Assessment of the Economics and Effectiveness of Alluvium Sorting as a Mine Waste Removal Strategy at the Project Implementation Level

Final Report
March 2008

Prepared by:
Idaho Department of Environmental Quality
Coeur d'Alene Regional Office
2110 Ironwood Parkway
Coeur d'Alene ID 83814

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Final Report: Assessment of the Economics and Effectiveness of Alluvium Sorting as a Mine Waste Removal Strategy at the Project Implementation Level

1.0 Executive Summary: Bench scale studies supported by the Environmental Protection Agency clearly demonstrate that in mixed alluvium contaminated through erosion of tailings and subsequent deposition, the metals concentrations are found in the 19-millimeter (mm) minus fraction. These results suggest that a sorting strategy could be cost-effective in the removal of wastes composed of contaminated alluvium. Costs of sorting might be offset by avoided haul costs and repository space savings. Sorted contaminated material might also have superior compaction and permeability characteristics. An effectiveness monitoring approach that targets the actual pollutant, streambed entrained tailings, could be a superior method compared to water column or bio-monitoring, which monitor surrogates of the actual pollutant.

The Monarch Mill site is located in Prichard Creek. Mine ore was milled at the site prior to the era of floatation technology. Jig tailings originally deposited near the mill site have been eroded and mixed with the stream alluvium over the majority of the site (3.5 acres). The Monarch site was well suited to test the economics of a sorting strategy and the resulting physical characteristics of sorted material at a project-level scale. The upstream location in the Prichard Creek watershed, and the fact that the streambed itself did not require removal treatment, made the site ideal for project monitoring through the assessment of streambed contaminant levels.

Mine wastes at the Monarch Mill site were removed during the 2005 construction season. Jig tailings were removed from areas 2 and 3, while the waste rock deposit (area 1) was left in place. Areas 4 and 5 at the site contained an alluvium-tailings mix. These areas were addressed with a sorting strategy that removed 14,119 cubic yards of material and sorted it on site to separate the 25-mm plus and 25-mm minus fractions. The 25 mm minus fraction was removed to a repository, while the 25-mm plus material was placed where it can be applied to the waste rock pile off the floodplain. Careful records were kept daily of the material treated and exported from the site. The final size of the tailings deposit was surveyed prior to repository closure. Materials testing of sorted and unsorted compacted materials were completed both in-situ and in the laboratory. Streambed sediments were sampled to assess the pre- and post-removal concentrations of metals contaminants.

The project level alluvium sorting provided an economic advantage. The project saved $92,889, because sorting was implemented on areas 4 and 5. The initial expense of sorting was more than offset by the savings recouped from not hauling and handling the 25-mm plus fraction. When the savings in repository space are factored in, sorting provided a large economic advantage. The savings would have been larger if an economic outlet for the 25-mm plus material had been developed. The project placed the 25-mm plus material where it could be incorporated into the waste rock pile off the floodplain. If this cost were avoided by having an outlet for the 25-mm plus material, the cost savings would have been $102,518 or 22% of the total project cost of $458,406.

Materials testing of sorted tailings did not identify a superior level of compaction compared to mixed materials, although the theoretical percentage of compaction of the sorted material was greater. Laboratory testing suggested the sorted material would have a two- to ten-fold lower permeability, but empirical measurements were not made.

Sufficient streambed sediment samples were collected prior to removal to assess whether a statistically significant change in bed load metals concentration occurs after removal and bank-full discharge events that are sufficient to cause streambed alteration. During the past two years, three bank-full discharge events occurred on the reach of Prichard Creek within the Monarch site. These discharge events had sufficient energy to dislodge and cause fluvial sorting of streambed substrate. Through this mechanism, sediment enriched in metals should be winnowed out of the streambed substrate. Post-removal sampling of streambed sediments demonstrates a statistically significant decline of zinc concentration in the 3-19 mm particle size fraction. Trend analysis predicts decline in zinc and lead concentrations in the less than 3 mm fraction. The trend lines indicate statistically significant values will be attained five years after removal. Lead concentration did not decline in the 3-19 mm particle size fraction from the already low 3-year average: 312 ug/g. This lead concentration is 137 ug/g higher than the estimated background lead concentration in the soils of the Coeur d'Alene Mining District. The lead concentration measured for this fraction may constitute a short term practical limit in a mineralized area where mining and milling have occurred.

