ENVIRONMENT
& HEALTH

MEMORANDUM

To: Dave Enos and Denise Mills, Teck American Incorporated

From: Rosalind Schoof, Ramboll; Amy Kephart, Ramboll; Nick Basta, Ohio State University; Shane Whitacre, Ohio State University

RE: PHASE IB: SOIL AMENDMENT TECHNOLOGY EVALUATION STUDY (SATES) SOIL AMENDMENT TECHNOLOGY SCREENING AND DESIGN

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This technical memorandum describes the soil amendment screening, evaluation, and selection process for bench-scale evaluation, as part of Phase IB of the Upper Columbia River (UCR) Soil Amendment Technology Evaluation Study (SATES). Initial screening of soil amendment technology options was completed as part of the Phase I Work Plan (Ramboll 2017a) to eliminate amendments that have clear drawbacks to their predicted potential for meeting study objectives. Evaluation of the remaining soil amendments and the selection of amendments for bench-scale testing in Phase IB is based on site-specific conditions (e.g., test plot soil chemical, mineralogical, and physical properties) as characterized during the test plot screening and characterization (Phase IA Parts 1 and 2).

Soil amendments selected in Phase IB will be evaluated during the Phase II bench-scale treatability study. A final list of amendments for pilot-scale testing on the test plots will be developed based on the bench-scale test results.

1. Phase IA Test Plot Soil Characterization Summary

In Phase IA, soil sampling was completed to provide a comprehensive understanding of the soil chemical, mineralogical, and physical properties at test plots located on three tribal allotments to: 1) identify the characteristics that will affect amendment performance and inform the design of appropriate soil amendment options for pilot testing, and 2) establish the baseline conditions at each test plot.

The data collection and analysis methods for Phase IA are detailed in the Phase I Work Plan (Work Plan; Ramboll 2017a), an addendum to the Work Plan (Work Plan Addendum; Ramboll 2017b), the resultant Phase IA data summary report (DSR) (Ramboll 2018), and supporting mineralogy reports *(*Scheckel et al., 2018; Hazen, 2018)*.*

Field activities from Phase IA included:

- <u>Phase IA Part 1: Initial Test Plot Screening</u> – Delineated six initial test plots within each of three decision units (DUs]): 401, 258, and 441. Initial screening of these test plots was conducted to identify the distribution of lead and arsenic concentrations in shallow soils across each test plot, soil pH values, and forest litter (duff) thicknesses (see Table 1). Based on the initial screening results, four test plots (258-3, 401-1, 401-2, and 441-1) were selected for additional characterization in Phase IA Part 2. The test plot locations are shown in DSR Figures 1-1, 1-2, 1-3, and 1-4.

- Phase IA Part 2: Test Plot Soil Characterization – Defined four sub-plot areas within each test plot for more detailed characterization. This involved depth-discrete soil sampling and analysis, incremental composite (IC) sampling and chemical analysis of two soil size fractions (< 2 millimeter [mm] and < 150 micrometers [µm]), soil classification, and mineralogical analyses of selected samples, as shown in Table 1.

A subset of the soil characterization data from the four test plots (258-3, 401-1, 401-2, and 441-1) was reviewed to evaluate how amendment performance may be affected by the existing soil conditions. The data was also reviewed to evaluate potential effects to soil conditions by the application of soil amendments. The test plot soils were evaluated for bioaccessible lead and arsenic, the lateral and vertical distribution of total lead and arsenic, soil physical properties (i.e. particle size, bulk density), pH, total organic carbon, and lead speciation/mineralogy.

Evaluation of the expected performance of the soil amendment technology options included reviewing available information and site-specific data to develop an understanding of mineral forms present, chemical reactions that could reduce reactivity and mobility of metal constituents, and appropriate amendments to drive those reactions. The evaluation also included a preliminary review of the infiltration characteristics and availability of soluble amendments to be applied to the soil.

The results of this review are summarized below and used in Section 2 to inform predictions on amendment performance and viability for further review in Phase II bench-scale investigations. Although characteristics of the soil at individual test plots and sub-plots vary, the soil properties that influence lead bioaccessibility are similar in each of the test plots. These properties inform predictions of amendment performance and the treatability of the soils and are discussed below.

Lead Bioaccessibility. Lead bioaccessibility was reviewed to identify the site soil's potential for remediation. In future phases, it will be a measure to evaluate soil treatment efficacy. Bioaccessible lead results for pH 1.5 are shown in Table 2.[1] Bioaccessible lead results for the < 150 µm soil fraction at pH 1.5 for test plot soils ranged from 63.2% to 82.2% (see Table 2). The primary soil parameter used to inform amendment selection for each of the test plots is a lead bioaccessibility above 60%. All of the test plots meet this criterion, which makes each test plot a good candidate for treatments to reduce lead bioaccessibility.

