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Final

**Phase II Investigation:
In Situ Reduction of Lead
Bioaccessibility in Soils,
Trail, British Columbia**

Prepared for

Trail Lead Program
Trail, British Columbia



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Prepared for

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Acronyms and Abbreviations

CEC	cation exchange capacity
EDS	energy-dispersive spectrometry
EMPA	electron microprobe analysis
FC	field capacity
HFO	hydrous ferric oxide
ICP	inductively coupled plasma
PBET	physiologically based extraction test
PWP	permanent wilting point
QA	quality assurance
QC	quality control
SPLP	synthetic precipitate leaching procedure
TCP	tri-basic calcium phosphate
TOC	total organic carbon
WDS	wavelength-dispersive spectrometry
XRF	x-ray fluorescence

Executive Summary

The goal of the Phase II investigation was to identify a soil amendment that would lower the risk posed to humans by lead-bearing soil surrounding Cominco's lead/zinc smelter in Trail, British Columbia, without increasing the risk posed by arsenic and cadmium that are also found in the site soils. The studies described below were conducted to accomplish this goal.

Stage 1—Baseline Geochemistry

The soil substrate that would be used in subsequent stages was characterized to provide a baseline against which to assess amendment effectiveness. In addition to determining the total lead, arsenic, and cadmium concentrations in this soil, the amounts of leachable lead, arsenic, and cadmium in the soil were measured using the synthetic precipitation leachate procedure (SPLP; EPA 1995). The fraction of lead, arsenic, and cadmium that would be available for adsorption by the body if that soil were ingested (i.e., the bioaccessible fraction) was measured using the physiologically based extraction procedure (PBET; Ruby et al. 1996; Medlin 1997).

Stage 2—Variable Concentration Tests

PTI's Phase I investigation indicated that the soil amendments—hydrous ferric oxide (HFO), phosphoric acid, and tri-basic calcium phosphate (TCP)—had the potential to meet the study goals. In addition, Cominco has been using Celgar Residual, an organic soil amendment product, to improve the agricultural properties of site soils in areas being revegetated. These four amendments were mixed—alone and in various combinations—with a composite site soil and water to form a slurry. Each slurry was aged for several days and then dried. The dried soils were subjected to the PBET and SPLP to determine which combination would achieve the lowest lead bioaccessibility without raising the bioaccessibility of arsenic or cadmium, or the leachability of any of the three contaminants.

The most effective amendment of all those tested (5 wt % iron and 0.5 wt % phosphorus as TCP) reduced lead bioaccessibility by 66 percent relative to the unamended soil. This amendment also lowered the arsenic bioaccessibility (61 percent reduction) and the lead and arsenic leachability, while having little effect on the cadmium bioaccessibility or leachability.

The Celgar amendment generally resulted in a slight decrease in the bioaccessibility of, and an increase in the leachability of, lead, arsenic, and cadmium. When used in conjunction with iron (as HFO) and phosphate (as either TCP or phosphoric acid), Celgar

Residual tended to lower both the leachability and bioaccessibility of lead and arsenic. However, the leachability and bioaccessibility of cadmium were slightly increased.

Stage 3—Long-Term Amendment Tests

The purpose of these tests was to determine if soil weathering would influence the effectiveness of the most promising amendments. To accomplish this, soils treated with six different amendment formulations were placed in humidity cells, which simulate natural wet-dry cycles and accelerate the soil weathering process. The treated soils and untreated control were analyzed using the PBET and SPLP after 0, 28, 56, 86, and 116 days of weathering.

Of all the soil amendments tested, soils amended with 0.5 wt % phosphorus as TCP and 5 wt % iron as HFO had the lowest average lead bioaccessibility over the course of the 116-day monitoring period (28 percent, compared to 66 percent for the unamended soil, which amounts to a reduction of 57 percent). This amendment also lowered the arsenic bioaccessibility from 98 percent to 28 percent, and had little effect on the cadmium bioaccessibility. It lowered the lead leachability from 3.4 mg/kg to 1.6 mg/kg and the arsenic leachability from 7.2 mg/kg to 1.7 mg/kg. Cadmium was not detected in any of the SPLP extracts during the long-term testing. These data indicate that this amendment was the most effective of all those tested. After an initial sharp reduction, the lead bioaccessibility increased slightly during the testing period. A similar trend was observed in the unamended soil, indicating that within the certainty of the test, this amendment appeared to provide a stable reduction in lead bioaccessibility.

The effectiveness of a 25 wt % application of Celgar Residual was also tested, both with and without 0.5 wt % phosphorus (as phosphoric acid) and 5 wt % iron (as HFO). As with the Stage 2 tests, the phosphorus- and iron-bearing Celgar Residual amendment proved the most effective of the Celgar Residual-bearing amendments at lowering the leachability and bioaccessibility of both lead and arsenic. However, the bioaccessibility of cadmium was increased in the soil sample that received this amendment. Cadmium was not leached from either of the two soils receiving the Celgar amendments during any of the SPLP tests that were performed during the long-term study.

Adsorption Capacity Study

Previous investigations suggested that addition of phosphorus to soils could enhance the leachability of arsenic from soils, possibly endangering the groundwater quality beneath the amended soils. The purpose of the adsorption capacity test was to determine whether the arsenic released from amended soils during SPLP tests would be re-adsorbed onto naturally occurring HFO that is found at depth in the B-horizon soils. The arsenic concentration of the SPLP extract was reduced from 0.53 to <0.05 mg/L when mixed with B-horizon soil at a 1:19 soil-to-water ratio, indicating that downward migration of the released arsenic would be limited by adsorption. However, when B-horizon soils were contacted by the leachate produced from SPLP testing of soils amended with Celgar

Residual, additional cadmium was released from the B-horizon soils. Similar, though less dramatic, results were observed when B-horizon soils were contacted with stock SPLP solution and with SPLP leachate of soils amended with phosphorus and iron.

Grass Sensitivity Study

This study was conducted to determine whether the soil amendments would inhibit grass growth. Grass planted in soils amended with the most successful amendment (0.5 wt % phosphorous as TCP and 5 wt % iron as HFO) was as likely to germinate and thrive as was grass planted in unamended soils.

Historical Phosphate-Application Site Sampling

Until recently, the Cominco facility also had a phosphate fertilizer manufacturing and distribution plant onsite. With this readily available source of phosphate fertilizer, many areas surrounding the plant may have historically received generous amounts of phosphate fertilizer, and soils from these areas could be used to assess the long-term effectiveness of phosphate-based amendments. Although several of the soils collected during this investigation contain phosphate concentrations equal to or greater than those tested during Stages 2 and 3, little to no reduction in lead bioaccessibility was evident in these soils. These results suggest that phosphate alone may not decrease lead bioaccessibility over the long term.

Conclusions

Results of the Phase II study indicate that the most effective soil amendment is one consisting of 5 wt % iron as HFO and 0.5 wt % phosphorus as TCP. This amendment successfully lowered soil lead bioaccessibility in both short- and long-term testing. It also lowered arsenic bioaccessibility and reduced the leachability of both lead and arsenic. The amendment enhanced the leachability and bioaccessibility of cadmium, though, so it should not be used on soils containing high cadmium concentrations.

The results of the variable concentration tests and the adsorption capacity study provide some evidence that the Celgar Residual may increase the leachability of cadmium from the Trail soils. These results suggest that the Celgar Residual should not be used to amend Trail soils containing highly elevated cadmium concentrations because of the risk that subjacent groundwater could be affected. However, the apparent increase in cadmium leachability was not evident during the long-term testing of the Celgar Residual-amended soils.

Introduction

In the Phase I investigation performed by PTI and the University of Colorado for the Trail Lead Program (PTI 1997), four different phosphate and iron amendments were evaluated under simulated natural conditions to determine if any could be used to effectively lower lead bioavailability *in situ*.

The results of the investigation showed that phosphate, in conjunction with iron, may be an effective amendment for reducing the bioaccessibility of lead. However, the bench-scale study also revealed problems that need to be addressed before such amendments can be tested in the field. These problems include:

- Adding soluble phosphate amendments causes arsenic in soils to be released
- None of the amendments consistently lowered the lead bioaccessibility by more than two-fold
- The phosphate amendments appeared to be phytotoxic at the concentrations used in the Phase I study.

The Phase II study, described herein, was conducted to address these problems. Previous studies (Ma et al. 1993, 1995) found that successful formation of lead phosphate resulted from the reaction of soluble lead and synthetic hydroxylapatite or natural apatite in phosphate rock. Based on these results, the soil amendments used in this study included tricalcium phosphate (TCP) from ground phosphate rock, and higher concentrations of iron as hydrous ferric oxide (HFO) than were tested in Phase I. The addition of TCP provides a less soluble phosphate onto which lead phosphate can precipitate, and may also reduce the risk of releasing arsenic from the treated soil. TCP may also reduce the phytotoxicity of the amendment formulation by reducing soil salinity. Higher HFO application rates were used during the Phase II test to reduce the risk of arsenic release by providing more surface sites onto which arsenate can adsorb.

As in the Phase I investigation, the Phase II study proceeded in three stages: baseline characterization (Stage 1), variable concentration amendment studies (Stage 2), and long-term monitoring study (Stage 3). In addition to this work, adsorption capacity studies, grass sensitivity studies, and analysis of soils from historical phosphate-amended sites were also performed.

Stage 1—Baseline Geochemistry

Soils used during the Stage 1 investigation were collected in the Tadanac area during October 27–30, 1996 (Figure 1). This composite soil was characterized to establish a baseline against which changes in soil chemistry as a result of the amendments could be compared. Analyses included total organic carbon (TOC), soil conductivity (a measure of soil salinity), cation exchange capacity (CEC), pH, total metals by x-ray fluorescence (XRF), and total metals using U.S. EPA method 3050 and inductively coupled plasma (ICP) spectroscopy. The total metals analysis included aluminum, arsenic, cadmium, iron, and lead. The lead, arsenic, and cadmium bioaccessibility—a measure of their solubility in the human gastrointestinal environment—was determined using the physiologically based extraction test (PBET) described by Medlin (1997). The leachability of lead, arsenic, and cadmium was measured using the synthetic precipitation leachate procedure (SPLP; EPA method 1312).

Materials and Methods

Eight soil samples were collected within the Tadanac neighborhood of Trail, British Columbia and composited (Figure 1). The composite was prepared by drying, homogenizing, and sieving to obtain the <4.75-mm size fraction. The composite was then subjected to the same geochemical characterization as described in the Phase I investigation (PTI 1997) following the standard procedure described therein.

Results

The baseline characterization indicates that the soils have a conductivity of 0.34 mS/cm and soluble phosphorus concentrations of 290 mg/L (Table 1). The high soluble phosphorus concentrations may be due to the extensive fertilization of the Tadanac area for more than 18 years, as described in a later section on historical fertilizer application.

Lead was detected at 1,400 mg/kg in both the <2-mm and <250- μ m fractions when analyzed using XRD. However, the lead concentration in the <250- μ m fraction was only 577 mg/kg when analyzed by wet chemical methods (i.e., ICP), indicating that there is a highly recalcitrant lead form in this soil sample (one that remains insoluble even when extracted using concentrated nitric/hydrochloric acid and hydrogen peroxide). The bioaccessibility values presented here were calculated using the ICP data.

The unamended Phase II soil produced bioavailability values of 58 percent for lead, 91 percent for arsenic, and 46 percent for cadmium. The SPLP leachability values for the unamended soil were 2.4 mg/kg for lead, 4.7 mg/kg for arsenic, and <0.06 mg/kg for cadmium. Subsequent measurements of bioaccessibility and leachability were made in

later stages of the investigation, and those values are presented in their respective sections below.

Stage 2—Variable Concentration Study

The variable concentration study was performed to narrow the range of feasible amendments for long-term monitoring. In the variable concentration amendment tests, five different amendment types were used.

- Amendment No. 1: Phosphorus as tri-basic calcium phosphate (TCP; ground phosphate rock) and iron as HFO
- Amendment No. 2: Phosphoric acid (H_3PO_4) followed by 1:1 lime:calcium carbonate (CaCO_3), TCP, and iron as HFO
- Amendment No. 3: Iron as HFO
- Amendment No. 4: Organic residual (Celgar Residual)
- Amendment No. 5: Celgar Residual, TCP, and iron as HFO.

Celgar Residual is a composted by-product of the paper pulping process, and was provided by the Celgar Pulp Company. This company produces 10–20 tonnes/day of residual from its effluent treatment plant. In efforts to re-evaluate their waste management operations, Celgar is studying reuse of the residual as a soil amendment for revegetation work and the production of landscape soil. The residual is a mixture of pulped wood fibers and nutrient-rich microbial biomass. Celgar Residual was chosen for this study because of its favorable agronomic properties. It has been used in various revegetation efforts around the smelter facility, so it was included in this test matrix, both alone and in combination with the other proposed amendments.