2.0 Introduction: Mixed bed load sediment-jig tailings deposits pose a removal challenge for metals cleanup projects in the upper basin of the Bunker Hill Superfund site (Operable Unit 3). All the material might be removed from the floodplain and stream channel and placed in a repository – an approach known as “dig and haul.” However, this approach introduces gross inefficiencies. A considerable volume of material with no metals contamination is transferred to waste repositories. Waste repository space is sufficiently limited that the placement of such “clean” alluvium is a waste of repository resource. In addition, the heterogeneous particle size of material removed in bulk may reduce the ability to attain desired compaction in the repository. Less compaction potentially compromises the repository function of isolating the tailings from water. In some cases, total removal locally at least temporally depletes the stream alluvium, the primary component of many stream channels.

Bench-scale studies demonstrated that in a tailings-alluvium mix, the metals-bearing material is in the fraction with particle size of 19 millimeter (mm) (three-quarter inch) or less (the 19-mm minus fraction) (Paulson et.al. 1996a; Paulson et.al. 1996b). Simple screening methods used routinely in gravel sorting are available to separate 19-mm minus material from larger alluvium. However, the economics of a sorting approach, based on its savings in haulage costs, reduced repository space, and more efficient compaction compared against the cost of additional handling had not been investigated at a project level. The contamination decline in streambed alluvium post-removal also had not been sufficiently assessed.

At the Monarch Mill Site in the Prichard Creek Watershed (Figure 1), a removal action from private land was planned by the Department of Environmental Quality in cooperation with its partner in mine remediation in the North Fork Coeur d’Alene Basin, the U.S. Forest Service. The Monarch Removal Action involved a floodplain area of approximately 3.5 acres, where alluvium was contaminated with “jig tailings” eroded from the two upstream tailings piles (Figure 2). The project provided an opportunity to assess the economics and physical compaction benefits of sorting alluvium and transporting only the contaminated fraction to the repository. For this project, the 25-mm minus fraction was sorted from the excavated material and placed in the repository. The oversized material was placed where it could be incorporated into the waste rock pile. Prichard Creek traverses the site and contaminated areas adjoin it closely in two locations; however, no removal of material from the stream bed was required in the remedial plan. For this reason, Prichard Creek as it traverses the project area was a good location for assessing the effectiveness of the remediation by assessing sediment contaminant levels before and after project implementation. The project removed the source of further contamination, but cleansing of the stream will require one or several bank-full discharge (channel-altering) events. This report provides post-removal streambed sediment metals concentration data, collected after three bank-full discharge channel-altering events. Definitive data on the economics and compaction effects of this application of a project-level alluvium sorting approach are provided.

3.0 Objective: The objective of the project was to establish, at a removal project level, the costs of a simple screening of excavated contaminated alluvium. The cost savings in reduced haulage, efficient compaction, and reduced requirements for repository space were measured to assess the overall value of the approach. The second objective was to assess the beneficial value of the removal strategy by assessing the change in metals content of the 19-mm minus fraction of the bed load sediment downstream. To obtain the entire data set required to achieve this objective, the intercession of one or more bank-full discharge events were required.

Figure 1. Vicinity Map of the Monarch Mill Site Removal Project.