Lead Concentrations and Soil Depth. Total lead concentrations were reviewed to understand the potential magnitude of bioaccessibility reductions. The total lead concentration by depth is summarized in Table 3. The majority of elevated lead concentrations occur in the first 0 to 4 inches of the soil (Table 3). Lead concentrations decreased with depth at each test plot. Even sampling points with high lead concentrations (> 1,000 mg/kg) in the top 2 inches showed less than 100 mg/kg lead at depths below 4 inches. As a result, amendments applied superficially with minimal incorporation into the soil would be expected to be effective at reducing lead exposure through reductions in lead bioaccessibility.

Bioaccessible and Total Arsenic. Arsenic concentrations were reviewed due to the potential increase in arsenic availability when phosphorus amendments are introduced. Arsenic

[1] Only pH 1.5 bioaccessible lead results are utilized for initial site assessment and pH 2.5 bioaccessible lead results are utilized for treatment efficacy, particularly phosphorus treatments.

concentrations from Phase IA provide a baseline to evaluate potential increases as a result of treatments applied to reduce lead bioaccessibility. Bioaccessible arsenic results for the < 150 µm soil fraction at pH 1.5 for test plot soils ranged from 8.6% to 24.7% (see Table 2), which is below the relative arsenic bioavailability default of 60% used in risk assessments. Similar to lead, arsenic concentrations decreased with depth at each test plot with total arsenic contents < 30 mg/kg at depths below 4 inches. Total arsenic concentrations by depth are summarized in Table 3.

Soil Physical Properties. Soil physical properties were reviewed to understand soil types and characteristics across the test plots. Particle size was reviewed as an indicator of the amount of reactive surface present and to understand the fraction of bulk soil potentially available for incidental ingestion. The lead bioaccessibility values measured are consistent with the sandy composition of the soil texture and only a small fraction of reactive fines capable of binding lead to oxide surfaces are present in the fines. Soils were composed of 2.49% to 4.52% fines (< 2 µm fraction), 12.9% to 39.3% silt (2 µm to 50 µm fraction), 57.6% to 84.7% sand (50 µm to 2 mm fraction), and 1.34% to 44.3% gravel (> 2 mm fraction). These results and field observations indicate that the soils are predominantly composed of sand and silt with varying fractions of gravel and minimal fines.

Duff Thickness. While the majority of the lead was contained in the top 0 to 4 inches of soil, the soils on most of the test plots have an additional duff layer on top of the mineral soil. The duff thickness overlying test plot soils ranged from 0 to 4 inches. The lateral variability in duff thickness for each test plot is shown in Figure 3-10 of the DSR and included in DSR Table 3-1. This will be an important consideration for amendments being considered for testing, especially those included in the study solely to provide a physical barrier to exposure without expected effects on lead bioaccessibility.

Soil pH. Soil pH values were reviewed because pH affects lead mineralogy, stability, and availability in soil. The pH of all the test plots was slightly to moderately acidic, which favors soil amendments that are non-acidic or slightly alkaline that would raise the test soil pH befitting plant growth and reduce lead phytoavailability. The mean pH measured in test plot soil was approximately pH 4.0. The pH values measured in the soil samples collected from each test plot are shown in DSR Figure 3-9.

Mineralogy and Organic Carbon Content. Lead speciation and mineralogy was reviewed to inform bioaccessibility results and potential for bioaccessibility reductions. Mineralogy determination by QEMSCAN (Hazen, 2018) identified a small percent (0.004% to 0.08%) of total mineral phases identified as non-specific lead-bearing minerals rather than discrete lead mineral phases (e.g., pyromorphite) (see Attachment A). The lead mineralogy by X-ray absorption spectroscopy (Scheckel et al., 2018) presented in Table 4 is more specific and identified lead sorbed to clay/oxide (0% to 70%) and/or bound to organic matter (30% to 100%). These forms of lead typically exhibit high bioaccessibility, which is confirmed by the analytical lead bioaccessibility results.

The lead mineralogy was similar across all test plots with lead sorbed to clay/oxide and/or bound to organic matter (Table 4). This is consistent with the relatively high total organic carbon (range of 4.25% to 6.99%) in soil within the test plots (Table 5). This will be an important consideration for amendments included in the study to improve soil quality by increasing the organic carbon content.

Key properties for individual test plots that influence soil amendment selection are summarized in Table 5. While there are some differences in the spatial distribution in the test plots and individual sub-plot properties, soils from each of the four selected test plots have relatively similar properties that influence lead bioaccessibility.

