened flood plain tailings was exhausted after only 20 days of leaching. If exchanges of Ca^{2+} and Mg^{2+} were occurring in columns containing other materials (i.e., finer fraction of the alluvium), the ion-exchange capacity had not yet been depleted at the end of the experiment. If a slurry of fine flood plain tailings produced from wet screening is placed in the vadose-like hydrologic setting of a repository, the interstitial waters will eventually drain, leading to greater oxygen penetration. Also, washout of the biological communities that accelerate sulfide mineral oxidation during wet screening may initially limit metal release. However, this effect is likely to be temporary also.

Washing of S from all Canyon Creek materials was primarily responsible for reductions in S release in the wet-screened size fractions. S release from the three Canyon Creek solids during both wet screening and the column experiments was much greater than releases from the respective composite (2 to 3.3 times greater). This observation is

consistent with the conclusion that the soluble salts from all the Canyon Creek composite materials had not been washed from the columns during these experiments. Much of the reduction in Cd release from the wet-screened fractions was a result of soil washing, with the exception of the reworked tailings.

Pb release from all materials was low (table 22). For the flood plain tailings, wet screening increased subsequent Pb release during the column experiments (table 24). As shown with the Nine Mile Creek material, Pb release from flood plain tailings is controlled by the solubility of anglesite (Paulson and others, 1996). Therefore, reductions in S concentrations lead to higher Pb concentrations and release. Pb concentrations in the processing water were comparable to those in the leachate of the column experiments. Because of the higher liquid-to-solids ratio inherent in the wet-screening process, greater amounts of Pb were released during wet screening than during the column leaching tests.

EFFECTS OF REMOVING MORE REACTIVE FRACTION

The experiments indicate that a disproportionate reduction in metal release would occur by removing the more reactive material from the site. In the following calculations, the effects of the oversized material were considered. The reductions in release as a result of changing the physical processes observed in the column leaching experiments are not valid for

a composite sample that includes oversized material. Therefore, the effects of metal release resulting from altering physical processes were ignored, and it is likely that the following estimates underestimate releases from the composite sample containing the oversized material and underestimate decreases in metal release.

Metal release from a composite sample containing material larger than 50 mm was examined using metal releases from the segregated fractions. In the cases of the alluvium and reworked tailings, release from the oversized material was assumed to be equal to metal release from the coarser fraction. Therefore—

$$R = (X_{oz} + X_c)R_c + X_f R_f \quad (4)$$

where the subscript oz represents the oversized material. The reduction in metal release from removal of the finer fraction was calculated based on metal release from the oversized and coarser fraction remaining on the site.

$$\text{Percentage of reduction} = \{[(X_{oz} + X_c)R_c/R] - 1.0\} \times 100, \quad (5)$$

where 0% reduction is no change and 100% reduction is no on-site metal release. For the Canyon Creek flood plain tailings, the small mass fraction of the +50-mm material was ignored, and release from the oversized fraction (-50 +19.5 mm) was included.

$$R = X_{oz} R_{oz} + X_c R_c + X_f R_f, \quad (6)$$

The reduction was calculated as—

$$\text{Percentage of reduction} = \{[(X_{oz} R_{oz} + X_c R_c)/R] - 1.0\} \times 100. \quad (7)$$

The Canyon Creek alluvium and reworked tailings composite samples contained a substantial amount of the naturally weathered rock and therefore less metals were released compared to the amount released from the flood plain tailings. For these two materials, significant reductions in on-site release of metals were estimated by removing the finer fraction after damp screening. Removing the -2-mm fraction of the alluvium composite after damp screening, which contributed 14% of the overall mass, was estimated to reduce S, Zn, Cd, and Pb releases by 43% to 50%. However, recall that the -2-mm material formed clay balls during damp screening. This observation suggests that damp screening could present an engineering challenge. It is estimated that damp screening and removing the tailings-like material (-19.5-m material) would remove 53% of the mass of the reworked tailings and reduce on-site releases of S, Cd, and Zn by about 85% and on-site release of Pb by 65%.

In contrast, smaller decreases in metal release are expected after the fine fraction of the flood plain tailings have been removed by damp screening. Removing the -2-mm Canyon Creek tailings material, which makes up 23% of the overall mass, only decreased S, Cd, and Zn releases by 37% and Pb release by 24%. Releases from the two gravel subfractions, which were also separated by damp screening, were compared directly with their respective damp-screened and wet-screened, gravel-sand (-19.5 +2 mm) fractions in a manner similar to that calculated in equation 2..