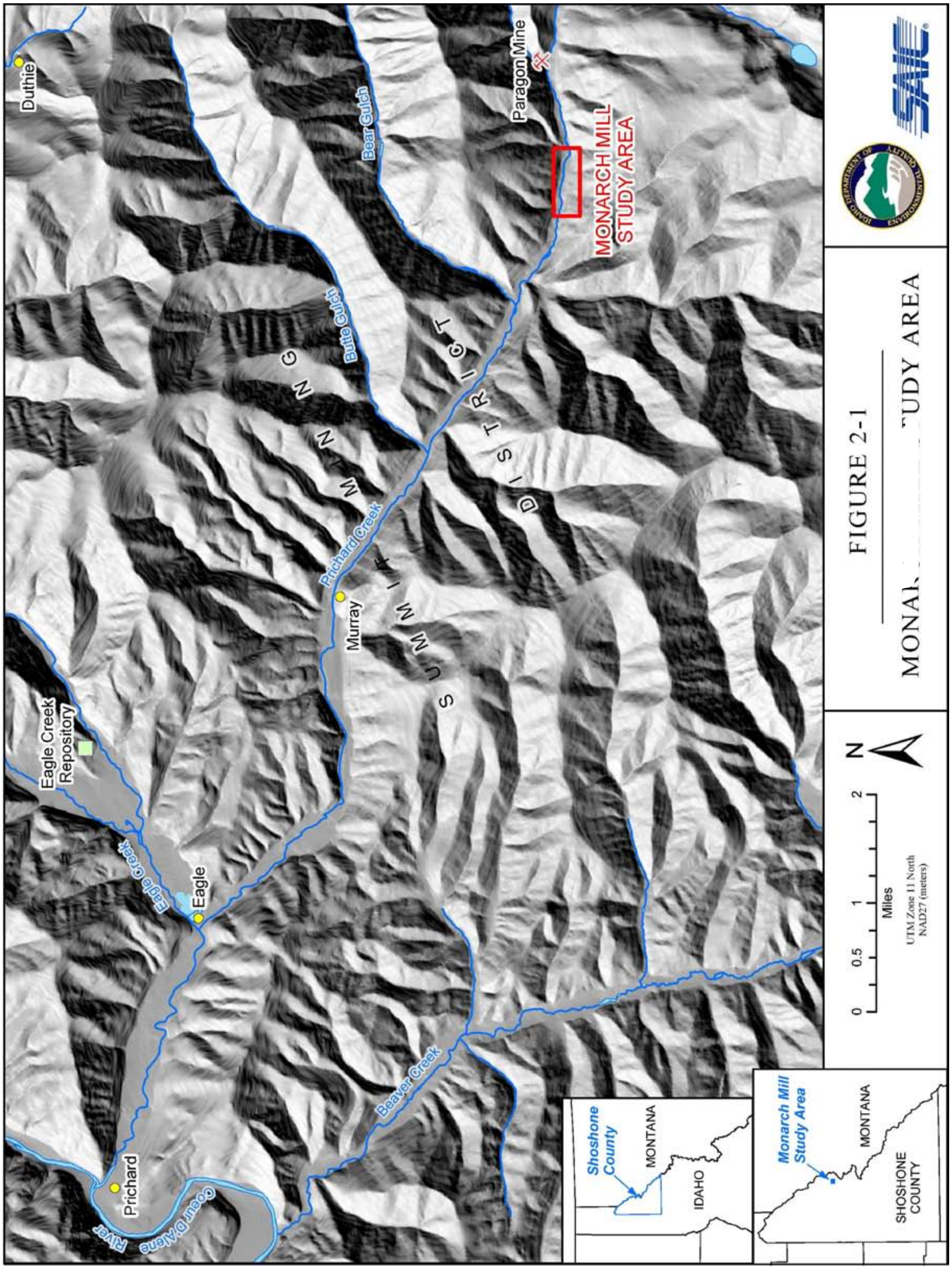
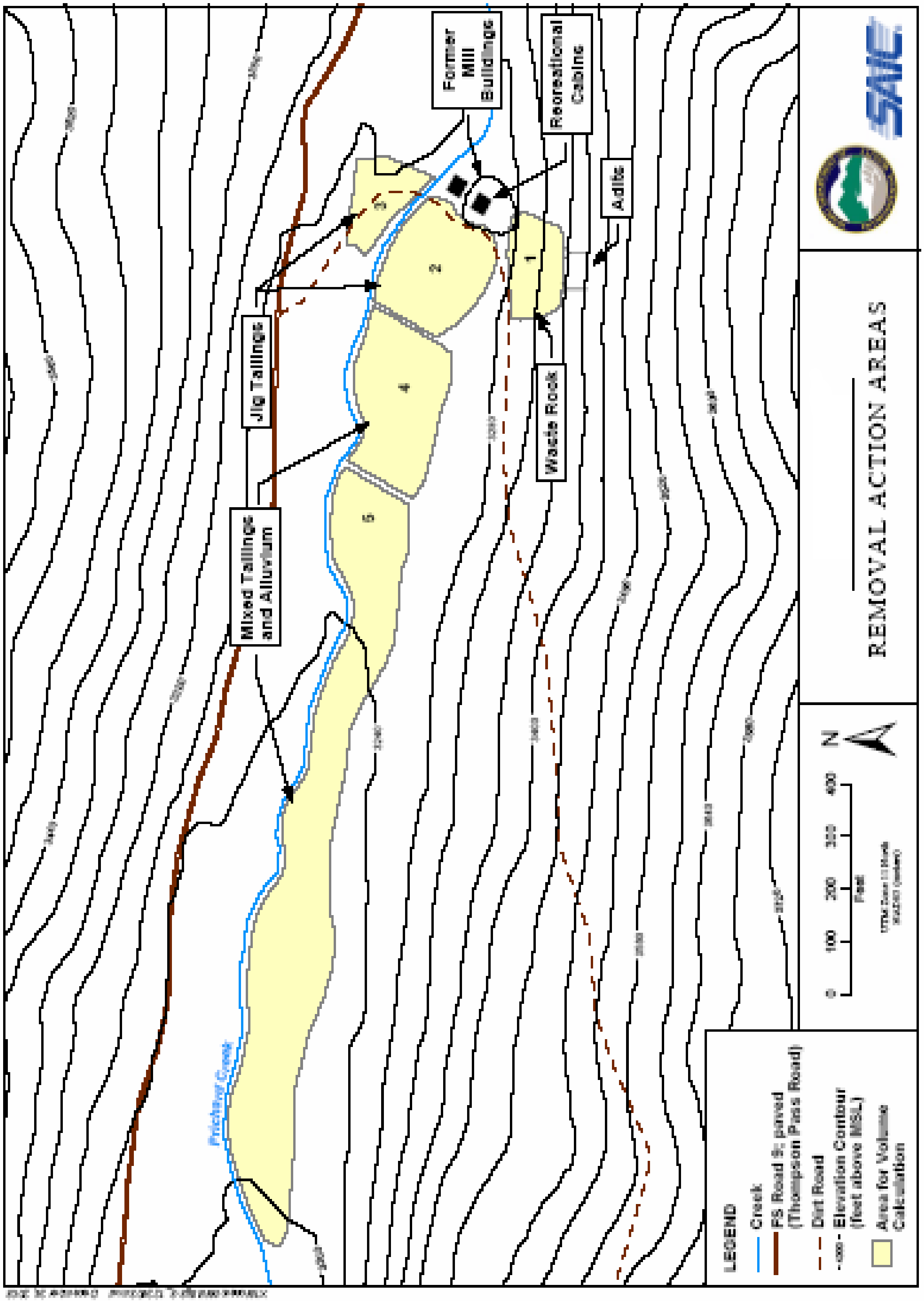