The five amendments were applied to the composite soil at various rates (Table 2). The success of each amendment was assessed based on the decrease in lead bioaccessibility relative to the unamended soil. Successful amendments were those that decreased lead bioaccessibility without increasing lead, arsenic, or cadmium leachability, or arsenic bioaccessibility.¹ A decrease in leachability indicated that the amendment decreased the ability of the metals to be mobilized from the soil, and a decrease in bioaccessibility indicated that the amendment decreased the fraction of the soil metal that would be soluble in the human gastrointestinal tract.

¹ Values of cadmium bioaccessibility are presented for screening purposes only, because the *in vitro* bioaccessibility procedure has not yet been validated for cadmium.

Materials and Methods

Using the amendment rates shown in Table 2, 60 g of the composite soil was amended and placed in a 250-mL wide-mouth bottle, along with 60 mL of deionized water. The sealed bottles were then shaken in a horizontal shaker for 1 hour, and allowed to settle for 24 hours. Shaking and settling were repeated, and then the soil slurry was moved to a covered bowl and allowed to dry (2 to 3 days). The amended soils were then split—10 g was sieved to <250 μm for PBET analysis, and 50 g was used for SPLP testing. Lead, arsenic, and cadmium concentrations in the SPLP and PBET extracts were determined by ICP–atomic emissions photospectrometry (LEGS 1995).

Quality control (QC) samples were included in both the SPLP and PBET tests, including matrix spikes, blanks, and replicates (Appendix A). Instrument QC checks were also run during the ICP analysis to assess equipment contamination and instrument drift. The QC checks did not identify any problems that would compromise the quality of the analytical data.

Results

Lead, arsenic, and cadmium bioaccessibility from the amended soils was compared to the unamended soil.

$$\text{Bioaccessibility}_{\text{amended}}/\text{Bioaccessibility}_{\text{unamended}}$$

A value of <1 for the above ratio indicates that bioaccessibility was reduced. Alternatively, the percent reduction in bioaccessibility can be calculated using the following equation:

$$\text{Reduction in bioaccessibility} = \frac{(\text{Bioaccessibility}_{\text{unamended}} - \text{Bioaccessibility}_{\text{amended}}) \times 100}{\text{Bioaccessibility}_{\text{unamended}}}$$

The amounts of leachable lead, arsenic, and cadmium were estimated using U.S. EPA method 1312. These data were used to calculate the ratio of leachability from amended soil to that of unamended soil:

$$\text{Leachability}_{\text{amended}}/\text{Leachability}_{\text{unamended}}$$

A value of <1 for the above ratio indicates that leachability was reduced. Leachability can also be expressed in terms of a percent reduction, analogous to the above expression for calculating the percent reduction in bioaccessibility.

All of the amendments lowered soil lead bioaccessibility relative to the unamended soil (Table 3). The greatest reduction in lead bioaccessibility was achieved using Amendments 1-3 and 2-2, both mixtures of HFO and phosphorus (as either TCP or phosphoric acid). These amendments also successfully lowered the bioaccessibility of arsenic and cadmium, and the leachability of lead, arsenic, and cadmium. Although the

amendments that contained only iron were the most effective at lowering the arsenic bioaccessibility, these amendments were not as effective at lowering the lead bioaccessibility as were those containing both phosphate and iron.

When used as the sole amendment, the Celgar Residual lowered the soil lead bioaccessibility by 22, 24, and 6 percent when added at 15, 25, and 50 wt %, respectively. However, this amendment increased the leachability of lead, arsenic, and cadmium (particularly when added at 25 wt % or more). When used in conjunction with iron (as HFO) and phosphorus (as either TCP or phosphoric acid), the amendment lowered the bioaccessibility of both lead and arsenic, as well as the leachability of lead. Arsenic leachability was also lowered when the phosphate amendment rate was 1.75 wt % or less and the iron amendment was 2.5 wt % or greater. Cadmium bioaccessibility was slightly increased in all of the soils that received the Celgar Residual/phosphorus/iron amendment. Similarly, the leachability of cadmium was increased in these soils, although the relative increase was smaller as the phosphorus amendment rate decreased and the iron amendment rate increased.

Stage 3—Long-Term Monitoring Study

Based on the results of the Stage 2 tests, four different non-Celgar and two Celgar amendments were chosen for the long-term monitoring study. The non-Celgar amendments included:

- Amendment 1-3 (0.5 wt % phosphorus as TCP, and 5 wt % iron as HFO)
- Amendment 2-2 (0.15 wt % phosphorus as H₃PO₄, 0.35 wt % phosphorus as TCP, and 5 wt % iron as HFO)
- Amendment 2-4 (0.53 wt % phosphorus as H₃PO₄, 1.22 wt % phosphorus as TCP, and 2.5 wt % iron as HFO)
- Amendment 3-2 (5 wt % iron as HFO).

Amendments 1-3 and 2-2 were chosen because they had, overall, the lowest bioaccessibility and leachability ratios for their respective amendment type. Although Amendment 3-3 was slightly more effective than Amendment 3-2, the latter was chosen for use in the Stage 3 tests because it had a lower iron concentration (test results on Amendment 3-2 would be valuable if iron proved to be phytotoxic [see discussion in later section]). Amendment 3-2 contained the same amount of iron as the mixed phosphate-iron amendments that were being included in the Stage 3 tests, which would facilitate comparison among those amendments containing phosphate and those without phosphate.

The Celgar amendments chosen for the long-term monitoring study included:

- Amendment 4-2 (25 wt % Celgar Residual)
- Amendment 5-6 (0.5 wt % phosphorus as TCP, 5 wt % iron as HFO, and 25 wt % Celgar Residual).

These two amendments were chosen because they had the lowest overall ratios for bioaccessibility and leachability of their respective amendment types.

The composite soils were amended with each of the six amendments at the application rates shown above. The amended soils, plus an unamended (control) soil, were placed in humidity cells to evaluate the long-term effectiveness of the various amendments under a controlled environment. The humidity cells replicate natural climate conditions by regulating the wetting-evaporation rates.

The humidity cells were sampled four times over 120 days. The samples were tested for bioaccessibility and leachability, for comparison to the unamended soils (Tables 4 and 5).

Materials and Methods

The soils were amended by adding both the unamended soil and the amendment materials to humidity cells and then blending them using a latex-gloved hand. Soils amended with Amendment 4 (the Celgar Residual) were saturated with deionized water before adding the amendment to facilitate mixing.

Soils receiving Amendment 2 were first amended with phosphorus as phosphoric acid in a 1.0 M solution. Two hours following application of the phosphoric acid solution, CaOH/CaCO₃ was applied to achieve a neutral soil pH, and the samples were homogenized. After an additional hour, iron as HFO was added to the soils and homogenized. The HFO was precipitated from a solution of FeCl₃·6H₂O by adding NaOH, and rinsing the precipitate with deionized water (Dzombak and Morel 1990).

To accelerate the soil reaction processes, the soils were subjected to a weekly wet/dry cycle. The water added to the humidity cells once a week was a simulated combination of Trail tap and rain water; it was prepared by adding 60:40 H₂SO₄/HNO₃ to Boulder tap water to lower the pH to 4.5±0.1.

Sufficient water was added once a week to achieve the field capacity (FC) of the soil, which was measured a priori on a split of the composite. The samples were then allowed to dry to their permanent wilting point (PWP, measured using Watermark soil moisture meters). FC and PWP moisture levels were chosen to represent the two extremes of water conditions naturally found in soil (Birkeland 1984). To maintain homogeneous drying, the soils were stirred once a week.

The amended soils were sampled following 28, 56, 86, and 116 days of weathering, or approximately 4, 8, 12, and 17 wet/dry cycles, respectively. Sixty grams of amended soil was removed from the humidity cells for each sampling event. The sample was dried, 10 g was sieved to <250 μm for PBET testing, and 50 g was used for leachability testing.

QC protocols were followed, as described in Appendix A. To prevent cross contamination in sampling, a new latex glove was used for each amendment and sampling event. Precautions were also taken in drying, storing, and sieving the soils, to avoid contamination. The various QC checks did not identify any problems that would compromise the quality of the data produced.

Results

Lead, arsenic, and cadmium bioaccessibility and leachability were assessed using the methods described for Stage 2 investigation.

Lead

With the exception of Amendment 4-2, which contained 25 wt % Celgar Residual, all the amendments lowered both the bioaccessibility and leachability of soil lead relative to the unamended soil. Amendment 1-3 (0.5 wt % phosphorus as TCP and 5 wt % iron as HFO) was the most effective amendment (Table 6). Over the 116-day monitoring period, the soil-lead bioaccessibility was reduced from an average 66 percent in the unamended soil, to 28 percent in the soil receiving Amendment 1-3 (Table 6). This corresponds to a lead bioaccessibility reduction ratio of 0.43, or an average reduction in bioaccessibility of 57 percent relative to the unamended soil. Leachable lead concentrations were reduced from 3.4 mg/kg to below the detection limit (1.6 mg/kg) using this same amendment (Table 6), indicating that Amendment 1-3 was also quite effective at lowering the lead leachability.

The soil receiving 25 wt % Celgar had an average lead bioaccessibility that was only slightly lower than the unamended soil (62 vs. 66 percent, respectively), indicating that Celgar Residual alone does not provide an effective method of lowering either the lead bioaccessibility or lead leachability. However, when used in conjunction with iron and phosphate (Amendment 5-6), Celgar Residual did lower the soil-lead bioaccessibility to 34 percent and the soil-lead leachability to <1.2 mg/kg, from 66 percent and 3.4 mg/kg, respectively. While this does represent a substantial reduction in bioaccessibility and leachability, the Celgar Residual-HFO-phosphate formulation was not as effective as iron and phosphate used alone.

Arsenic

The amendment that was most effective at lowering the bioaccessibility of lead, Amendment 1-3, also lowered the arsenic bioaccessibility from 98 percent (unamended soil) to 28 percent. Amendment 1-3 also lowered the average arsenic leachability from 7.2 mg/kg (unamended soil) to 1.7 mg/kg.

Amendment 3-2 (5 wt % iron) was even more effective than Amendment 1-3 at reducing the bioaccessibility and leachability of arsenic. Average arsenic bioaccessibility in soil receiving this amendment was lowered to 16 percent (from 98 percent in the unamended soil), and average leachability was lowered from 7.2 mg/kg to <1.5 mg/kg (Table 6).

One concern with adding phosphate to soils containing elevated concentrations of arsenic is that it may increase the amount of arsenic that is available to leach to underlying groundwater. The added phosphate may effectively compete with arsenic for the limited number of soil sorption sites, resulting in a displacement of arsenic from these sites, and an increase in arsenic leachability. However, this effect was not evident during these tests. Amendments 1-3 and 2-2, which contained 0.5 wt % phosphorus as either TCP or phosphoric acid (and 5 wt % iron as HFO) released only slightly more arsenic during the SPLP test than did the soil containing HFO only. These data indicate that by adding the HFO, the amount of available sorption sites increased to the point where the competition between arsenic and phosphorus sorption sites becomes unimportant (i.e., sufficient sorption sites are available for both).

Cadmium

Although the bioaccessibility of cadmium generally increased slightly with the addition of amendments (Table 6), the cadmium concentration in the <250- μm fraction of the soils (14 mg/kg, Table 1) is below the level of concern if the soil were ingested (i.e., >50 mg/kg; BC Environment 1997). Therefore, this slight increase in cadmium bioaccessibility would not represent a significant risk.

Cadmium leachability did not increase with the addition of the amendments. It was below the detection limit (<0.06 mg/L) for all amended and unamended soils.

Cadmium bioaccessibility was generally unaffected by the amendments (Table 4), particularly following the initial sampling events, and the amendments had no discernible effect on cadmium leachability; therefore, cadmium is not included in the following discussions concerning long-term bioaccessibility and leachability trends.

Changes in Lead and Arsenic Bioaccessibility with Time

Lead bioaccessibility from all soils, including the unamended soil, generally was lowest immediately following amendment (i.e., at time "0" on Figure 2, which represents the data points collected during the Stage 2 test). This is consistent with the results of the Phase I investigation, and with investigations conducted at a smelter site in Murray, Utah (Sellstone 1996), both of which showed that the greatest reduction in lead bioaccessibility occurs immediately following amendment.

In this study, the lead bioaccessibility from soil samples collected 28 days following amendment was consistently higher than the initial bioaccessibility measurement (Figure 2), but after 28 days, no consistent trend prevailed. For example, with respect to lead bioaccessibility, Amendment 1-3—the most effective amendment—showed a slight decrease with time in amendment effectiveness, and Amendment 4-2—the least effective amendment—showed a slight increasing trend in effectiveness during the 28–116 day period. Similar variabilities in lead bioaccessibility were observed in both amended and unamended soils, suggesting that while the changes observed in lead bioaccessibility may represent true changes in the geochemical behavior of the amended soil, it is not possible to distinguish such trends (if they occur) from analytical noise. Instead, these overall changes in bioaccessibility between sampling events may be due to small differences in the apparatus (e.g., difference in the pH meter calibration).