$$\text{Percentage of reduction} = [(X_g R_g/R_g) - 1.0] \times 100. \quad (8)$$

For the damp-screened, gravel-sand fraction that had no contact with water, removing the sand (-4.8 +2 mm) subfraction, which constituted 37% of the mass, resulted in decreases in S, Cd, and Zn releases by about 57% and Pb release by 41%. Removing the sand subfraction from the wet-screened, gravel-sand fraction by damp screening decreased S, Cd, and Zn releases by about 76% and Pb release by 57%. The greater reduction in releases from the wet-screened, gravel-sand fraction relative to the damp-screened, gravel-sand fraction was partially a result of more efficient separation. More mass (46%) was removed as sand from the gravel-sand fraction that had been initially wet screened than from the gravel-sand fraction that had been initially damp screened (37%). Also, fewer fines were found in the wet-screened, gravel subfraction (0.3%) than in the damp-screened, gravel subfraction (17%) (table 5). Biogeochemical changes brought about by the initial wet-screening process may have continued to affect the release of metals even after the wet-screened, gravel-sand fraction was further separated by damp screening.

The effects of removing the finer fractions of the alluvium and reworked tailings after wet screening were also estimated by calculating the metal release from the segregated wet-screened fractions, assuming that the oversized material had the same release rate as the coarser fraction. As when arriving at the estimates from damp screening, the decreases from altering physical processes were ignored, and some assumptions were required concerning the +50-mm oversized material that was not tested. In these calculations, it was assumed that the oversized material did not release significant amounts of metals into the processing water. Therefore, the release of an element during the wet-screening process (R_p) was decreased by the mass fraction of the oversized material, X_{oz} . The estimated total release from a composite sample was calculated as follows:

$$R = (X_{oz} + X_c)R_c + X_f R_f + (1 - X_{oz}) R_p. \quad (9)$$

The equation for percentage reduction is—

$$\text{Percentage of reduction} = \{[(X_{oz} + X_c)R_c/R] - 1.0\} \times 100. \quad (10)$$

The decrease in metal release from alluvial material resulting from removing the finer fraction by wet screening was greater than the decreases resulting from damp screening (table 24). These more significant decreases in releases were largely a result of soil washing and greater efficiency of removal of fines during wet screening. In contrast, the decreases of metal release from the reworked tailings as a result of wet screening were only slightly lower than the decreases as a result of damp screening. The similar amounts of fines attached to the two coarser fractions of the reworked tailings (table 5) may have resulted in a similar release from the damp- and wet-screened, coarser fraction of the reworked tailings (figure 6).

For the flood plain tailings, the small amount of +50-mm material was again ignored. The release from a -50-mm composite sample was calculated as follows:

$$R = X_{oz} R_{oz} + X_c R_c + X_f R_f + R_p \quad (11)$$

No correction to R_p needs be made because the oversized material was included in the wet-screened material. The decrease in metal release was calculated according to equation 7. Decreases of 60% to 70% in on-site releases of S, Zn, and Cd as a result of removing the wet-screened, -2 mm tailings, which made up 35% of the total mass, were calculated. The initial decreases in metal releases may be underestimated because the effects of particle size and biogeochemical changes as a result of the wet screening were ignored. On the other hand, these calculations may have overestimated the long-term benefits of wet screening, since the calculations are affected by biogeochemical changes that may be temporary.

CONCLUSIONS

The releases of metals and S from columns containing three types of material collected mostly from the saturated zone of the Canyon Creek flood plain were examined. Samples of alluvium were collected below the organic layer thought to be the original ground surface before mining began. The alluvium is composed mostly of alluvial gravels, but the finest fraction had higher concentrations of metals, the origin of which is not known. Reworked tailings were collected from gravel bars within the stream bed. The composition of the reworked tailings is approximately 50% alluvial cobbles and 50% tailings. Flood plain tailings were collected above the organic layer.

Leaching from historic mine wastes occurs through dissolution of soluble secondary minerals or through the effects of oxidation of sulfide minerals. Metal releases from the alluvium and reworked tailings during a 72 day, 17-leaching-column test in which a wet period and a dry period were incorporated were much less than releases from flood plain material thought to be primarily mine tailings. In all three types of columns, dissolution of secondary minerals was the predominant mode of release as determined by the ratio of metal release during column leaching tests to metal release during static tests.

The effects of damp and wet screening on the release of metals and S from each of these three types of material were examined by comparing release from the composite to average release from the coarser and finer fractions, weighted by the fraction's mass contribution to the composite. Conceptually, this comparison would represent the process of screening material and leaving all solids on-site. Only the physical processes associated with particle size were altered as a result of damp screening, and metal releases from all three column types were decreased by less than 25%. Thus, damp screening as the sole remediation process would provide few benefits.

In addition to altering physical processes associated with particle size, wet screening introduces changes in the biogeochemical interactions between solids and solution. Such biogeochemical processes include (1) flushing of soluble secondary salts from the system with the processing water (soil washing), (2) uptake of Ca^{2+} and Mg^{2+} from tap water during the wet-screening process, which subsequently buffers the pH of the column through ion exchange between divalent cations and H^+ , (3) saturation of the column with water, which reduces oxygen penetration into the column, and (4) washout of the organisms that enhance sulfide mineral oxidation. Wet screening reduced Cd, Zn, and S releases in this experiment between 25% and 85%, except for a 30% increase in S release from reworked tailings.