2. Soil Amendment Evaluation and Screening Based on Site-Specific Data

Based on the initial screening of soil amendment technology options in the Work Plan, certain amendments were eliminated from further consideration that have clear drawbacks to their predicted potential to meet study objectives. This section summarizes the additional soil amendment evaluation method and the soil amendment technology options evaluated for further assessment in Phase II.

Methods for Soil Amendment Selection for Phase II Bench-Scale Testing

The soil amendment qualities that were evaluated, in order of importance, include the ability to: 1) reduce lead bioaccessibility; 2) improve vegetative barrier through improved soil quality or improve soil structure to reduce mobility of contaminated soil; and 3) establish a physical barrier to exposure to soils with elevated lead concentrations. The decision basis for each of these criteria are described below and illustrated in a diagram in Figure 1:

1. Soil amendments were first assessed based on predicted ability to reduce lead bioaccessibility (i.e., predicted lead binding, available phosphorus content, and lead sorption and retention capacity). If an amendment has potential to reduce lead bioaccessibility, it is retained as a candidate for bench testing.
2. If the soil amendment does not show potential to reduce lead bioaccessibility but it has properties that could influence soil quality (i.e., nutrients, organic carbon, and pH), then it remains a candidate for bench testing, as it may be used as a combination treatment that is applied with another amendment.[2]
3. If the amendment does not show potential to convert the lead to a less bioaccessible form or to improve soil quality, but it can act as a physical barrier to lead-impacted soil, then it will not be included in the bench-scale testing. Bench testing is not an appropriate method to confirm the qualities of the physical barrier created by these types of amendments. However, note that these amendments will be retained for potential use in later pilot testing or field-scale testing.
4. Each amendment will also be reviewed for local source options and ease of application.

Soil Amendment Screening and Evaluation Summary

Three amendments that were initially considered were eliminated from further consideration based on preliminary screening criteria in the Work Plan.

1. Phosphorus as apatite was eliminated due to the inability to locate a local source at the quantities needed for field-scale application and the need for soil blending for effective application of the material.

[2] As part of the Phase II soil amendment evaluation, a decision will need to be made if adjustments to soil quality are necessary and/or beneficial. This may be site-specific and applicable beyond the SATES test plots, so treatments that have potential to influence soil quality are included in Phase II bench-scale testing. They would be applied in combination with other amendment alternatives to assess the effect on soil quality.

2. Manganese oxides were removed from further consideration primarily due to the potential to discolor the application area and damage plants in the treatment areas.
3. Proprietary treatments such as ECOBOND were eliminated due to supply concerns, the proprietary nature of the products, and the need for soil blending for effective material application.

The data collected in Phase IA did not offer new information about the test plot conditions that would support reconsideration of these amendments. The remaining soil amendment alternatives are discussed below.

Soluble Phosphorus

Phosphorus is the most extensively-studied amendment with proven efficacy to reduce lead bioaccessibility. A clear link between lead pyromorphite formation and bioaccessibility reduction has been demonstrated in several studies. Additionally, reductions in bioaccessibility associated with pyromorphite formation are considered to be permanent unless extreme changes in soil conditions occur, although phosphorus addition has the potential to increase arsenic bioaccessibility. At the SATES test plots, bioaccessible arsenic concentrations (Table 2) are well below the relative bioavailability default (60%) used in risk assessments, indicating that the arsenic on these sites is bound tightly to the soil. This suggests that additions of phosphorus may not cause an increase in arsenic mobilization risk that would offset the benefit of bioaccessible lead reductions. The data collected in Phase IA revealed test plot conditions that support continued evaluation of soluble phosphorus during bench-scale testing.

Biosolids

High-iron biosolids have also been shown to reduce lead bioaccessibility. The reductions in bioaccessibility are associated with lead sorption to iron oxide surfaces. However, the efficiency of this reaction depends on the amount and type of iron in the biosolids. A biosolid with greater than 8 grams per kilogram (g/kg) total iron would be considered a high-iron biosolid and a good candidate for treatment to reduce lead bioaccessibility. In addition, increased concentrations of total iron as amorphous iron increases the likelihood of lead sorption to the iron oxide. The data collected in Phase IA revealed test plot conditions that support continued evaluation of biosolids during bench-scale testing.

Wood Ash

Wood ash has not been thoroughly tested for its ability to reduce lead bioaccessibility. However, wood ash does often contain phosphorus that could play a role in pyromorphite formation depending on the quantity and availability of the phosphorous present. The data collected in Phase IA revealed test plot conditions that support continued evaluation of wood ash during bench-scale testing.