Arsenic bioaccessibility from the unamended soil varied less throughout the tests than did lead bioaccessibility, making it more likely that systematic changes in arsenic bioaccessibility across time within a given soil represent true changes in the geochemical behavior of that soil (Figure 3). However, no pronounced systematic changes in arsenic bioaccessibility were evident.

Changes in Arsenic and Lead Leachability with Time

With the exception of the unamended soil and the soil amended with the Celgar Residual only (Amendment 4-2), the initial arsenic leachability measurement was the highest value observed during the test (Figure 4), suggesting that it requires time for the arsenic to be bound up by the amendment. Once bound, it appears that the arsenic then remains bound, showing a consistent reduction in arsenic leachability relative to the unamended soil. The leachability of arsenic from soil amended with the Celgar Residual may increase with time, but it is not possible to determine this with certainty, as the leachability of the unamended soil was equally variable (Figure 4) making it difficult to distinguish potential changes that were due to differences in the SPLP extraction solution from true changes in soil chemistry.

Celgar Residual-amended soil released slightly more lead than the unamended soil, but all other amendments significantly reduced lead leachability. No systematic changes in lead leachability were evident during the test (Figure 5).

Adsorption Capacity Study

The Phase I investigation showed that certain phosphate-bearing amendments may enhance the leachability of arsenic. Because such a release has the potential to affect groundwater quality beneath amended soils, an investigation was undertaken to determine whether the unamended soils that would underlay the amended soils would adsorb the released arsenic, thus preventing its transport to the underlying groundwater.

As natural soils undergo weathering, they typically develop chemically distinct layers or horizons. The simplest classification system divides the soil profile into three horizons: A, B, and C. As the A horizon—the shallowest of the three—develops in temperate regions (such as Trail), most of the soil materials dissolve, leaving behind silica-rich compounds and depleting this horizon of iron and aluminum. The aluminum and iron that dissolve from the A horizon often reprecipitate as amorphous hydrous oxides (HFO and aluminum hydroxide) within the underlying layer, the B horizon. The B horizon is underlain by the C horizon, which consists of relatively unweathered soil and/or bedrock. During both the current study and the Phase I investigation, sorption tests were conducted to determine whether arsenic mobilized from amended A-horizon soils would subsequently be adsorbed by the iron and aluminum hydroxide-rich B-horizon soil. This determination was made by first extracting amended soils with the SPLP leachate, and then using this leachate to perform batch-type adsorption testing of B-horizon soils.

The Phase I investigation determined that the extractable lead, arsenic, and cadmium are at their highest concentrations within the A-horizon soils. This would be expected given that the vast majority of these metals were likely derived from aerial deposition of smelter fallout. The Phase I investigation also showed that the oxalate-extracted iron and aluminum concentrations (which indicate the amounts of HFO and aluminum hydroxide that are present) were higher within the B horizon in all four profiles studied. This is consistent with what would be expected in a typical temperate-zone soil profile. If an amendment caused arsenic to leach from the shallow soils, it was hypothesized that the arsenic would then adsorb to the amorphous iron and aluminum oxides within the B horizon.

To determine whether arsenic would adsorb to B-horizon Tadanac soil, an adsorption capacity study was conducted. The adsorption capacity study consisted of batch studies using SPLP extraction fluid from two amended soils: Amendment 2-2 (0.15 wt % P as phosphoric acid, 0.35 wt % P as TCP, and 5 wt % Fe as HFO), and Amendment 4-2 (25 wt % residual) and representative Tadanac B-horizon soils.

Materials and Methods

The SPLP leachates were prepared by leaching Phase II composite soil that had been amended with either Amendment 2-2 (0.15 wt % P as phosphoric acid, 0.35 wt % P as

TCP, and 5 wt % Fe as HFO) or Amendment 4-2 (25 wt % Celgar). The amended soils were shaken with the SPLP leachate solution (EPA 1990) as a 1:5 soil:solution ratio in an end-over-end shaker for 24 hours. After shaking, the slurry settled for another 24 hours and then was filtered to 0.45 μm . Splits of the leachate were taken for analysis of lead, arsenic, and cadmium, as well as conductivity and pH.

The Tadanac-area B-horizon soil used during this test was prepared by combining the subsamples that were collected from two sites (Figure 1) during October 1996. The B-horizon soils were identified visually, air dried, homogenized, composited, and sieved to <4.75 mm.

The batch tests were run using EPA procedures (U.S. EPA 1987) and using the soil and solution weights shown in Table 7. The B-horizon soil was placed in a 250-mL wide-mouth bottle along with SPLP leachate. The sealed bottles were then shaken in a horizontal shaker for 24 hours, and allowed to settle for 24 hours, at which time the pH and conductivity were measured. The samples were then filtered to 0.45 μm . Lead, arsenic, and cadmium concentrations were determined by ICP-atomic emissions photospectrometry (LEGS 1995).

To maintain quality assurance (QA), one sample from each leachate type was run in triplicate. Process blanks were also run for each leachate type. Analyses of the batch test samples were also run using standard QA/QC protocols, as described in Appendix A.

Results

The arsenic concentration in the SPLP extract of soils amended with Amendment 2-2 was 0.53 mg/L. When this solution was equilibrated with the B-horizon soil, the arsenic concentration in the SPLP solution decreased dramatically, and the amount of decrease was directly proportional to the mass of soil that was added to the SPLP extract. For example, when only 1 g of the B-horizon soil was added to 199 mL of the SPLP extract, the arsenic concentration in that extract dropped from 0.53 mg/L to 0.28 mg/L, indicating that the B-horizon soils have a large capacity to adsorb arsenic. When the water:soil ratios approached values that would be more indicative of natural soil conditions (i.e., 1 g of soil to 1 g of SPLP extract), the arsenic concentration dropped to 0.07 mg/L, only slightly higher than the detection limit. These data indicate that although some phosphate-bearing amendments would release arsenic into the infiltrating pore waters, this arsenic would likely be adsorbed onto the underlying iron- and aluminum-rich B-horizon soils, and would not pose a threat to underlying water quality. No detectable arsenic was released from the soil amended with Celgar Residual (amendment 4-2) during SPLP testing. As a result, it was not possible (or necessary) to assess the arsenic adsorption capacity of the B-horizon soil samples exposed to this SPLP extract.

Neither lead nor cadmium was detected in the SPLP leachates of either of the two amended soils, and thus the adsorption capacity of the B-horizon soils for these metals could not be evaluated. However, cadmium was released from the B-horizon soils when the soils were contacted with SPLP extract solution that had previously been contacted

with the amended soils. The amount of cadmium released was directly proportional to the amount of B-horizon soil added during the test. For example, the SPLP leachate from soil receiving Amendment 2-2 contained no detectable cadmium (detection limit of 0.003 mg/L). But when this leachate was equilibrated with an equal mass of B-horizon soil, the cadmium concentration increased to 0.16 mg/L. This trend was more evident in the soil receiving SPLP leachates from the Celgar Residual-amended soil—the cadmium concentration in the extract increased from <0.003 mg/L to 0.40 mg/L following equilibration with equal masses of extract and amended soil (Table 8). The batch tests conducted with mixtures of stock SPLP solution and the B-horizon soil also exhibited this trend, but it was not as pronounced, with the maximum cadmium concentration reaching 0.09 mg/L. These data suggest that the addition of the soil amendments—particularly Celgar Residual—may enhance the ability of infiltrating water to liberate cadmium from the underlying B-horizon soil.

Grass Sensitivity Study

The ability of amended soils to support vegetation is an important factor in successful soil remediation. This ability was evaluated in the grass sensitivity study. Splits from the amended soils chosen for the long-term monitoring study, as well as an unamended control soil, were potted and planted with grass seed. The health of the grass was then monitored over a 4-month period.

Materials and Methods

Five clay flower pots were prepared by filling one pot with unamended Tadanac soil, two with Tadinac soil amended with Amendment 2-4, and two with Tadinac soil amended with Amendment 1-3. Each pot was then seeded with 250 seeds each, and placed in the Department of Biology greenhouse at the University of Colorado. The grass seeds were a mixture of tufted wheat grass, slender wheat grass, fescue, rye grass, Kentucky blue grass, oat gramma, little bluestem, and blue gramma. This seed blend was formulated for relatively dry climates, such as that of Trail. One pot of unamended Tadanac soil was also seeded with 250 seeds and placed with the other four.

For the first two weeks after seeding (i.e., during germination), the soils were watered twice daily. Watering frequency was then reduced to once a day for the next four months. After two and four months, the grass blades that had sprouted were counted. At four months, the conductivity and soluble phosphorus concentrations were also measured. The grass growing in the Amendment 2-4 soil was cut twice during the four months. (Grass was cut when it was so long that it bent over and covered the smaller grass shoots.)

Results

From the results of the grass sensitivity study, the following conclusions can be drawn:

- Both amended soils supported grass germination and growth equal to or greater than the unamended soil (Table 9), indicating that the grass germination was either unaffected or improved following amendment.
- Soil with Amendment 2-4 contained the highest concentration of soluble phosphorus and produced the highest number of germinated grass seeds.
- Grass in the soil with Amendment 2-4 also grew the most (height). This soil required two cutting events to prevent the long grass from shading smaller blades, while the other two soils required no cutting.

- Conductivity within all of the amended soils was below 1 mS/cm, the salinity at which even the most salt-sensitive crops are affected (Sposito 1989).

These results indicate that the amended soils will be capable of supporting vegetation with equal or greater ability than the unamended soil.

During the proposal stages of this task, there was concern that the high iron concentrations in these amended soils might be phytotoxic. However, Tate et al. (1991) demonstrated that it was not the presence of amorphous iron, but rather the reduced available phosphorus concentrations, that limited the growth of biota in HFO-rich soils. This is likely due to the ability of amorphous iron to strongly adsorb phosphate, thus limiting its availability to plants. The results of this grass sensitivity study are consistent with those findings. Both Amendment 2-4 and Amendment 1-3 soils contained amorphous iron (2.5 and 5 wt % respectively), but Amendment 2-4 soil had soluble phosphorus concentrations 100× higher than Amendment 1-3 soil, resulting in a higher seed germination rate and healthier grass growth. While these data suggest that soils amended with Amendment 2-4 would provide a better growth medium than those amended with Amendment 1-3, they also indicate that Amendment 1-3 could be used without any grass-phytotoxic effects.

Historical Phosphate Amendment Study

Until recently, the Cominco facility also had a phosphate fertilizer manufacturing and distribution plant onsite. With this readily available source, it was thought that many areas surrounding the plant had historically received generous amounts of phosphate fertilizer. Given that continuous loading of phosphate at other sites containing lead-bearing soils had resulted in formation of lead phosphate minerals (Ruby et al. 1994), generous application of phosphate fertilizer in certain areas of Trail may have resulted in the formation of lead phosphate minerals, resulting in lead-bearing soils with low lead bioaccessibilities. To determine whether such applications have occurred in Trail, sites suspected of receiving historically high phosphate applications were sampled and analyzed using the PBET. Soils were collected from intervals of 0–3, 3–6, 6–9 and 9–12 in. using a hand auger. They were analyzed for lead, arsenic, and cadmium bioaccessibility, as well as total phosphorus concentration. It was proposed originally that samples exhibiting reduced lead bioaccessibility would be analyzed by electron microprobe (EMPA) to determine the mineralogy of lead and phosphates that might be present. However, no such soils were identified, so EMPA was not performed.

Materials and Methods

During the October 1996 sampling event, seven core samples were collected within the Tadanac neighborhood and the area near the Warfield fertilizer plant (Figure 1). Site locations were chosen by the Trail Lead Program, PTI, and CU, based on information from Bob Marshall, head groundsman for Cominco. A brief description of each of the selected sites is presented in Table 10.

Cores were sampled with an AMS Core Soil Sampler with plastic (butyrate) liners to prevent cross-contamination. To prepare the soils for analysis, the cores were split into four 3-inch sections. The soil from each section was then air dried, homogenized, and sieved to <250 μm . The <250- μm fractions were split for PBET bioaccessibility analysis and for determination of total lead, arsenic, cadmium, and phosphorus concentration by XRF (LEGS 1995).

Results

The estimated phosphorus application rate ranged between 0.003 and 0.06 wt % phosphorus (Table 10), based on anecdotal accounts of fertilizer usage. However, given the uncertainty in the frequency of application and the actual amount of fertilizer applied, these estimated application rates are, at best, rough. The measured total phosphorus concentration in the historical phosphate application study soils (Table 11) ranged between 0.3 and 1.5 wt %, considerably higher than the estimated application rates for the historically amended soils. The observed phosphorus contents in the historical

phosphate application study soils were also higher than the phosphorus content of the Phase II composite soil (0.2 wt % phosphorus or 0.5 wt % P₂O₅ [Table 1]), indicating that fertilizer application at these location may have resulted in increased phosphorus concentrations.