Of these four effects of wet-screening, only the effects of soil washing could be directly calculated from data collected in these experiments. When dissolution into the processing water was considered, the overall releases of Zn from the wet-screened alluvium and flood plain tailings were within 15% of Zn releases from the composite materials. Even after accounting for the amount of Zn released into the processing water, Zn release from the wet-screened reworked tailings was 24% less than Zn release from the composite. Wet-screening released greater quantities of S than released from the columns. The larger volume of water per mass of solids used in the wet-screening process relative to the volume used in the column leaching experiments explains this result. The lesser amount of S released during the column leaching experiment was consistent with the finding that soluble S had not been flushed from the columns during the 17 leachings.

The releases of Pb from the wet-screened alluvium and reworked tailings fractions were 45% and 35% less than releases from the composite after accounting for soil washing. In contrast, more Pb was released from Canyon Creek flood

plain tailings as a result of wet screening. Earlier examination of the saturation indices of minerals for solutions leached from Nine Mile Creek flood plain tailings indicated that anglesite solubility controlled Pb concentrations in leachates (Paulson and others, 1996). Similar examinations of the geochemistry of leachates from the Canyon Creek flood plain tailings are beyond the resources available for this experiment. However, the results of these experiments, corroborated by theoretical calculations, indicate that wet screening of tailings can lead to dramatic decreases in S, which in turn can lead to increases in soluble Pb.

Many of the changes in biogeochemical interactions brought about by wet screening may be only temporary. The ion-exchange capacity of the solids is replenished by uptake of divalent cations from tap water, but this capacity is exhausted over time because of inherent acid production by the solids. The decrease in pH (i.e., increase in H^+) in the wet-screened, fine tailings was accompanied by a decrease in divalent cation release. The effects of loading the columns as a slurry were diminished over time as the vadose-like columns began to drain. Again, the increase in Zn release from the wet-screened, fine tailings after the dry periods suggests such a phenomenon. Once alluvium, reworked tailings, and flood plain tailings from the saturated zone are displaced into the vadose-like zone of an uncapped mine waste repository, higher rates of oxidation would probably occur over periods longer than the duration of this experiment.

Regardless of the changes in physical and biogeochemical factors as a result of screening, removal of the more reactive size fraction can lead to disproportionate decreases in metal release. The greatest benefits of selective removal are found when there is a significant difference in the nature of the solids removed compared to those left on-site. The alluvium and reworked tailings are prime candidates for selective removal. When 14% of the alluvium was removed as -2-mm fines by damp screening, releases of S and metal decreased by about

50%. The effects of more efficient separation and soil washing by wet screening led to decreases in releases of 64% and 81% for Zn and Cd, respectively, when 23% of the solids was removed as fines. The decreases in Pb release from all materials were less than the decreases in S, Cd, and Zn releases. Damp screening of the reworked tailings led to decreases in metal releases approaching 90% when 50% of the solids was removed as -19.5-mm material. Little improvement was observed following wet screening. The relatively clean boulders and cobbles left on-site could be used for riparian restoration. When the characteristics of different size fractions of soils impacted by mine waste differ dramatically, removal of the more reactive finer fraction results in disproportionate decreases in metal releases.

Decreases in metal releases with the removal of flood plains tailings were not as dramatic as were decreases from the alluvium and reworked tailings. Damp screening and removing 23% of the flood plain tailings as -2-mm fines decreased Zn and Cd releases by about 35%. Wet screening resulted in the removal of 35% of the mass and decreased Zn and Cd releases by about 65%. Metal releases from the sand subfraction (-4.8 +2 mm) were also found to be greater than metal releases from the gravel subfraction (-19.5 +4.8 mm).

The characteristics of the different size fractions of the Canyon Creek flood plain tailings do not differ as dramatically as the characteristics of the alluvium and reworked tailings. Therefore, the benefits of selective removal by size fraction were not as dramatic. Removal of 35% of the mass as -2-mm material resulted in decreases in release of about 65%. To obtain decreases in metal release by 90% requires removing 70% of the material as -4.8-mm sands and fines by wet screening. Unless savings in transportation costs warrant the additional costs of screening and water treatment, on-site disposal of the coarser fraction is not warranted in light of our lack of knowledge of the long-term effects of biogeochemical processes that tend to reduce initial metal release rates.