Biochar

Similar to wood ash, biochar has not been thoroughly tested for its ability to reduce lead bioaccessibility. However, biochar has the advantage of being a tailored product and biochar tailored to reduce lead may have potential. In particular, biochar made from manures can potentially be a source of soluble phosphorus in addition to highly reactive surfaces. The data collected in Phase IA revealed test plot conditions that support continued evaluation of biochar during bench-scale testing.

Woody Debris

Woody debris was included as a potential physical barrier to lead exposure and is not expected to reduce lead bioaccessibility. As discussed previously, most of the test plots contain a duff layer that acts as a physical barrier. As a result, the woody debris would need to contribute a desirable change to soil quality to be considered a candidate for bench-scale testing. Because of the high organic carbon content of soils in the test plots, adding a strictly organic amendment such as woody debris is not likely to improve soil quality. However, if site-specific reductions in bioaccessibility cannot be achieved with the treatments evaluated in the bench-scale testing, then woody debris could be used as a physical barrier to direct exposure.

Compost

Composts are a good source of organic matter and nutrients. Compost can contain significant levels of phosphorus, which has the potential to reduce bioaccessible lead. It may be desirable to use it in combination with other alternatives. Compost has the potential to improve soil structure, serve as a physical barrier to soil exposure, and support development of a vegetative barrier to soil exposure. When used alone, however, it is not likely to serve as a long-term physical barrier due to decomposition. Composts can affect the nitrogen content and pH in soil, so the potential effects on native and non-native plants should be considered in the evaluation of alternative amendments or amendment mixtures.

3. Recommendations and Conclusions

Based on the criteria presented in Section 2, treatments that pass the screening for the potential to reduce lead bioaccessibility should be carried into Phase II for bench testing. These include soluble phosphorus, biosolids, wood ash, biochar, and compost. These materials should be tested as individual soil treatments and in combination with other treatments to monitor and evaluate the effectiveness of different treatment alternatives for reducing lead bioaccessibility and how they may affect soil structure, texture, nitrogen content, and chemistry.

4. References

Hazen (Hazen Research, Inc.). 2018. QEMSCAN Analysis of Four Samples from the Upper Columbia River Remedial Investigation and Feasibility Study and Background Information on QEMSCAN Technology. Prepared by Hazen Research, Inc., Golden, CO, for Teck American Incorporated. March 30.

Ramboll (Ramboll Environ). 2017a. FINAL Work Plan for the Soil Amendment Technology Evaluation Study Phase I: Test Plot Characterization and Initial Amendment Alternatives Evaluation. Prepared by Ramboll Environ, Seattle, WA, for Teck American Incorporated. Seattle, WA. July.

Ramboll. 2017b. Addendum - Soil Amendment Technology Evaluation Study (SATES) Final Work Plan for the Soil Amendment Technology Evaluation Study, Phase I: Test Plot Characterization and Initial Amendment Alternatives Evaluation. Prepared by Ramboll Environ, Seattle, WA, for Teck American Incorporated. September 29.

Ramboll. 2018. Draft Data Summary Report for the Soil Amendment Technology Evaluation Study Phase IA: Test Plot Selection and Characterization. Prepared by Ramboll, Seattle, WA for Teck American Incorporated.. July.

Scheckel, K., R. Karna, and T. Luxton. 2018. UCR Soil-Pb Speciation Report. U.S. Environmental Protection Agency National Risk Management Research Laboratory, Cincinnati, OH. March.

TABLES

Table 1. Summary of Phase IA Parts 1 and 2 Analyses

Analysis	Sieve Fraction	Party	Grab Sample	IC Sample
Phase IA Part 1[a]				
Analysis	**Sieve Fraction**	**Party**	**Grab Sample**	**IC Sample**
Total Arsenic and Lead	< 2 mm	ALS Environmental	100	NA
pH	Bulk	Field personnel	100	NA
Soil description	Bulk	Field personnel	100	NA
Forest litter (duff) thickness	Bulk	Field personnel	100	NA
Phase IA Part 2[b]				
Analysis	**Sieve Fraction**	**Party**	**Grab Sample**	**IC Sample**
Total TAL Metals (except Hg)	< 2 mm (grab)	OSU	24	NA
	< 2 mm (IC)	OSU	NA	8
	< 150 µm (IC)	OSU	NA	8
SPLP TAL Metals (except Hg)	< 2 mm	ALS Environmental	0	4
Bioaccessible Arsenic and Lead	< 150 µm	OSU	0	4
	< 150 µm	OSU	0	4
Mehlich III Extractable Lead and Phosphorus	< 150 µm	OSU	0	4
Electrical Conductivity	Bulk	OSU	0	4
Chloride	< 2 mm	OSU	0	4
Sulfate	< 2 mm	OSU	0	4
Sulfide	Bulk	ALS Environmental	0	4
Total Carbon and Nitrogen	< 2 mm	OSU	0	4
Total Organic Carbon	Bulk	ALS Environmental	0	4
Soil Moisture Holding Capacity	Bulk	OSU	4	0
Grain Size Analysis	Bulk	OSU	0	4
Lead/Arsenic and General Soil Mineralogy	< 150 µm (IC) < 2 mm (grab)	USEPA Kirk Scheckel	1	4
	< 2 mm (grab)	Hazen Labs	1	0
Soil Horizon Descriptions	Bulk	Field Personnel	NA	NA
In Situ Bulk density	Bulk	HWA Geosciences, Inc.	4	0
In Situ Permeability	Bulk	HWA Geosciences, Inc.	4	0