The lead bioaccessibility in soils that have historically received phosphate was highly variable, ranging from 15 to 81 percent (Table 11). The total lead concentration in these same samples was also variable, from 7 to 1,950 mg/kg. Comparing the phosphorus content of the samples with their lead bioaccessibility values (Figure 6) reveals no strong correlation between the two. However, ignoring those data points that were derived from soils containing less than 500 mg/kg of lead, there is a slight correlation between phosphate content and lead bioaccessibility ($R^2=0.50$, $n=10$), indicating that the lead bioaccessibility of soils receiving phosphate-bearing fertilizer may have been lowered slightly. However, given that the average lead bioaccessibility of the unamended Phase II composite soil (66 percent, Table 6) was only slightly higher than the average lead bioaccessibility of the >500-mg/kg lead soils from the historical phosphate application study (58 percent), the reduction in lead bioaccessibility that may have resulted from the historical phosphate additions probably has been small.

Like lead, the ranges in both the total arsenic concentration (13–132 mg/kg), and arsenic bioaccessibility (9–95 percent) were large. And like lead, no strong correlation was evident between the soil phosphorus content and the arsenic bioaccessibility (Figure 7). In general, all the soils tested during the historical phosphate amendment investigation had lower arsenic bioaccessibility values than did the unamended Phase II composite soil (98 percent, Table 6), suggesting that while no clear correlation was evident between phosphorus content and arsenic bioaccessibility, it is possible that at least some benefit with respect to arsenic bioaccessibility had been gained following fertilization.

Conclusion

Overall, the Phase II study indicates that the most effective soil amendment is one consisting of 5 wt % iron as HFO and 0.5 wt % phosphorus as TCP. This amendment successfully lowered soil lead bioaccessibility in both short- and long-term testing. It also lowered arsenic bioaccessibility during both tests. Cadmium bioaccessibility was also lowered during the short-term tests, but was little changed during the long-term testing. The HFO/TCP amendment also reduced the leachability of lead and arsenic during the two tests, while cadmium leachability was changed only slightly.

Stage 1—Study Soil Characterization

This stage of the investigation was conducted to characterize the soil substrate that would be used in subsequent stages, providing a baseline against which to compare the composition of amended soils. The results of that characterization are presented in Table 1.

Stage 2—Variable Concentration Tests

In the short-term batch test, soil lead bioaccessibility was reduced by 66 percent, relative to the unamended soil, when both iron and phosphate were added at 5 and 0.5 wt %, respectively. The type of phosphorus added, either tri-basic calcium phosphate (TCP) or phosphoric acid, appeared to have only minimal influence on the extent to which the amendment lowered lead bioaccessibility; amendment formulations containing predominantly TCP proved slightly more effective than those containing predominantly phosphoric acid. The effectiveness of the iron-bearing amendments was directly proportional to the amount of iron added as HFO. Addition of iron alone was not as effective as the iron and phosphorus combination.

Celgar Residual by itself lowered the lead, cadmium, and, in most cases, arsenic bioaccessibility of the soil. However, the Celgar Residual generally increased the leachability of these three metals. When used in conjunction with iron as HFO and phosphate as either TCP or phosphoric acid, the Celgar Residual lowered the bioaccessibility and leachability of lead and, in most cases, arsenic. However, the leachability of cadmium was still enhanced relative to the unamended soils, particularly at high phosphorus and low iron amendment rates. In addition, the bioaccessibility of cadmium was slightly increased in the soils receiving these amendments relative to the unamended soil sample.

Stage 3—Long-Term Amendment Tests

The amendment that produced the lowest average lead bioaccessibility over the course of the 116-day monitoring period (28 percent) contained 0.5 wt % phosphorus as TCP and 5 wt % iron as HFO. The unamended soils had an average lead bioaccessibility of 66 percent over this same period. This amendment also lowered average arsenic bioaccessibility from 98 percent to 28 percent, but had little effect on cadmium bioaccessibility. It lowered lead leachability from 3.4 mg/kg to 1.6 mg/kg, and arsenic leachability from 7.2 mg/kg to 1.7 mg/kg. No samples contained detectable SPLP-leachable cadmium.

Following an initial sharp decrease in lead bioaccessibility (to 19 percent), the 0.5 wt % phosphorus- and 5 wt % iron-amended soil showed an increasing trend in lead bioaccessibility with time (23, 32, 26, and 31 percent following 28, 56, 86, and 116 days, respectively). A similar trend was observed in the unamended soil (58, 65, 68, 72, and 58 percent following 0, 28, 56, 86, and 116 days, respectively), indicating that within the certainty of the test, this amendment provided a stable reduction in lead bioaccessibility.

The effectiveness of a 25 wt % application of Celgar Residual was tested during the long-term amendment tests, both with and without an addition of 0.5 wt % of phosphorus (as phosphoric acid) and 5 wt % iron (as HFO). As with the Stage 2 tests, the phosphorus/iron-bearing Celgar Residual amendment proved the most effective of the two at lowering the bioaccessibility and leachability of both lead and arsenic. However, the phosphorus/iron-bearing Celgar Residual amendment included in the Stage 3 test slightly increased the bioaccessibility of cadmium. Cadmium leachability from the soils was not affected by the addition of either of the Celgar Residual-based amendments during Stage 3 testing.

Adsorption Capacity Study

The Phase I investigation of soil amendments demonstrated that when phosphate was added to arsenic-bearing soil, synthetic rainwater leached more arsenic from the amended soils than it leached from the unamended soil. The Stage 2 and 3 tests conducted during Phase II demonstrated that this problem has been largely eliminated through the use of HFO; however, the SPLP leachates from amended soils still contained some arsenic. When these arsenic-bearing leachates were brought into contact with B-horizon soils, the arsenic adsorbed to the soils, reducing arsenic concentrations in leachates to near the detection limit (0.05 mg/L). These results indicate that if arsenic were to be liberated by a soil amendment, the B-horizon soils would likely sequester this arsenic before it could reach the underlying groundwater.

The B-horizon soils were found to release cadmium when contacted with the SPLP leachate solution. This effect was even more pronounced when the leachate solution was pre-contacted with amended soils—particularly the soil amended with 25 wt % Celgar Residual. These data suggest that the addition of the amendments to soils containing elevated cadmium concentrations could adversely affect subjacent groundwater quality.

Grass Sensitivity Study

Grass seeds planted in soils amended with 0.53 wt % phosphorus as phosphoric acid, 1.22 wt % phosphorus as TCP, and 2.5 wt % iron as HFO were more likely to germinate, and the grass grew faster than grass planted in unamended soil. Grass seed planted in soils amended with 0.5 wt % phosphorus as TCP and 5 wt % iron as HFO was equally likely to germinate, and the grass was as likely to thrive as was grass grown on unamended soils. These results indicate that the most effective soil amendment identified during the long-term amendment tests is unlikely to adversely affect the ability of the soil to support grass growth.

Historical Phosphate-Application Site Sampling

Although several of the soils collected during this investigation appeared to have received historical applications of phosphorus at rates equal to or greater than the application rates tested during the Stage 2 and Stage 3 tests, little to no reduction in lead bioaccessibility from these soils appears to have resulted. These results suggest that when phosphate is used alone as a soil amendment, it may not reduce lead bioaccessibility over the long term.

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Figures

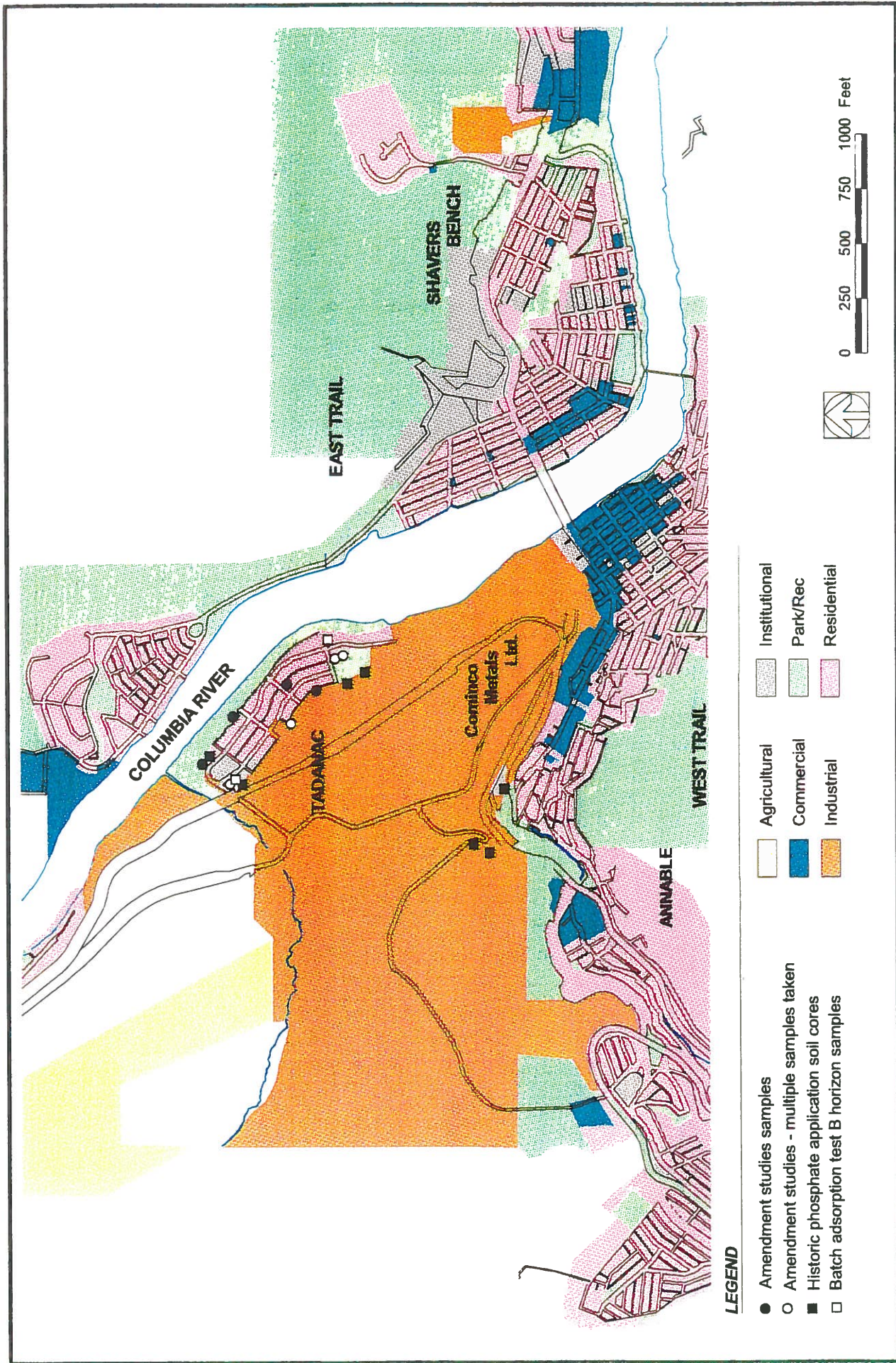


Figure 1. Map showing the approximate locations of soils samples collected during the Phase II *in situ* soil amendment investigation.