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APPENDIX A

Table A-1. Metal concentrations of the size fractions of alluvium, reworked tailings and flood plain tailings not included in composite samples, weight percent

Sample	Depth range, cm	Sample type	Size interval, mm	Elements, wt pct										
				Al	Ca	Cu	Fe	K	Mg	Mn	Na	Pb	S	Zn
A2	0-51	Alluvium	-2	7.34	0.30	0.01	3.23	2.32	0.33	0.11	1.90	0.47	0.10	0.46
A2	0-51	Alluvium	-50 + 2	6.11	0.10	0.00	3.03	2.49	0.32	0.07	2.14	0.18	0.20	0.55
C22	64-127	Alluvium	-2	7.31	0.27	0.00	1.53	2.30	0.29	0.01	2.46	0.03	0.0	0.33
C22	64-127	Alluvium	-50 + 2	6.64	0.19	0.00	1.35	2.51	0.21	0.01	2.18	0.03	0.0	0.12
A26	64-127	Alluvium	-2	6.24	0.23	0.01	2.29	2.12	0.26	0.05	1.63	0.07	0.14	0.03
A26	64-127	Alluvium	-50 + 2	6.60	0.24	0.00	2.57	2.57	0.25	0.05	1.21	0.00	0.24	0.02
D26	51-127	Tailing, alluvium	-19.5	7.77	0.11	0.00	2.84	3.13	0.22	0.04	2.53	0.12	0.05	0.06
D26	51-127	Tailing, alluvium	-50 + 19.5	7.39	0.86	0.00	3.60	3.58	0.26	0.04	3.10	0.00	0.03	0.04
C34	0-76	Reworked	-19.5	6.00	0.10	0.01	5.47	2.07	0.25	0.39	1.84	2.74	1.64	1.47
C34	0-76	Reworked	-50 + 19.5	4.40	0.04	0.00	3.36	1.73	0.16	0.48	1.10	0.36	0.68	0.86
B2	?	Tailings	-2	4.77	0.22	0.02	6.98	1.73	0.23	0.20	0.36	2.61	1.37	1.62
B2	?	Tailings	-50 + 2	5.45	0.19	0.02	4.56	2.06	0.17	0.19	2.19	0.85	1.31	0.78
B20	?	Tailings	-2	6.13	0.18	0.00	1.59	2.21	0.24	0.02	0.69	0.02	0.03	0.04
B20	?	Tailings	-50 + 2	4.90	0.09	0.00	2.30	1.71	0.16	0.03	0.86	0.00	0.07	0.02

Table A-2. Metal concentrations of the size fractions of alluvium, reworked tailings, and flood plain tailings included in composite samples