Notes:
[a] Grab samples per test plot on 401-1, 401-2, 258-1, 258-2, 258-3, and 441-1
[b] Grab samples per test plot on 401-1, 401-2, 258-3, and 441-1; and IC samples per test plot on 401-1, 401-2, 258-3, and 441-1
µm = micrometer
mm = millimeter
NA = not analyzed

Table 2. Bioaccessible (pH 1.5) and Total Arsenic and Lead (< 150 μm fraction) by Sub-plot in Test Plots 401-1, 401-2, 258-3, and 441-1

Test Plot		**401-1**		
Sub-plot	401-1A	401-1B	401-1C	401-1D
IVBA Arsenic (%)	17.6	16.7	17.5	17.6
IVBA Lead (%)	74.4	65.3	78.4	73.4
Total Arsenic (mg/kg)	68.4	87.5	80.1	92.4
Total Lead (mg/kg)	1,130	1,230	1,320	1,450
Test Plot		**401-2**		
Sub-plot	401-2A[a]	401-2B	401-2C	401-2D
IVBA Arsenic (%)	21.5	16.9	16.7	18.7
IVBA Lead (%)	76.7	82.2	68.9	77.5
Total Arsenic (mg/kg)	114.6	83.8	99.2	87.8
Total Lead (mg/kg)	1,587	964	1,350	1,180
Test Plot		**258-3**		
Sub-plot	258-3A	258-3B	258-3C	258-3D
IVBA Arsenic (%)	8.6	8.9	13.0	12.5
IVBA Lead (%)	69.1	63.2	73.8	69.3
Total Arsenic (mg/kg)	37.3	36.7	33.3	42.2
Total Lead (mg/kg)	419	547	651	672
Test Plot		**441-1**		
Sub-plot	441-1A	441-1B	441-1C	441-1D
IVBA Arsenic (%)	24.7	23.9	24.7	21.6
IVBA Lead (%)	76.9	78.6	80.7	81.4
Total Arsenic (mg/kg)	33.3	40.8	37.8	38.7
Total Lead (mg/kg)	552	556	612	441

Notes:

[a] Average of three separate IC samples

No data validation qualifiers are shown in this table. Refer to the Phase IA DSR for data validation qualifiers.

μm = micrometer

IVBA = in vitro bioaccessibility

mg/kg = milligrams per kilogram

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Table 3. Total Arsenic and Lead Concentrations by Depth and Sub-plot in Test Plots 401-1, 401-2, 258-3, and 441-1 (< 2 mm fraction)