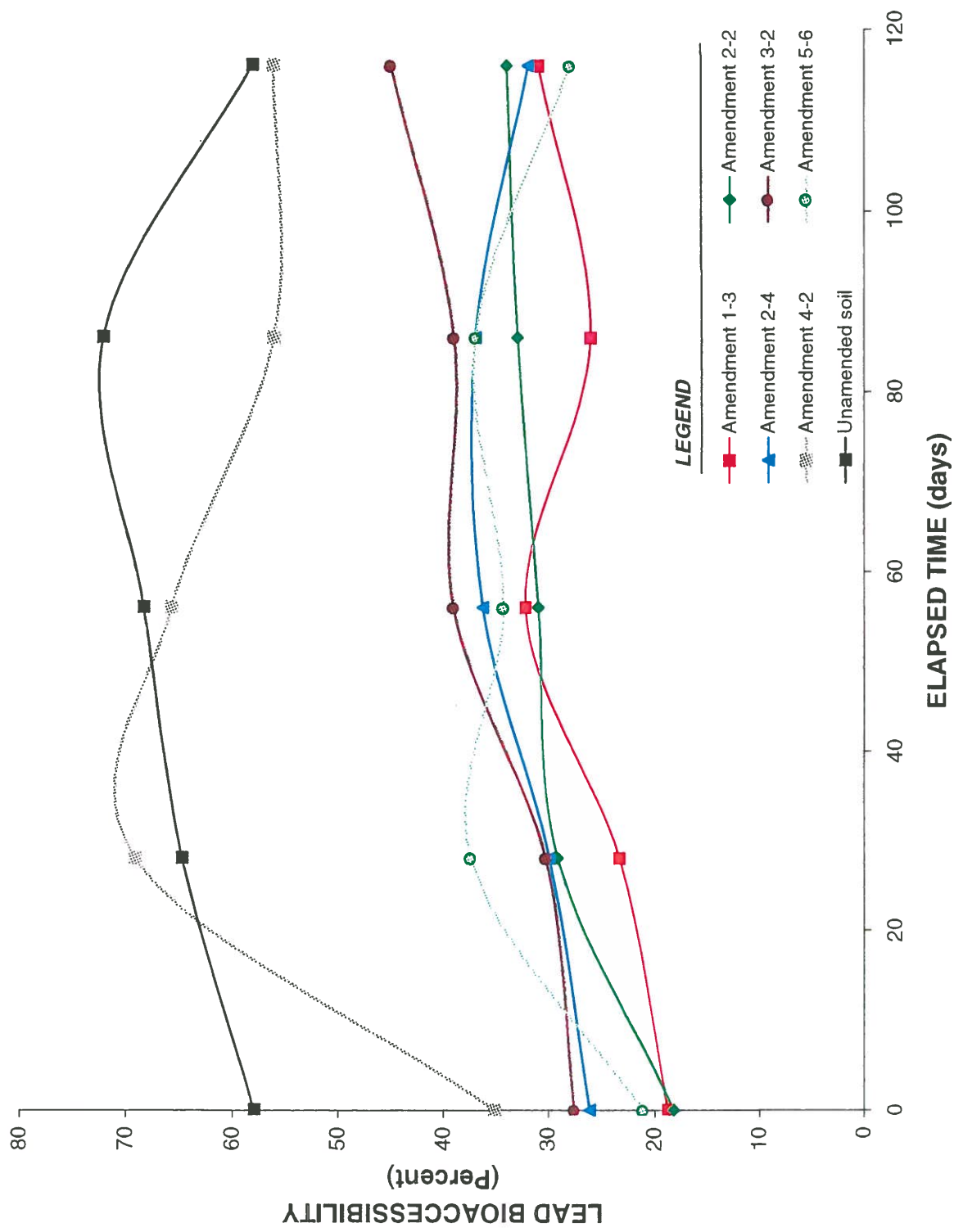


Figure 2. Changes in lead bioaccessibility with time.

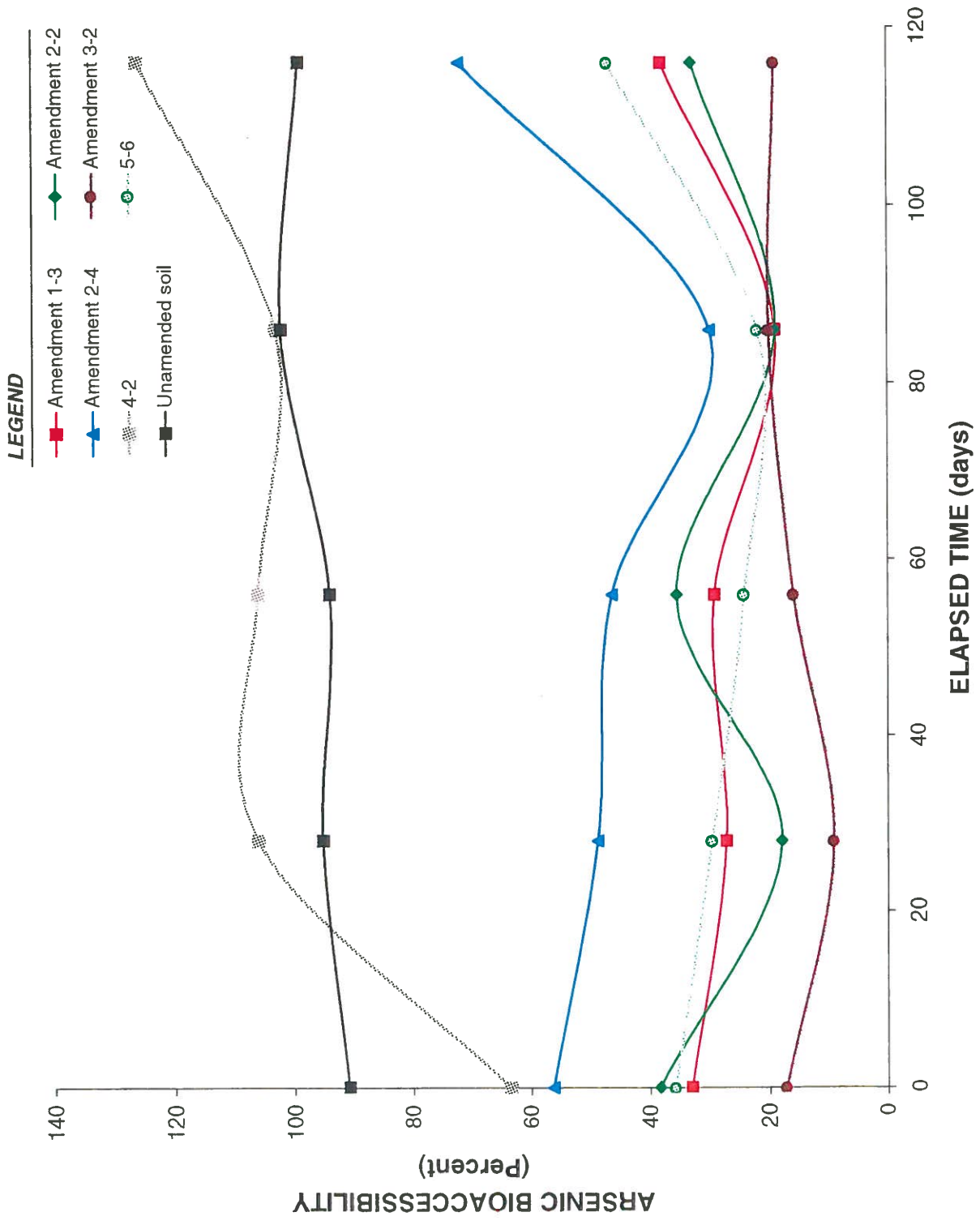


Figure 3. Changes in arsenic bioaccessibility with time.

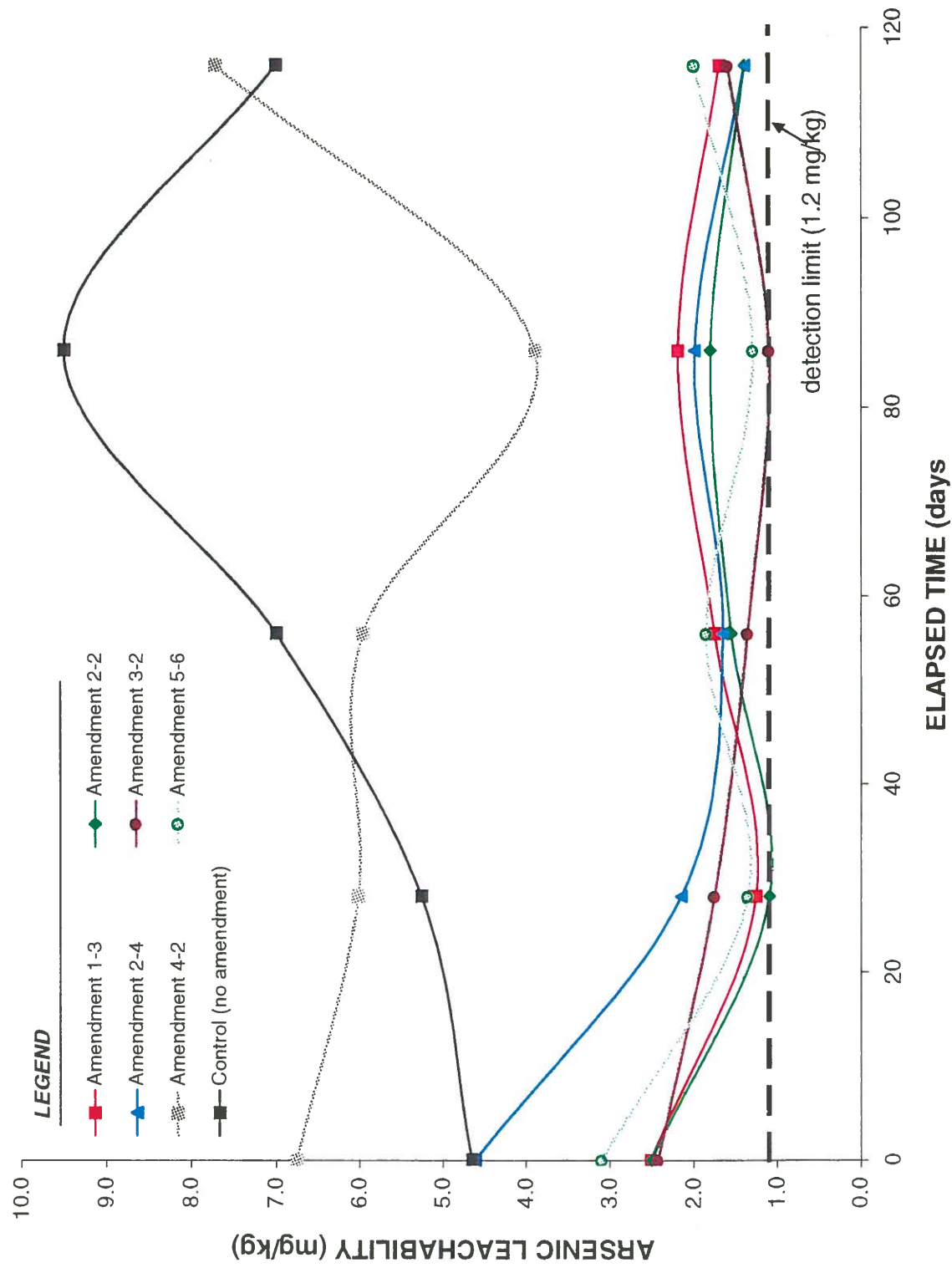


Figure 4. Changes in arsenic leachability with time.

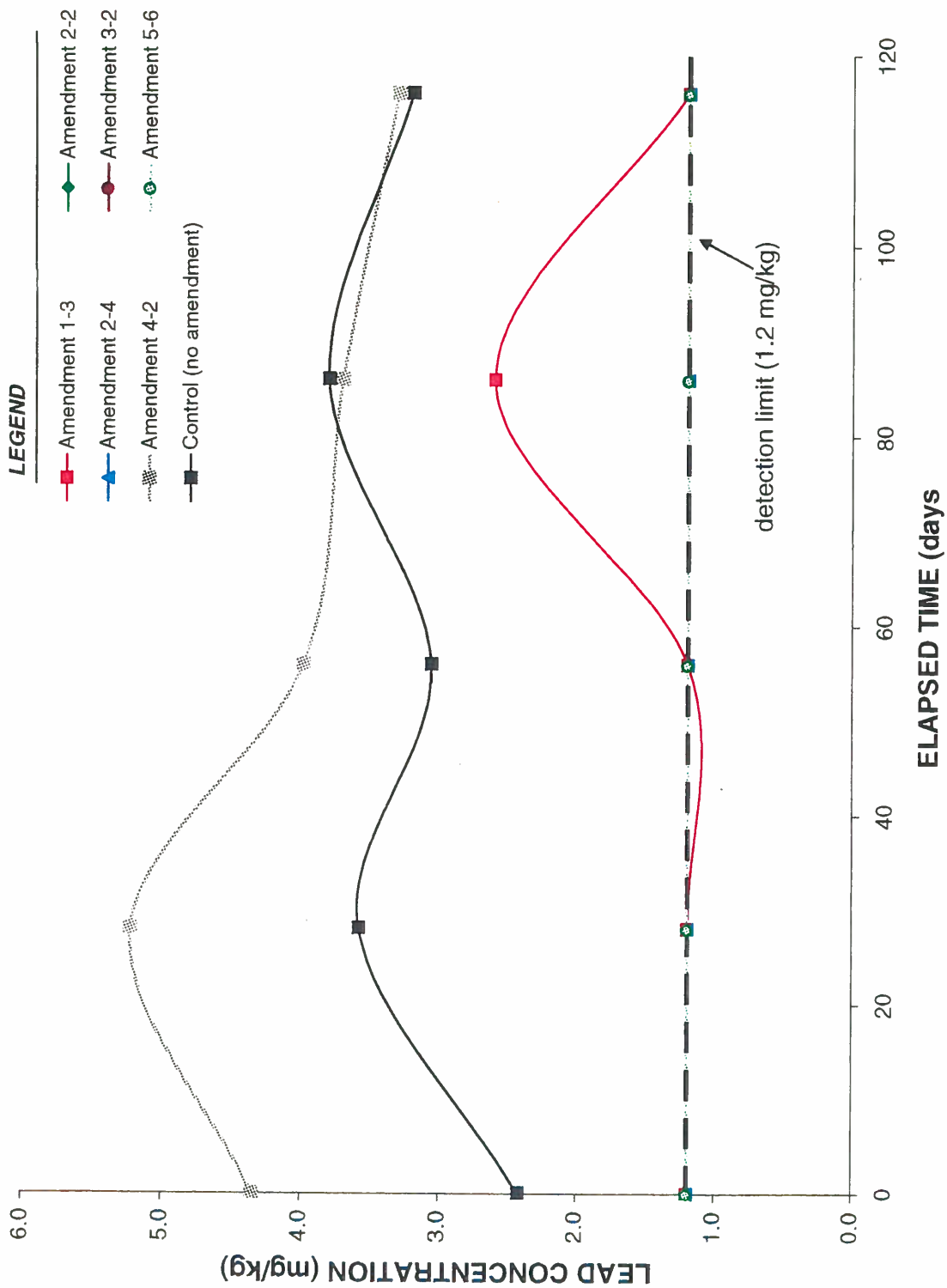


Figure 5. Changes in lead leachability with time.