Sample	Depth range, cm	Size interval, mm	Elements, wt pct											Mass fraction %
			Al	Ca	Cu	Fe	K	Mg	Mn	Na	Pb	S	Zn	
Alluvium														
A14	64-76	-2	7.25	0.11	<0.01	2.71	2.99	0.31	0.02	2.61	0.05	0.1	0.23	38.4
A4	152-178	-2	7.48	0.17	<0.01	2.03	2.81	0.26	0.08	2.64	0.20	<0.1	0.11	14.8
B18	25-76	-2	6.79	0.26	<0.01	1.14	2.58	0.24	0.02	2.78	0.06	<0.1	0.03	29.8
B36	102-178	-2	7.44	0.21	<0.01	2.18	2.56	0.25	0.03	2.37	0.04	<0.1	0.03	38.8
PP1	38-102	-2	7.07	0.15	<0.01	2.11	2.78	0.22	0.04	2.26	0.10	<0.1	0.08	14.3
A40	123-152	-2	7.17	0.20	<0.01	2.11	2.78	0.26	0.15	2.49	0.19	<0.1	0.06	27.5
B24	38-152	-2	6.01	0.10	<0.01	1.83	2.00	0.18	0.10	2.06	0.06	<0.1	0.04	14.4
A14	64-76	-50 + 2	6.90	0.07	<0.01	2.30	2.69	0.34	0.01	2.71	0.04	0.1	0.05	61.6
A4	152-178	-50 + 2	5.21	0.08	<0.01	2.92	2.26	0.10	0.42	2.26	0.05	<0.1	0.04	85.2
B18	25-76	-50 + 2	5.92	0.29	<0.01	1.25	2.29	0.21	0.03	1.99	0.04	0.1	0.04	70.2
B36	102-178	-50 + 2	6.73	0.11	<0.01	2.40	2.69	0.23	0.05	2.85	0.04	<0.1	0.02	61.2
PP1	38-102	-50 + 2	6.71	0.09	<0.01	2.01	2.64	0.23	0.04	2.66	0.05	<0.1	0.02	85.7
A40	123-152	-50 + 2	6.56	0.21	0.02	2.08	2.94	0.24	0.03	2.12	0.03	<0.1	0.12	43.2
B24	38-152	-50 + 2	6.25	0.09	<0.01	1.69	2.23	0.20	0.04	2.00	0.01	<0.1	0.02	72.2
Reworked tailings														
C24 ¹	0-91	-19.5	4.98	0.15	0.01	4.97	2.00	0.20	0.24	0.50	0.76	0.5	0.48	48.5
C4	0-76	-19.5	6.40	0.44	0.01	4.91	2.48	0.25	0.30	2.34	0.55	0.4	0.48	28.5
D18	0-64	-19.5	6.72	0.26	0.01	5.09	2.69	0.28	0.21	2.04	0.67	0.3	0.37	37.5
C12	0-25	-19.5	5.86	0.20	0.01	3.84	2.15	0.22	0.18	1.25	1.02	0.7	0.37	37.3
CO	0-25	-19.5	5.94	0.30	0.01	3.06	2.55	0.21	0.11	1.63	0.14	0.2	0.15	26.3
D22	0-76	-19.5	5.62	0.35	0.01	5.00	2.25	0.28	0.31	2.02	1.62	0.7	0.34	28.5
C24	0-91	-50 + 19.5	5.17	0.08	0.01	1.60	2.09	0.17	0.02	0.92	0.05	<0.1	0.03	51.5
C4	0-76	-50 + 19.5	6.32	0.16	<0.01	1.86	2.21	0.20	0.02	2.81	0.02	<0.1	0.05	19.2
D18	0-64	-50 + 19.5	6.85	0.09	<0.01	1.78	2.59	0.12	0.02	2.17	0.02	0.1	0.04	62.5
C12	0-25	-50 + 19.5	5.88	0.06	<0.01	1.74	2.21	0.22	0.02	1.89	0.02	0.1	0.02	62.7
CO	0-25	-50 + 19.5	5.14	0.08	<0.01	2.08	2.12	0.14	0.04	1.03	0.00	0.1	0.02	73.7
D22	0-76	-50 + 19.5	5.67	0.15	<0.01	2.18	1.94	0.14	0.07	1.52	0.02	0.1	0.04	71.5
Flood plain tailings														
A12	0-51	-2	4.50	0.11	0.01	9.49	1.89	0.19	0.15	0.44	4.62	1.1	0.22	28.4
A30	0-51	-2	4.79	0.10	0.03	5.58	1.77	0.17	0.29	0.31	2.41	1.6	1.95	40.3
A8	0-51	-2	5.88	0.35	0.02	6.00	2.19	0.27	0.26	1.67	2.05	0.3	0.40	52.4
A20 ²	0-127	-2	5.87	0.14	0.04	4.12	2.49	0.21	0.17	3.18	1.74	0.5	0.20	7.8
A28	0-64	-2	4.91	0.25	0.03	5.61	1.89	0.29	0.22	1.97	3.63	1.0	0.76	29.0
A38	0-64	-2	6.20	0.14	0.02	6.32	2.24	0.21	0.23	3.45	3.84	1.4	0.62	14.3
C10	0-64	-2	5.58	0.19	0.04	5.59	1.91	0.25	0.18	3.09	3.97	1.5	1.35	27.2
N0	76-114	-2	3.87	0.27	0.01	11.54	1.67	0.19	0.19	1.73	2.96	0.8	0.17	40.4
B24	0-25	-2	5.61	0.15	0.01	4.39	2.02	0.19	0.08	0.39	1.72	0.4	0.24	51.6
C08	0-51	-2	4.61	0.21	0.05	8.38	1.68	0.20	0.21	0.32	5.65	1.8	1.57	
A12	0-51	-50 + 2	3.97	0.05	<0.01	2.13	1.69	0.09	0.05	0.22	0.17	0.1	0.08	71.6
A30	0-51	-50 + 2	4.16	0.06	<0.01	2.26	1.89	0.14	0.08	0.17	0.26	0.3	0.32	59.7
A8 ³	0-51	-50 + 2	5.65	0.26	0.03	5.29	2.43	0.27	0.31	1.22	1.10	0.6	0.52	47.6
A20	0-127	-50 + 2	6.01	0.06	<0.01	2.55	2.57	0.20	0.06	2.97	0.22	0.2	0.09	92.2
A28	0-64	-50 + 2	4.43	0.98	0.02	3.90	1.57	0.42	0.15	2.99	0.34	0.4	0.23	71.0
A38	0-64	-50 + 2	5.89	0.07	<0.01	2.10	2.42	0.19	0.07	1.79	0.20	0.2	0.20	43.6
C10	0-64	-50 + 2	7.39	0.08	<0.01	2.42	3.28	0.19	0.07	3.39	0.23	0.2	0.32	72.8
N0	76-114	-50 + 2	5.50	0.16	<0.01	5.17	2.54	0.23	0.10	2.28	0.89	0.2	0.05	59.6
B24	0-25	-50 + 2	5.36	0.07	<0.01	3.00	2.01	0.15	0.09	0.43	0.30	0.4	0.46	48.4
C08	0-51	-50 + 2	5.43	0.09	<0.01	6.11	2.01	0.19	0.31	0.15	0.93	1.2	1.74	

¹ Cd = 26 ppm

² Cd = 76 ppm

³ Cd + 95 ppm.