Depth (inches)	0-2	2-4	4-6	6-8	8-10	10-12	0-2	2-4	4-6	6-8	8-10	10-12
Test Plot	**401-1**											
Sub-plot	401-1-A						401-1-B					
Arsenic (mg/kg)	16.9	39.3	29.8	7.7	3.8	3.6	47.5	6.1	10.1	5.3	3.6	3.7
Lead (mg/kg)	1,010	487	199	41.2	14.2	14.1	113	14.6	32.1	11.0	6.4	7.0
Sub-plot	401-1-C						401-1-D					
Arsenic (mg/kg)	38.3	30.6	5.7	4.2	4.6	2.9	45.0	17.5	5.9	4.7	4.2	4.9
Lead (mg/kg)	884	82.4	11.7	7.4	8.3	6.8	1,160	75.9	14.2	10.9	9.0	7.9
Test Plot	**401-2**											
Sub-plot	401-2-A						401-2-B					
Arsenic (mg/kg)	75.7	19.1	6.6	4.3	4.6	4.1	34.8	26.0	15.1	4.4	4.3	3.8
Lead (mg/kg)	384	71.5	13.4	13.5	12.7	6.6	329	869	72.1	7.6	6.8	7.0
Sub-plot	401-2-C						401-2-D					
Arsenic (mg/kg)	62.6	69.6	18.7	6.9	4.1	4.4	35.6	42.0	54.2	15.4	4.9	4.6
Lead (mg/kg)	996	335	107	20.7	10.2	10.9	843	901	564	18.2	15.6	11.7
Test Plot	**258-3**											
Sub-plot	258-3-A						258-3-B					
Arsenic (mg/kg)	21.5	22.5	22.9	8.1	4.3	3.9	35.8	11.6	2.5	1.9	2.3	2.0
Lead (mg/kg)	474	85.4	78.8	23.9	8.9	7.0	216	30.8	9.9	5.0	4.1	4.1
Sub-plot	258-3-C						258-3-D					
Arsenic (mg/kg)	9.4	15.9	13.1	3.6	2.9	3.0	13.4	11.4	2.8	1.9	1.7	2.1
Lead (mg/kg)	102	243	112	9.3	6.8	4.7	196	150	7.0	4.6	2.9	3.2
Test Plot	**441-1**											
Sub-plot	441-1A						441-1B					
Arsenic (mg/kg)	22.5	19.8	16.7	15.7	16.7	12.7	40.2	21.9	15.5	10.6	6.9	7.9
Lead (mg/kg)	1,020	105	37.2	29.6	13.8	13.1	674.5	44.1	188	33.5	22.0	14.9
Sub-plot	441-1C						441-1D					
Arsenic (mg/kg)	34.8	16.6	8.0	8.1	6.0	6.3	19.8	13.4	7.4	5.8	6.2	5.9
Lead (mg/kg)	38.3	16.3	9.6	9.6	8.9	10.1	143	62.1	19.2	9.8	9.5	8.8

Notes:

No data validation qualifiers are shown in this table. Refer to the Phase IA DSR for data validation qualifiers.

mg/kg = milligrams per kilogram

mm = millimeter

Table 4. Lead Speciation Distribution Based on X-ray Absorption Spectroscopy Analysis

SATES Phase IA Part 2 Sample ID	EPA Lab ID	Speciation Distribution (%)		Mean Squared Error (χ2 [error])
		Organic Matter Bound	Clay/Oxide Sorbed	
IC-401-1A-101017	Pb_K17_001	76	24	0.0206
IC-401-1B-101017	Pb_K17_002	57	43	0.0114
IC-401-1C-101117	Pb_K17_003	43	64	0.0242
IC-401-1C-101117-D	Pb_K17_004	78	26	0.0116
IC-401-1D-101117	Pb_K17_005	63	41	0.0090
IC-401-2B-101117	Pb_K17_006	51	55	0.0201
IC1-401-2A-101217	Pb_K17_007	79	25	0.0057
IC2-401-2A-101217	Pb_K17_008	65	41	0.0151
IC3-401-2A-101217	Pb_K17_009	73	30	0.0086
IC-401-2C-101217	Pb_K17_010	46	56	0.0097
IC-401-2D-101217	Pb_K17_011	94	10	0.0166
IC-258-3A-101717	Pb_K17_012	58	42	0.0567
IC-258-3B-101717	Pb_K17_013	71	30	0.0365
IC-258-3C-101717	Pb_K17_014	30	70	0.0218
IC-258-3D-101717	Pb_K17_015	78	22	0.0347
IC-441-1A-101617	Pb_K17_016	53	47	0.0553
IC-441-1B-101617	Pb_K17_017	51	55	0.0294
IC-441-1C-101617	Pb_K17_018	39	64	0.0269
IC-441-1D-101617	Pb_K17_019	67	35	0.0710
D-401-1B-100317-0-3	Pb_K17_001_CDA_OUT	75	25	0.0008
D-401-2C-100317-0-3	Pb_K17_002_CDA_OUT	66	34	0.0085
D-258-3C-100317-0-3	Pb_K17_003_CDA_OUT	100	0	0.0292
D-441-1B-100317-0-3	Pb_K17_004_CDA_OUT	64	36	0.0044

Notes:

Data from Scheckel et al., 2018.