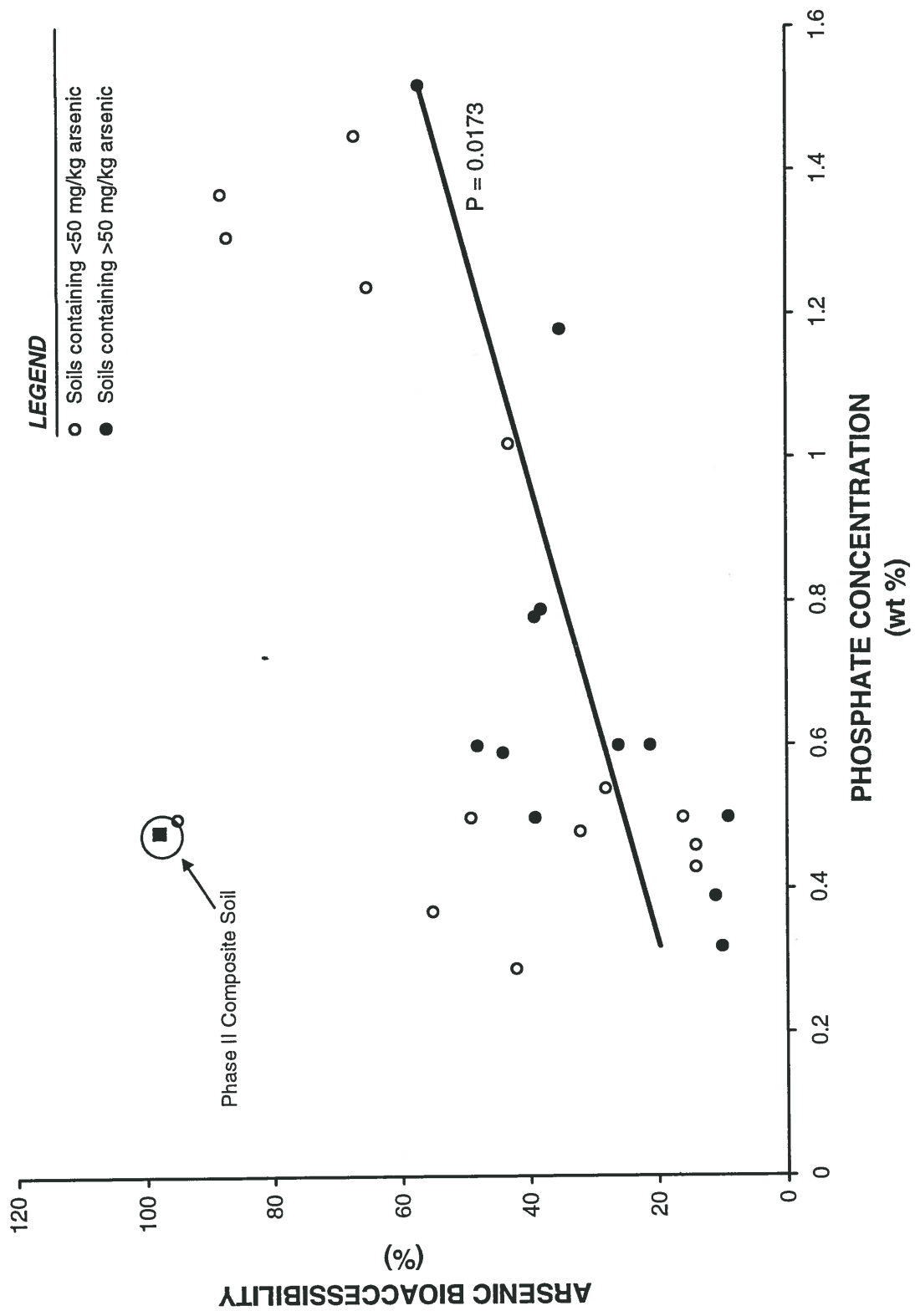


Figure 7. Arsenic bioaccessibility and phosphate concentration in the historical phosphate application samples.

Tables

**TABLE 1. BASELINE GEOCHEMISTRY
OF THE PHASE II COMPOSITE SOIL**

Size Fraction/Analyte	Value	Units
Properties of the <2-mm soil fraction		
pH	5.91	s.u.
Soluble P	290	mg/L
Conductivity	0.34	mS/cm
Cation exchange capacity	20	meq/100g
Total organic carbon	2	percent
Total metals by XRF ^a in the <2-mm soil fraction		
Lead	1400	mg/kg
Arsenic	86	mg/kg
Cadmium	9	mg/kg
Iron	3.73	wt %
Aluminum	14	wt %
Phosphorus (as P ₂ O ₅)	0.48	wt %
Total metals by XRF ^a in the <250-µm soil fraction		
Lead	1400	mg/kg
Arsenic	57	mg/kg
Cadmium	14	mg/kg
Extractable metals by ICP ^b in the <2-mm soil fraction		
Lead	577	mg/kg
Arsenic	78	mg/kg
Cadmium	7	mg/kg
PBET-Bioaccessibility		
Lead	58	percent
Arsenic	91	percent
Cadmium	46	percent
SPLP-Leachability		
Lead	2.4	mg/kg
Arsenic	4.7	mg/kg
Cadmium	<0.06	mg/kg

^a Measured using x-ray fluorescence.

^b Measured by first extracting the soil using USEPA method 3050, and analyzing the extract using inductively coupled plasma.

**TABLE 2. TEST MATRIX FOR THE VARIABLE CONCENTRATION TESTS
(STAGE 2 OF THE PHASE II AMENDMENT INVESTIGATION)**

Amendment ID	Type and Quantity of Amendment (wt %)			
	P as H ₃ PO ₄	P as TCP	Iron as HFO	Celgar Residual
Amendment No.1				
Amendment 1-1	--	3	0.5	--
Amendment 1-2	--	1.75	2.5	--
Amendment 1-3	--	0.5	5	--
Amendment No. 2				
Amendment 2-1	0.35	0.15	5	--
Amendment 2-2	0.15	0.35	5	--
Amendment 2-3	1.22	0.53	2.5	--
Amendment 2-4	0.53	1.22	2.5	--
Amendment 2-5	2.1	0.9	0.5	--
Amendment 2-6	0.9	2.1	0.5	--
Amendment No. 3				
Amendment 3-1	--	--	2.5	--
Amendment 3-2	--	--	5	--
Amendment 3-3	--	--	5.75	--
Amendment No. 4				
Amendment 4-1	--	--	--	15
Amendment 4-2	--	--	--	25
Amendment 4-3	--	--	--	50
Amendment 5				
Amendment 5-1	3	--	0.5	15
Amendment 5-2	1.75	--	2.5	15
Amendment 5-3	0.5	--	5	15
Amendment 5-4	3	--	0.5	25
Amendment 5-5	1.75	--	2.5	25
Amendment 5-6	0.5	--	5	25
Amendment 5-7	3	--	0.5	50
Amendment 5-8	1.75	--	2.5	50
Amendment 5-9	0.5	--	5	50

**TABLE 3. RESULTS OF THE VARIABLE-CONCENTRATION AMENDMENT TESTS
(STAGE 2 OF THE PHASE II AMENDMENT INVESTIGATION)**

	Type and Quantity of Amendment (wt %)				Bioaccessibility Ratios			Leachability Ratios		
	P as H ₃ PO ₄	P as TCP	Iron as HFO	Celgar Residual	Pb Ratio	As Ratio	Cd Ratio	Pb Ratio	As Ratio	Cd Ratio
	Amendment No.1									
Amendment 1-1	--	3	0.5	--	0.62	1.23	1.24	0.26	0.61	1.23
Amendment 1-2	--	1.75	2.5	--	0.54	0.94	1.05	0.17	0.58	1.15
Amendment 1-3	--	0.5	5	--	0.35	0.39	0.68	0.16	0.54	1.09
Amendment No.2										
Amendment 2-1	0.35	0.15	5	--	0.41	0.39	0.59	0.16	0.54	1.08
Amendment 2-2	0.15	0.35	5	--	0.34	0.46	0.66	0.16	0.54	1.09
Amendment 2-3	1.22	0.53	2.5	--	0.64	0.93	1.36	0.17	0.84	1.14
Amendment 2-4	0.53	1.22	2.5	--	0.52	0.71	1.12	0.18	0.99	1.15
Amendment 2-5	2.1	0.9	0.5	--	0.53	1.05	0.99	0.18	6.50	1.20
Amendment 2-6	0.9	2.1	0.5	--	0.36	1.03	1.10	0.18	2.62	1.22
Amendment No. 3										
Amendment 3-1	--	--	2.5	--	0.66	0.33	0.82	0.15	0.51	1.03
Amendment 3-2	--	--	5	--	0.60	0.22	0.79	0.16	0.52	1.05
Amendment 3-3	--	--	5.75	--	0.50	0.20	0.78	0.19	0.53	1.06
Amendment No. 4										
Amendment 4-1	--	--	--	15	0.78	0.90	0.56	0.70	1.59	2.30
Amendment 4-2	--	--	--	25	0.76	0.87	0.48	1.80	1.45	2.08
Amendment 4-3	--	--	--	50	0.94	1.39	0.89	2.32	4.41	2.00
Amendment 5										
Amendment 5-1	3	--	0.5	15	0.63	1.39	1.20	1.69	0.69	1.38
Amendment 5-2	1.75	--	2.5	15	0.48	0.90	1.07	0.31	0.65	1.30
Amendment 5-3	0.5	--	5	15	0.57	0.39	1.19	0.35	0.62	1.24
Amendment 5-4	3	--	0.5	25	0.58	1.35	1.16	1.95	0.74	2.46
Amendment 5-5	1.75	--	2.5	25	0.48	0.66	1.23	0.21	0.70	1.87
Amendment 5-6	0.5	--	5	25	0.49	0.52	1.21	0.20	0.67	1.34
Amendment 5-7	3	--	0.5	50	0.62	1.48	1.39	2.69	0.86	1.73
Amendment 5-8	1.75	--	2.5	50	0.60	0.82	1.10	0.46	0.82	2.76
Amendment 5-9	0.5	--	5	50	0.51	0.57	1.25	0.24	0.79	1.59

Shaded rows are amendments that were included in the subsequent long-term monitoring tests.

^a Bioaccessibility ratio = $\text{Bioaccessibility}_{\text{amended soil}} / \text{Bioaccessibility}_{\text{unamended soil}}$

^b Leachability ratio = $\text{Leachability}_{\text{amended soil}} / \text{Leachability}_{\text{unamended soil}}$

**TABLE 4. PBET RESULTS FROM THE LONG-TERM MONITORING TESTS
(STAGE 3 OF THE PHASE II AMENDMENT INVESTIGATION)**

Amendment	Days:	Lead Bioaccessibility (Percent)			Arsenic Bioaccessibility (Percent)			Cadmium Bioaccessibility (Percent)							
		0 ^a	28	56	86	116	0 ^a	28	56	86	116				
1-3	19	23	32	26	31	33	27	29	19	38	29	52	62	59	
	18	29	31	33	34	38	18	36	19	33	28	55	59	70	61
2-2	26	30	36	37	32	56	49	46	30	72	45	59	75	68	
	28	30	39	39	45	17	9	16	20	19	34	47	63	65	
3-2	35	69	66	56	56	64	106	106	103	126	18	48	58	59	
	21	37	34	37	28	36	30	24	22	47	42	56	74	73	
5-6	58	65	68	72	58	91	95	94	102	99	46	52	58	47	
	Unamended soil														
Bioaccessibility ratio^b															
1-3		0.32	0.36	0.47	0.36	0.53	0.36	0.29	0.31	0.38	0.63	1.00	1.06	0.93	1.26
2-2		0.31	0.45	0.45	0.46	0.59	0.42	0.19	0.38	0.33	0.61	1.05	1.01	1.04	1.30
2-4		0.45	0.46	0.53	0.51	0.55	0.62	0.51	0.49	0.73	0.98	1.13	1.29	1.15	1.45
3-2		0.48	0.47	0.57	0.54	0.78	0.19	0.10	0.17	0.19	0.73	0.90	1.08	0.97	1.38
4-2		0.61	1.07	0.96	0.78	0.97	0.70	1.11	1.13	1.27	0.38	0.92	0.99	0.88	1.26
5-6		0.36	0.58	0.50	0.51	0.48	0.39	0.31	0.26	0.47	0.91	1.09	1.26	1.39	1.55

^a The initial data point was taken from the Stage 2 test (variable-concentration test).