Table A-3. Leachates from alluvium composite and damp-screened fractions not analyzed for metals

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/ cm
		added	recovered		
ALLUVIUM COMPOSITE (DA1)					
18	79	225	37.25	4.71	
19	86	225	151.38	4.81	0.541
20	91	225	83.94	4.87	1.259
21	99	225	49.16	4.64	
22	102	225	132.52	4.69	0.528
23	103	225	188.06	4.84	0.513
24	104	450	357.77	4.75	0.459
25	105	450	386.77	4.67	0.392
26	106	450	506.17	4.82	0.349
27	109	225	120.70	4.92	0.342
28	113	225	96.10	5.02	0.361
29	116	225	120.70	4.92	0.342
30	119	225	125.44	5.31	0.378
31	124	225	53.51	5.61	
32	144	225	72.24	4.86	
DAMP-SCREENED, COARSER ALLUVIUM (DA2)					
18	79	225	99.05	4.95	0.172
19	86	225	186.63	5.89	0.155
20	91	225	136.43	5.49	0.299
21	99	225	66.04	4.88	
22	102	225	31.02	5.83	
23	103	225	50.44	6.31	
24	104	450	83.24	6.52	0.137
25	105	450	74.48	6.59	0.131
26	106	450	187.36	6.55	0.119
27	109	225	158.37	6.68	0.118
28	113	225	96.18	6.63	0.116
29	116	225	158.37	6.68	0.118
30	119	225	97.96	6.38	0.104
31	124	225	24.58	6.51	
32	144	225	72.04	7.18	
DAMP-SCREENED, FINER ALLUVIUM (DA3)					
18	79	225	4.87	4.65	
19	86	225	124.15	4.48	1.052
20	91	225	57.02	4.55	1.145
21	99	225	18.85	4.28	
22	102	225	117.85	4.43	1.077
23	103	225	189.01	4.47	1.043
24	104	450	403.14	4.48	0.953
25	105	450	414.08	4.44	0.855
26	106	450	417.76	4.46	0.787
27	109	225	111.48	4.43	0.739
28	113	225	113.37	4.51	0.771
29	116	225	111.48	4.43	0.739
30	119	225	129.10	4.45	0.763
31	124	225	65.62	4.78	
32	144	675	129.93	4.29	0.930

Table A-4. Leachates from wet-screened alluvium and reworked tailings not analyzed for metals

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/ cm
		added	recovered		
COARSER ALLUVIUM FRACTION (WA2)					
18	77	225	168.4	6.06	0.057
19	84	225	123.3	5.42	0.126
FINER ALLUVIUM FRACTION (WA3)					
18	77	225	16.4	6.56	
19	84	225	85.8	3.96	0.410
COARSER REWORKED TAILINGS FRACTION (WR2)					
18	77	225	154.6	5.35	0.117
19	84	225	167.7	6.35	0.054
FINER REWORKED TAILINGS FRACTION (WR3)					
18	77	225	27.3	6.67	
19	84	225	123.9	6.68	1.389

Table A-5. Leachates from original reworked tailings composite and damp-screened fractions not analyzed for metals

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/cm
		added	recovered		
REWORKED TAILINGS COMPOSITE (DR1)					
18	79	225	67.24	6.20	0.559
19	86	225	166.40	6.08	0.512
20	91	225	95.50	6.02	0.673
21	99	225	72.48	5.96	0.548
22	102	225	149.14	6.09	0.527
23	103	225	196.55	6.38	0.497
24	104	450	411.94	6.30	0.394
25	105	450	421.61	6.25	0.358
26	106	450	421.61	6.19	0.307
27	109	225	120.04	6.47	0.354
28	113	225	128.56	6.25	0.346
29	116	225	120.04	6.47	0.354
30	119	225	147.92	6.11	0.376
31	124	225	104.24	6.06	0.383
32	144	450	206.70	6.21	0.400
COARSER REWORKED TAILINGS FRACTION (DR2)					
18	79	225	142.08	6.52	0.069
19	86	225	187.45	6.50	0.071
20	91	225	152.80	6.49	0.238
21	99	225	149.58	6.11	0.309
22	102	225	180.15	6.56	0.073
23	103	225	202.66	6.61	0.071
24	104	450	430.74	6.52	0.063
25	105	450	424.08	6.60	0.057
26	106	450	434.41	6.56	0.050
27	109	225	171.67	6.73	0.064
28	113	225	169.72	6.68	
29	116	225	171.67	6.73	0.064
30	119	225	167.86	6.64	0.077
31	124	225	75.56	6.65	0.082
32	144	225	182.67	6.75	0.800
FINER REWORKED TAILINGS FRACTION (DR3)					
18	79	225	47.16	6.29	0.751
19	86	225	146.89	6.17	0.723
20	91	225	76.96	6.08	0.909
21	99	225	41.56	5.81	
22	102	225	137.99	6.30	0.734
23	103	225	188.08	6.46	0.753
24	104	450	404.69	6.28	0.673
25	105	450	429.95	6.32	0.692
26	106	450	425.97	6.26	0.642
27	109	225	119.78	6.41	0.541
28	113	225	126.72	6.38	0.533
29	116	225	119.78	6.41	0.541
30	119	225	139.74	6.17	0.048
31	124	225	92.89	6.21	0.476
32	144	225	278.51	6.21	