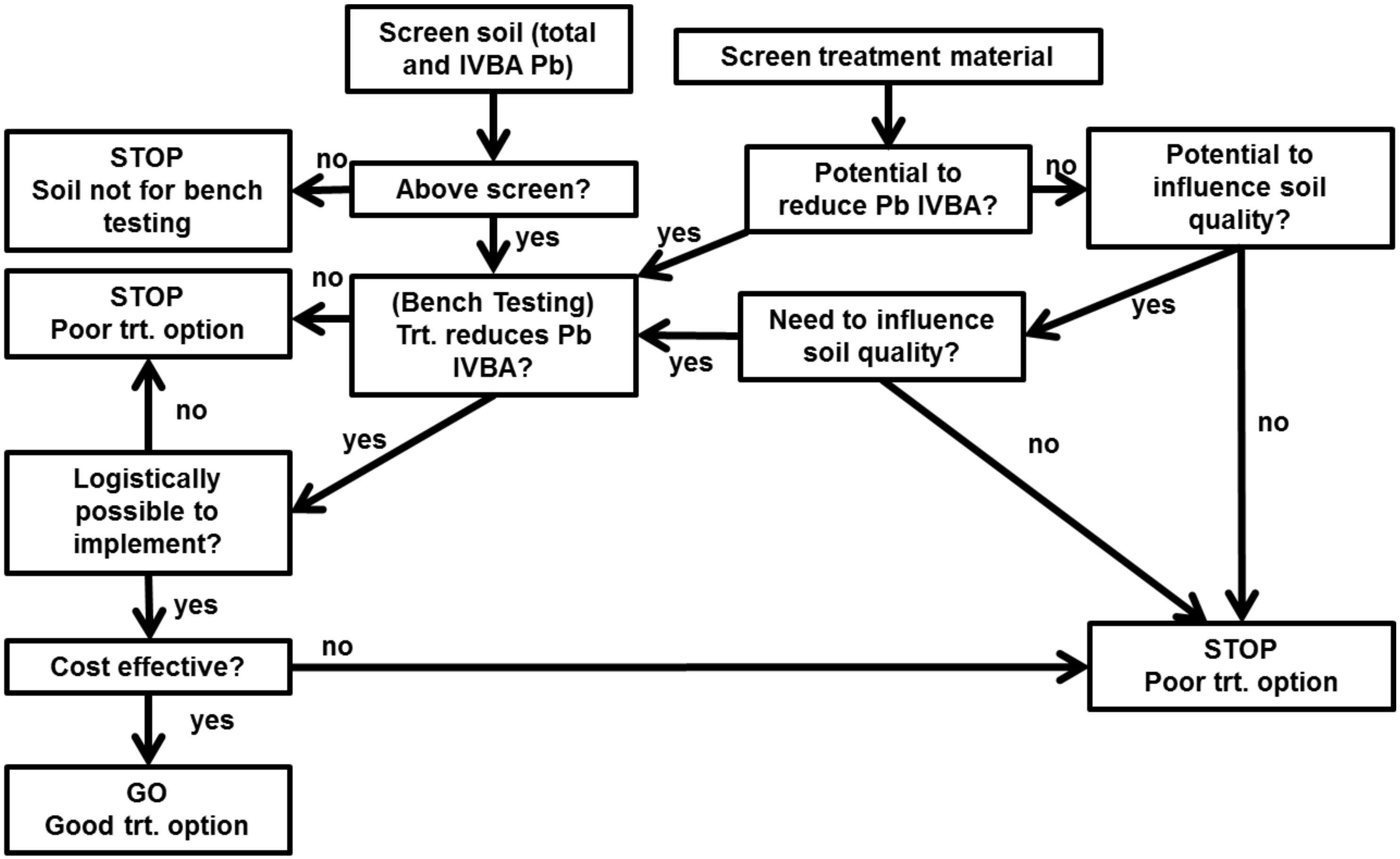
Table 5. Summary of Key Properties of Test Plot Soils that Influence Amendment Selection

		Test Plot Averages				All IC samples from Test Plots		
Parameter	**Unit**	**401-1**	**401-2**	**258-3**	**441-1**	**Overall minimum**	**Overall maximum**	**Overall mean**
Total Lead (< 150 µm)	mg/kg	1283	1270	572	540	419	1587	916
Total Arsenic (< 150 µm)	mg/kg	82.1	96.4	37.4	37.6	33.3	114.6	63.4
IVBA Arsenic (pH 1.5; < 150 µm)	%	17.3	18.4	10.8	23.7	8.6	24.7	17.6
IVBA Lead (pH 1.5, < 150 µm)	%	72.9	76.3	68.9	79.4	63.2	82.2	74.4
pH		4.81	4.79	5.27	5.99	4.55	6.16	5.21
Total Organic Carbon	%	5.34	6.44	4.25	6.99	3.33	8.48	5.75
Sand	%	80.6	74.3	82.4	60.2	57.6	84.7	74.4
Silt	%	16.0	21.6	14.8	36.3	12.8	39.3	22.2
Fines	%	3.36	4.10	2.80	3.52	2.49	4.52	3.45
Gravel	%	25.9	38.0	2.37	35.3	1.34	44.3	25.4

Notes:
µm = micrometer
IVBA = in vitro bioaccessibility
mg/kg = milligrams per kilogram

FIGURE

Figure 1. Flow chart for selecting amendments for Phase II bench testing and implementation.