^b Bioaccessibility ratio = Bioaccessibility_{amended soil} / Bioaccessibility_{unamended soil}

**TABLE 5. SPLP RESULTS FROM THE LONG-TERM MONITORING TESTS
(STAGE 3 OF THE PHASE II AMENDMENT INVESTIGATION)**

Amendment	Days:	Lead Concentration (mg/kg)					Arsenic Concentration (mg/kg)					Cadmium Concentration (mg/kg)				
		0 ^a	28	56	86	116	0 ^a	28	56	86	116	0 ^a	28	56	86	116
1-3		1.2 u	1.2 u	1.2 u	2.6	1.2 u	2.5	1.3	1.8	2.2	1.7	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
2-2		1.2 u	1.2 u	1.2 u	1.2 u	1.2 u	2.5	1.1 u	1.6	1.8	1.4	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
2-4		1.2 u	1.2 u	1.2 u	1.2 u	1.2 u	4.6	2.2	1.7	2.0	1.4	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
3-2		1.2 u	1.2 u	1.2 u	1.2 u	1.2 u	2.4	1.8	1.4	1.1 u	1.6	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
4-2		4.4	5.2	4.0	3.7	3.3	6.8	6.0	6.0	3.9	7.7	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
5-6		1.2 u	1.2 u	1.2 u	1.2 u	1.2 u	3.1 ^c	1.4	1.9	1.3	2.0	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
Unamended soil		2.4	3.6	3.1	3.8	3.2	4.7	5.3	7.0	9.5	7.0	0.06 u	0.06 u	0.06 u	0.06 u	0.06 u
Leachability ratio^b																
1-3		0.50	0.34	0.39	0.68	0.38	0.54	0.24	0.25	0.23	0.24	--	--	--	--	--
2-2		0.50	0.34	0.39	0.32	0.38	0.54	0.21	0.22	0.19	0.20	--	--	--	--	--
2-4		0.50	0.34	0.39	0.32	0.38	0.99	0.41	0.24	0.21	0.20	--	--	--	--	--
3-2		0.50	0.34	0.39	0.32	0.38	0.52	0.33	0.19	0.12	0.23	--	--	--	--	--
4-2		1.80	1.46	1.30	0.97	1.03	1.45	1.14	0.85	0.41	1.10	--	--	--	--	--
5-6		0.50	0.34	0.39	0.32	0.38	0.67	0.26	0.27	0.14	0.29	--	--	--	--	--

^a The initial data point was taken from the Stage 2 test (variable-concentration test).

^b Leachability ratio = $\frac{\text{Leachability}_{\text{amended soil}}}{\text{Leachability}_{\text{unamended soil}}}$

u = Analyte was below the detection limit.

-- = Cadmium was not detected in the SPLP extracts.

**TABLE 6. AVERAGE^a PBET AND SPLP RESULTS FROM THE LONG-TERM MONITORING TESTS
(STAGE 3 OF THE PHASE II AMENDMENT INVESTIGATION)**

Amendment	Type and Quantity of Amendment (wt %)				Average ^a Bioaccessibility (%)			Average ^a Leachability (mg/kg)		
	P as H ₃ PO ₄	P as TCP	Iron as HFO	Celgar Residual	Lead	Arsenic	Cadmium	Lead	Arsenic	Cadmium
Amendment 1-3	--	0.5	5	--	28	28	59	1.6 dl	1.7	0.06 u
Amendment 2-2	0.15	0.35	5	--	32	26	61	1.2 u	1.5 dl	0.06 u
Amendment 2-4	0.53	1.22	2.5	--	34	49	70	1.2 u	1.8	0.06 u
Amendment 3-2	--	--	5	--	38	16	60	1.2 u	1.5 dl	0.06 u
Amendment 4-2	--	--	--	25	62	110	56	4.1	5.9	0.06 u
Amendment 5-6	0.5	--	5	25	34	31	74	1.2 u	1.6	0.06 u
Unamended soil	--	--	--	--	66	98	56	3.4	7.2	0.06 u

TABLE 6. (cont.)

Amendment	Type and Quantity of Amendment (wt %)					Celgar Residual	Ratio of Averages										
	P as H ₃ PO ₄	P as TCP	Iron as HFO	C	Residual		Average Bioaccessibility _{amended soil} /Average Bioaccessibility _{unamended soil}					Average Leachability _{amended soil} /Average Leachability _{unamended soil}					
							Lead	Arsenic	Cadmium	Lead	Arsenic	Cadmium	Lead	Arsenic	Cadmium		
Amendment 1-3	--	0.5	5	5	--	0.43	0.29	1.05	0.45	0.24	--	0.43	0.27	1.09	0.35	0.20	--
Amendment 2-2	0.15	0.35	5	5	--	0.48	0.27	1.09	0.35	0.20	--	0.51	0.51	1.24	0.35	0.25	--
Amendment 2-4	0.53	1.22	2.5	5	--	0.58	0.16	1.07	0.35	0.20	--	0.94	1.13	1.00	1.19	0.82	--
Amendment 3-2	--	--	5	5	25	0.52	0.31	1.32	0.35	0.23	--	0.52	0.31	1.32	0.35	0.23	--
Amendment 4-2	--	--	--	5	25												
Amendment 5-6	0.5	--	5	5	25												

^a The averages were calculated for the Stage 3 data only (i.e., the 0 data point is not included in the average calculations).

u = Analyte was below the detection limit.

dl = Detection limit values were used in calculating the average. To be conservative, the detection limit (rather than 1/2 the detection limit) was used when calculating the averages.

-- = Cadmium was not detected in the SPLP extracts.

TABLE 7. STUDY MATRIX FOR THE ADSORPTION CAPACITY STUDY

Sample ID	Leachate Used in Test	Mass of Soil (g)	Volume of Leachate (mL)	Water:Soil Ratio (mass:mass)	Notes
T(2-2)1	SPLP Leachate of Amendment 2-2 Soil ^a	100	100	1:1	
T(2-2)2:1	SPLP Leachate of Amendment 2-2 Soil ^a	50	150	3:1	Triplicate QA sample
T(2-2)2:2	SPLP Leachate of Amendment 2-2 Soil ^a	50	150	3:1	Triplicate QA sample
T(2-2)2:2	SPLP Leachate of Amendment 2-2 Soil ^a	50	150	3:1	Triplicate QA sample
T(2-2)3	SPLP Leachate of Amendment 2-2 Soil ^a	20	180	9:1	
T(2-2)4	SPLP Leachate of Amendment 2-2 Soil ^a	10	190	19:1	
T(2-2)5	SPLP Leachate of Amendment 2-2 Soil ^a	5	195	39:1	
T(2-2)6	SPLP Leachate of Amendment 2-2 Soil ^a	2	198	99:1	
T(2-2)7	SPLP Leachate of Amendment 2-2 Soil ^a	1	199	199:1	
T(2-2)8	SPLP Leachate of Amendment 2-2 Soil ^a	0	200		Blank QA sample
T(4-2)1:1	SPLP Leachate of Amendment 4-2 Soil ^b	100	100	1:1	Triplicate QA sample
T(4-2)1:2	SPLP Leachate of Amendment 4-2 Soil ^b	100	100	1:1	Triplicate QA sample
T(4-2)1:3	SPLP Leachate of Amendment 4-2 Soil ^b	100	100	1:1	Triplicate QA sample
T(4-2)2	SPLP Leachate of Amendment 4-2 Soil ^b	50	150	3:1	
T(4-2)3	SPLP Leachate of Amendment 4-2 Soil ^b	20	180	9:1	
T(4-2)4	SPLP Leachate of Amendment 4-2 Soil ^b	10	190	19:1	
T(4-2)5	SPLP Leachate of Amendment 4-2 Soil ^b	5	195	39:1	
T(4-2)6	SPLP Leachate of Amendment 4-2 Soil ^b	2	198	99:1	
T(4-2)7	SPLP Leachate of Amendment 4-2 Soil ^b	1	199	199:1	
T(4-2)8	SPLP Leachate of Amendment 4-2 Soil ^b	0	200		Blank QA sample
T(blank)1:1	SPLP Solution	100	100	1:1	Triplicate QA sample
T(blank)1:2	SPLP Solution	100	100	1:1	Triplicate QA sample
T(blank)1:3	SPLP Solution	100	100	1:1	Triplicate QA sample
T(blank)2	SPLP Solution	50	150	3:1	
T(blank)3	SPLP Solution	20	180	9:1	
T(blank)4	SPLP Solution	10	190	19:1	
T(blank)5	SPLP Solution	5	195	39:1	
T(blank)6	SPLP Solution	2	198	99:1	
T(blank)7	SPLP Solution	1	199	199:1	
T(blank)8	SPLP Solution	0	200		Blank QA sample

^a Amended with 0.15 wt % phosphorus as H₃PO₄, 0.35 wt % phosphorus as TCP, and 5 wt% iron as HFO.

^b Amended with 25 wt % Celgar Residual.

TABLE 8. RESULTS OF THE ADSORPTION CAPACITY STUDY

Sample ID	Water:Soil Ratio (mass:mass)	Metal Concentrations (mg/L)			Specific Conductivity (mS/cm)	pH (s.u.)
		Lead	Arsenic	Cadmium		
Tests using SPLP leachates from soils amended with Amendment 2-2 ^a						
T(2-2)1	1:1	0.06 u	0.07	0.16	0.81	6.15
T(2-2)2 ^b	3:1	0.06 u	0.05 u	0.072	0.85	7.17
T(2-2)3	9:1	0.06 u	0.07	0.051	0.90	6.61
T(2-2)4	19:1	0.06 u	0.05 u	0.035	0.97	6.87
T(2-2)5	39:1	0.09	0.07	0.035	1.02	7.06
T(2-2)6	99:1	0.08	0.22	0.006	1.08	7.22
T(2-2)7	199:1	0.08	0.28	0.004	1.06	7.27
T(2-2)8		0.06 u	0.53	0.003 u	1.05	7.40
Tests using SPLP leachates from soils amended with Amendment 4-2 ^c						
T(4-2)1 ^b	1:1	0.06 u	0.06	0.40	2.28	5.62
T(4-2)2	3:1	0.06 u	0.05 u	0.28	2.28	5.82
T(4-2)3	9:1	0.06 u	0.05 u	0.11	2.31	7.14
T(4-2)4	19:1	0.06 u	0.05 u	0.088	2.29	7.22
T(4-2)5	39:1	0.06 u	0.05 u	0.039	2.37	6.77
T(4-2)6	99:1	0.06 u	0.05 u	0.010	2.29	7.22
T(4-2)7	199:1	0.06 u	0.05 u	0.009	2.38	7.14
T(4-2)8		0.06 u	0.05 u	0.003 u	2.34	7.58
Tests using stock SPLP solution and the B-horizon soil						
T(blank)1 ^b	1:1	0.06 u	0.08	0.09	0.26	5.52
T(blank)2	3:1	0.06 u	0.05 u	0.05	0.16	5.88
T(blank)3	9:1	0.06 u	0.09	0.02	0.08	6.03
T(blank)4	19:1	0.06 u	0.08	0.01	0.06	5.96
T(blank)5	39:1	0.06 u	0.06	0.01	0.04	5.89
T(blank)6	99:1	0.06 u	0.06	0.01	0.03	5.86
T(blank)7	199:1	0.06 u	0.05 u	0.01	0.02	5.64
T(blank)8		0.06 u	0.05 u	0.003 u	0.05	4.39

u = Detection limit value.

^a 0.15 wt % phosphorus as H₃PO₄, 0.35 wt % phosphorus as TCP, and 5 wt % iron as HFO.

^b Average result of triplicate analyses.

^c 25 wt % Celgar Residual.

TABLE 9. RESULTS OF THE GRASS SENSITIVITY TESTS

Soil Amendment	Number of Seeds Germinated		Chemical Parameters ^a	
	After 2 Months	After 4 Months	Conductivity (mS/cm)	Soluble P (mg/kg)
Amendment 1-3				
Duplicate 1	20	24	0.28	8
Duplicate 2	20	17	0.53	3
Amendment 2-4				
Duplicate 1	58	37	0.21	1056
Duplicate 2	45	45	0.38	1073
Unamended soil	14	17	0.12	197

^a Measured 4 months following planting.