Table A-6. Leachates from original flood plain tailings composite not analyzed for metals.

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/cm
		added	recovered		
OM1					
18	75	100	44.13	4.63	2.810
19	79	100	71.28	4.49	2.721
20	82	100	57.38	4.61	2.810
21	84	100	71.41	4.69	2.730
22	86	100	75.07	4.63	2.982
23	89	100	44.72	4.82	
24	89	200	159.89	4.71	2.550
25	90	200	194.98	4.65	2.630
26	91	200	189.86	4.75	2.380
27	92	100	110.54	4.65	2.411
28	97	100	50.64	4.58	
29	99	100	74.34	4.58	2.628
30	106	100	34.37	4.63	
31	109	100	18.17	4.38	
32	145	300	120.36	4.53	3.025
OM2					
18	75	100	39.26	4.56	3.090
19	79	100	69.46	4.51	3.114
20	82	100	52.91	4.55	3.090
21	84	100	73.29	4.64	3.050
22	86	100	74.87	4.55	3.132
23	89	100	41.18	4.65	
24	89	200	176.89	4.63	2.850
25	90	200	203.49	4.65	2.540
26	91	200	181.77	4.68	2.110
27	92	100	110.43	4.70	2.148
28	97	100	39.12	4.53	
29	99	100	77.77	4.54	2.318
30	106	100	28.32	4.47	
31	109	100	12.63	4.33	
32	145	300	112.66	4.55	2.771

**Table A-7. Leachates from damp-screened,
gravel-sand fraction of flood plain tallings
not analyzed for metals.**

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/ cm
		added	recovered		
DGS1					
18		100	46.25	4.38	2.070
19	79	100	73.16	4.38	1.431
20	82	100	60.87	4.45	2.010
21	84	100	74.58	4.54	1.948
22	86	100	82.05	4.51	1.957
23	89	100	55.16	4.69	1.940
24	89	200	180.44	4.71	1.742
25	90	200	211.25	4.79	1.598
26	91	200	187.88	4.84	1.462
27	92	100	124.28	4.49	1.773
28	97	100	55.68	4.08	1.746
29	99	100	83.79	4.15	1.699
30	106	100	50.47	4.26	1.777
31	109	100	37.25	4.27	
32	145	250	86.86	4.54	2.142
DGS2					
18	75	100	45.66	4.44	1.750
19	79	100	76.65	4.40	2.157
20	82	100	58.20	4.48	2.500
21	84	100	75.10	4.52	2.450
22	86	100	83.58	4.44	2.439
23	89	100	49.77	4.62	2.380
24	89	200	174.23	4.50	1.889
25	90	200	207.43	4.53	1.672
26	91	200	186.08	4.58	1.467
27	92	100	110.43	4.42	1.767
28	97	100	50.35	4.29	
29	99	100	86.22	4.38	1.899
30	106	100	43.70	4.34	
31	109	100	33.63	4.31	
32	145	300	125.86	4.36	2.365

Table A-8. Leachates from wet-screened fractions of flood plain tailings not analyzed for metals.

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/ cm
		added	recovered		
GRAVEL-SAND (WGS1)					
18	73	100	73.8	4.64	0.991
19	77	100	98.0	4.63	0.899
20	80	100	83.8	4.69	0.865
21	82	100	93.5	4.68	0.791
22	84	100	101.3	4.70	0.748
GRAVEL-SAND (WGS2)					
18	73	100	71.3	4.63	0.928
19	77	100	92.0	4.63	0.859
20	80	100	78.0	4.68	0.821
21	82	100	88.3	4.73	0.798
22	84	100	98.5	4.69	0.000
GRAVELS (WG)					
18	73	100	66.4	4.74	0.590
19	77	100	101.9	4.76	0.520
20	80	100	75.2	4.82	0.481
21	82	100	88.9	4.78	0.479
22	84	100	110.7	4.78	0.474
SANDS (WS)					
18	73	100	68.7	4.63	1.448
19	77	100	92.8	4.60	1.321
20	80	100	81.6	4.63	1.257
21	82	100	87.8	4.68	1.181
22	84	100	93.8	4.58	1.200
FINES (WF1)					
18	73	100	76.4	5.34	1.237
19	77	100	89.4	4.93	1.412
20	80	100	89.1	4.77	1.160
21	82	100	91.7	4.77	1.161
22	84	100	87.7	4.55	1.386
FINES (WF2)					
18	73	100	71.8	4.43	2.250
19	77	100	87.6	4.04	2.177
20	80	100	86.2	4.06	2.190
21	82	100	88.7	4.10	1.973
22	84	100	85.7	4.14	2.080