Notes:
Trt. = Treatment
Pb IVBA = Lead in vitro bioaccessibility

ATTACHMENT A

Table 2. Mineral Abundance of Minus 2 mm Fractions

Client sample ID	**D-401-1B**	**D-401-2C**	**D-258-3C**	**D-441-1B**
HRI number	**54909-1-5**	**54909-2-5**	**54909-3-5**	**54909-4-5**
Mineral	**Mass, %**			
Pb-bearing	0.08	0.02	0.004	0.02
Arsenopyrite	0.08	0.0003	0.001	0.0003
Fe sulfides	0.03	0.001	0.001	0.001
Quartz	32	33	35	19
Feldspar	49	46	50	54
Mica–chlorite–talc	5.1	8.5	4.2	9.2
Other silicates	9.2	9.0	8.5	11.0
Apatite	0.3	0.3	0.2	1.2
Barite	0.003	0.0005	0.0002	0.0004
Rutile or anatase	0.1	0.2	0.2	0.1
Fe–(Ti) oxides	2.2	2.0	0.9	1.6
Ce-phosphate (monazite)	0.02	0.01	0.01	0.02
Carbonate	0.1	0.04	0.05	0.1
Organics[a]	0.1	0.03	0.02	0.1
Miscellaneous	0.4	0.5	0.2	0.9
Unidentified	1.4	1.1	0.7	2.6
Total	**100**	**100**	**100**	**100**

Note: the results are normalized and exclude the main portion of the organics reporting to the minus 2 mm fraction.
[a]The reported mass of organics in the table represents only a portion of the total organics reporting to the size fraction. The organics were analyzed because of elevated BSE signal levels.

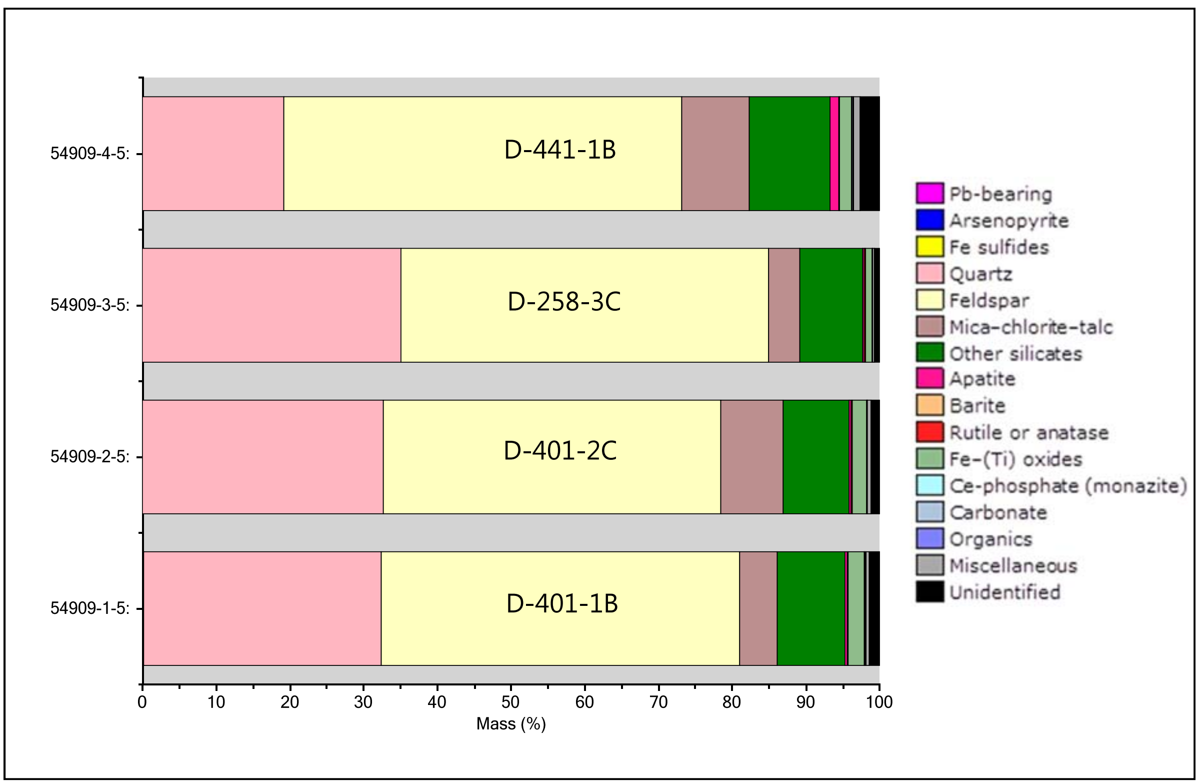


Figure 1. Bar Graph of Mineral Abundance Data of Minus 2 mm Fractions