TABLE 10. HISTORICAL PHOSPHATE APPLICATION AT SAMPLING SITES

Core No.	Site Location	Phosphate application history
1	East of Fertilizer plant on Bingay Rd., 20-25°, tree-covered slope	Not known
2	East of Fertilizer plant on Bingay Rd., grassy, flat area	Not known
3	Southwest of Fertilizer plant off of Route 2220, 25° slope facing northwest	Not known
4	Off of Kootenay Ave. on Cominco property	13-16-10 fertilizer ^a was applied twice during a single one-year period at 200 lbs/acre. Slate lime was also added.
5	Cominco president's garden - Ritchie Ave.	There has been an inconsistent application over the past 20+ years (around vegetation only). Manure from Trail area was also used.
6	Playground near school on Kootenay Ave.	Over an 18+ year period, 13-16-10n ^b fertilizer was applied twice per year at 200 lbs/acre. There was also an occasional summer application of 18-19-18 at 200 lbs/acre.
7	Tadanac Pitch on Kootenay Ave. (approximately 100 ft from Cominco fence)	Over an 18+ year period, 13-16-10n fertilizer was applied twice per year at 200 lbs/acre. There was also an occasional summer application of 18-19-18s ^c at 200 lbs/acre.

^a 13-16-10 fertilizer contains 13 percent nitrogen, 16 percent phosphorus, and 13 percent nitrogen.

^b 13-16-10n fertilizer contains 13 percent nitrogen, 16 percent phosphorus, and 13 percent nitrogen. The components of this type of fertilizer are released immediately into the soils.

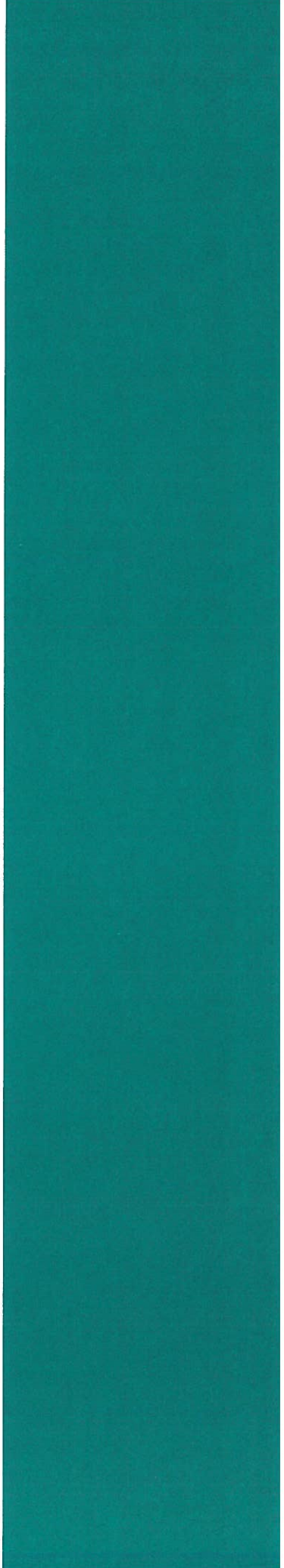
^c 18-19-18s fertilizer contains 18 percent nitrogen, 19 percent phosphorus, and 18 percent nitrogen. The components of this type of fertilizer are released slowly into the soils.

TABLE 11. RESULTS OF THE HISTORICAL PHOSPHATE APPLICATION STUDY

Sample ID	Depth Interval (inches)	Lead Bioaccessibility (%)	Total Lead (mg/kg)	Arsenic Bioaccessibility (%)	Total Arsenic (mg/kg)	Total Phosphorus (wt %)
Core 1	3-6	51	648	43	44	1.02
	6-9	48	245	28	47	0.54
	9-12	51	282	12	83	
Core 2	0-3	68	334	95	13	0.50
	3-6	60	29	10	66	0.32
	6-9	56	70	42	22	0.29
	9-12	48	128	55	15	0.37
Core 3	0-3	46	497	21	63	0.60
	3-6	42	278	16	47	0.50
	6-9	55	71	9	64	0.50
	9-12	15	18	11	56	0.39
Core 4	0-3	64	1260	48	86	0.60
	3-6	66	1090	44	84	0.59
	6-9	65	1090	39	132	0.78
	9-12	56	485	26	122	0.60
Core 5	0-3	50	762	87	17	1.31
	3-6	58	681	65	26	1.24
	6-9	59	1250	67	45	1.45
	9-12	58	1420	88	36	1.37
Core 6	0-3	81	366	49	34	0.50
	3-6	58	112	32	16	0.48
	6-9	41	80	14	41	0.43
	9-12	47	78	14	42	0.46
Core 7	0-3	52	1950	57	55	1.52
	3-6	58	1590	35	86	1.18
	6-9	67	228	38	51	0.79
	9-12	37	7	39	53	0.50

Appendix A

**Quality Assurance and
Quality Control**



**TABLE A-1. QUALITY CONTROL SAMPLES EVALUATED DURING
THE PBET ANALYSIS
(apparatus spike or replicate samples)**

Stage	Run Number	As Percent Difference Between Duplicates ^a	Pb Spike ^a Recovery	Cd Percent Difference Between Duplicates ^a
Stage 2				
	1	0.2%	81%	7.1%
	2	12%	75%	13%
	3	0.8%	91%	3.8%
	4	13%	96%	3.6%
	5	17%	64%	7.6%
	6	7.5%	100%	2.2%
	7	36%	93%	4.7%
	8	0.0%	92%	0.0%
Stage 3, Sampling 1				
	1	17%	84%	3.1%
	2	0.0%	93%	10%
Stage 3, Sampling 2				
	1	2.2%	100%	7.0%
	2	0.0%	93%	10%
Stage 3, Sampling 3				
	1	16%	91%	13%
	2	1.8%	93%	0.0%
Stage 3, Sampling 4				
	1	2.4%	92%	1.6%
	2	4.4%	96%	9.1%
Historical Application Study				
	core #3 9-12	5.6%	97%	--
	core #4 6-9	13%	98%	--
	core #5 3-6	5.5%	90%	--
	core #6 0-3	23%	99%	--
	core #6 9-12	3.9%	94%	--
	core #7 6-9	0.0%	82%	--
	core #7 9-12	19%	86%	--

^a Since neither arsenic nor cadmium were added during the spiking of soil, the relative percent difference was calculated by comparing the results of the soil spiked with lead, and the soil that did not receive the lead spike.

^b The spike was added to the PBET apparatus along with the stomach solution and a soil sample.

**TABLE A-2. RELATIVE PERCENT DIFFERENCE BETWEEN
 REPLICATE SPLP TESTING OF SOILS
 (apparatus replicate samples)**

Test Stage /Sample ID	As	Pb	Cd
Stage 2 Tests			
VCA 1	3.7%	8.7%	0.0%
VCA 2	1.4%	12%	50% ^a
VCA 3	16%	16%	50% ^a
Stage 3 Tests			
Sampling 1	16%	12%	10%
Sampling 2	16%	10%	50% ^a
Sampling 3	0.0%	0.1%	25%
Sampling 4	1.3%	7.4%	25%

^a The high relative percent differences are driven by detection limit values.

**TABLE A-3. LEAD SPIKE RECOVERY
DURING THE SPLP TESTS
(apparatus spike or replicate samples)**

Test Stage/Sample ID	As Percent Difference Between Duplicate ^a	Pb Spike Recovery ^b	Cd Percent Difference Between Duplicate ^a
Stage 2			
VCA 1	12%	93%	0.0%
VCA 2	0.37%	98%	0.0%
Stage 3			
Sampling 1	0.46%	99%	0.0%
Sampling 2	4.0%	100%	0.0%
Sampling 3	25%	96%	13%
Sampling 4	2.5%	97%	8%

^a Since neither arsenic nor cadmium were added during the spiking of soil, the relative percent difference was calculated by comparing the results of the soil spiked with lead, and the soil that did not receive the lead spike.

^b The spike was added to the PBET apparatus along with the stomach solution and a soil sample.

**TABLE A-4. RESULT OF BLANK SAMPLES INCLUDED IN THE SPLP
TESTS CONDUCTED DURING STAGES 1, 2, AND 3.
(apparatus blank samples)**

Blank No.	As	Pb	Cd
Blank 1	0.068	0.06 u	0.004
Blank 2	0.05 u	0.06 u	0.006
Blank 3	0.05 u	0.06 u	0.005
Blank 4	0.05 u	0.06 u	0.004
Blank 5	0.05 u	0.06 u	0.003 u
Blank 6	0.05 u	0.06 u	0.003 u
Blank 7	0.05 u	0.06 u	0.003 u
Blank 8	0.05 u	0.06 u	0.003 u
Blank 9	0.05 u	0.06 u	0.003 u
Blank 10	0.05 u	0.06 u	0.003 u
Blank 11	0.05 u	0.06 u	0.003 u

u = not detected

**TABLE A-5. RELATIVE PERCENT DIFFERENCE BETWEEN
MEASURED AND ACTUAL CONCENTRATIONS IN STANDARDS
DURING THE ICP ANALYSIS OF EXTRACTS
(instrument replicate samples)**

Stage	Run Number	As	Pb	Cd
Stage 2				
	1	16%	5%	0%
	2	8.8%	1.0%	5.6%
	3	7.3%	8.4%	5.2%
	4	12%	8.6%	5.1%
	5	12%	6.9%	4.0%
	6	21%	13%	23%
	7	17%	16%	22%
Stage 3, Sampling 1				
	1	4.6%	0.8%	1.4%
	2	5.1%	1.3%	1.4%
	3	2.6%	25%	2.8%
Stage 3, Sampling 2				
	1	2.4%	2.3%	0.6%
	2	2.2%	25%	0.6%
	3	4.0%	7.9%	1.7%
Stage 3, Sampling 3				
	1	8.0%	2.0%	2.0%
	2	10.0%	3.0%	3.0%
	3	18.0%	6.0%	1.0%
Stage 3, Sampling 4				
	1	3.0%	8.6%	0.9%
	2	2.7%	14%	2.6%
	3	0.3%	8.5%	1.2%
Historical Application Study				
	1	2.3%	9.1%	1.8%
	2	5.5%	11%	1.6%
	3	3.0%	8.6%	0.9%
	4	2.7%	15%	2.6%
	5	0.3%	8.5%	1.2%
	6	3.0%	11%	0.7%
	7	8.1%	0.8%	0.2%
	8	1.1%	2.1%	0.7%
	9	0.3%	5.0%	— ^a
	10	1.4%	5.0%	— ^a
	11	0.8%	5.1%	— ^a
	12	6.4%	6.0%	— ^a
	13	0.6%	6.4%	— ^a
	14	2.3%	7.4%	— ^a
Batch Adsorption Tests				
	1	8.0%	16.9%	0.2%
	2	6.0%	28.0%	3.4%
	3	0.3%	16.1%	1.4%
	4	9.4%	16.6%	0.2%
	5	6.7%	7.2%	1.7%
	6	2.4%	9.4%	0.4%

^a Cadmium standard was not run.

**TABLE A-6. ARSENIC, LEAD AND CADMIUM CONCENTRATIONS
IN INSTRUMENT BLANKS ANALYZED
DURING THE ICP ANALYSIS OF EXTRACTS
(mg/L)**

Stage	Run Number	As	Pb	Cd
Stage 2	1	0.05 u	0.06 u	0.003 u
	2	0.05 u	0.06 u	0.003 u
Stage 3, Sampling 1	1	0.067	0.072	0.005
Stage 3, Sampling 2	1	0.05 u	0.06 u	0.007
Stage 3, Sampling 3	1	0.05 u	0.06 u	0.004
Stage 3, Sampling 4	1	0.054	0.06 u	0.003
Historical Application Study	1	0.05 u	0.06 u	0.003 u
	2	0.05 u	0.06 u	0.005
	3	0.05 u	0.06 u	0.003 u
Batch Adsorption Tests	1	0.058	0.06 u	0.003 u

**TABLE A-7. RESULTS OF TRIPPLICATE ANALYSIS PERFORMED
DURING THE BATCH ADSORPTION TESTS
(apparatus triplicate samples)
(mg/L)**

Sample ID	As	Pb	Cd
Triplicate Set 1			
T(4-2)1:1	0.074	0.074	0.13
T(4-2)1:2	0.05 u	0.06 u	0.12
T(4-2)1:3	0.066	0.06 u	0.16
Triplicate Set 2			
T(2-2)2:1	0.05 u	0.06 u	0.24
T(2-2)2:2	0.05 u	0.06 u	0.28
T(2-2)2:3	0.05 u	0.06 u	0.26
Triplicate Set 3			
T(b)3:1	0.11	0.06 u	0.013
T(b)3:2	0.065	0.06 u	0.020
T(b)3:3	0.093	0.06 u	0.021

u = not detected

**TABLE A-8. RESULTS OF MULTIPLE SPLP ANALYSIS OF
THE UNAMENDED PHASE II SOIL
(mg/kg)**

Sample ID	As	Pb	Cd
Replicate 1	6.92	2.4	0.12
Replicate 2	3.20	2.4	0.1
Replicate 3	3.02	2.28	0.1
Replicate 4	6.88	2.64	0.06 u
Replicate 5	3.10	2.1	0.06 u
Replicate 6	4.80	2.7	0.06 u
Average ^a	4.65	2.42	0.07
Standard Deviation ^a	1.86	0.22	0.04

u = not detected

^a Calculated using one half the detection limit values.