Table A-9. Leachates from damp-screened, gravel and sand subfractions of flood plain tailings not analyzed for metals

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/cm
		added	recovered		
GRAVEL SUBFRACTION (DG)					
18	75	100	58.87	4.44	1.344
19	79	100	82.82	4.39	0.897
20	82	100	68.88	4.48	1.296
21	84	100	80.32	4.53	1.226
22	86	100	87.10	4.44	1.193
23	89	100	65.18	4.64	1.122
24	89	200	188.90	4.60	0.833
25	90	200	212.30	4.63	0.687
26	91	200	188.95	4.65	0.621
27	92	100	102.09	4.49	1.126
28	97	100	66.66	4.50	0.807
29	99	100	89.62	4.47	0.845
30	106	100	63.34	4.32	0.959
31	109	100	58.85	4.28	1.053
32	145	200	97.96	4.42	1.167
SAND SUBFRACTION (DS)					
18	75	100	51.25	4.31	2.660
19	79	100	78.20	3.84	1.018
20	82	100	61.21	4.43	2.530
21	84	100	77.62	4.46	2.550
22	86	100	84.82	4.41	2.560
23	89	100	52.12	4.58	2.530
24	89	200	183.76	4.59	2.220
25	90	200	211.99	4.72	1.918
26	91	200	188.46	4.61	1.674
27	92	100	111.98	4.59	1.582
28	97	100	55.23	4.47	
29	99	100	88.03	4.49	1.644
30	106	100	52.54	4.51	
31	109	100	40.45	4.42	
32	145	250	72.36	4.52	2.314

Table A-10. Leachates from damp-screened fine, fraction of flood plain tailings not analyzed for metals

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/ cm
		added	recovered		
DF1					
18	75	100	22.65	3.84	
19	79	100	67.53	4.34	1.733
20	82	100	40.54	3.91	4.050
21	84	100	66.54	4.02	4.140
22	86	100	78.19	3.99	4.417
23	89	100	25.36	4.12	
24	89	200	171.94	4.32	4.210
25	90	200	198.83	4.64	3.880
26	91	200	183.87	4.65	3.300
27	92	100	114.53	4.58	3.197
28	97	100	26.63	4.44	
29	99	100	83.15	4.33	2.958
30	106	100	22.29	4.23	
31	109	100	6.48	4.09	
32	145	300	111.36	4.59	2.507
DF1					
18	75	100	29.21	4.00	
19	79	100	69.53	3.88	2.681
20	82	100	49.03	3.93	3.760
21	84	100	85.02	3.94	3.830
22	86	100	79.35	3.89	4.106
23	89	100	28.39	4.06	
24	89	200	174.90	4.06	3.740
25	90	200	198.77	4.24	3.060
26	91	200	185.19	4.31	2.480
27	92	100	125.26	4.26	2.572
28	97	100	42.91	4.11	
29	99	100	82.62	4.06	2.538
30	106	100	28.13	4.00	
31	109	100	17.58	3.95	
32	145	300	111.34	4.54	4.111

Table A-11. Leachates from oversized flood plain tailings not analyzed for metals

Cycle	Time leachate added, days	Volume, mL		pH	EC, millimohs/cm
		added	recovered		
DAMP-SCREENED (DTOS)					
18	75	225	162.12	4.68	0.209
19	79	225	187.61	4.61	0.212
20	82	225	184.05	4.65	0.167
21	84	225	188.55	4.71	0.182
22	86	225	193.93	4.63	0.188
23	89	225	161.72	4.72	0.181
24	89	450	440.04	4.70	0.126
25	90	450	427.74	4.72	0.126
26	91	450	432.45	4.72	0.154
27	92	225	215.67	4.75	0.997
28	97	225	170.90	4.63	0.217
29	99	225	194.18	4.62	0.167
30	106	225	167.09	4.58	0.168
31	109	225	147.07	4.57	0.160
31a	125	225	124.19	5.04	0.147
32	145	225	129.16	4.49	0.142
WET-SCREENED (WTOS)					
18	73	225	195.8	4.80	0.181
19	77	225	203.6	4.73	0.177
20	80	225	207.1	4.73	0.172
21	82	225	209.3	4.76	0.179
22	84	225	103.9	4.73	0.178