Figure 2. Monarch Mill Site Map.



4.0 Method and Results:

4.1 Alluvium Sorting Economics:

4.1 Alluvium Sorting Economics: During project implementation, daily records were made of 1) the number of trucks full of material moved either to the sorter or to the repository (truck counts) and 2) time and material costs for repository construction, alluvium sorting, and oversize material redistribution as a contractual requirement. These values were verified daily by DEQ personnel as daily reports were received and balanced against payment made to the contractor. These data constitute the raw data from which six values must be calculated to assess the economic aspects of alluvium sorting. These six values are:
1) repository cost to construct and close per cubic yard of waste placed; 2) volume of alluvium removed from the floodplain and sorted; 3) cost to sort the alluvium excavated; 4) cost to excavate (dig), haul, and place a yard of bulk or sorted material; 5) cost difference between a dig and haul approach compared to a dig, sort, and haul only the contaminated fraction approach; and 6) cost to redistribute oversized material removed from the floodplain when a sorting approach is used.

4.1.1 Repository Cost: The repository base was prepared by the contractor between July 13, 2005, and July 29, 2005. Time and materials costs for this work amounted to $52,702 (Table 1). Excavation and placement of wastes ended August 24, 2005 and repository closure was implemented through October 26, 2005. The closure costs totaled $102, 278. The combined cost to construct and close is $154,980. The volume placed in the repository was estimated based on truck count, however, the contractor was paid on a per yard basis for the material hauled, placed, and compacted at the repository with the total yards the difference between the surveyed volume of the repository prior to placement and after placement and compaction. The truck count volume placed in the repository was 12,947 cubic yards. This material included jig tailings from areas 2 and 3 and the sorted fraction from areas 4 and 5. The survey volume of the placed and compacted material was 9,301 cubic yards. The bulk compaction level was 28.2%. The cost per yard hauled was $11.97, while the cost per yard placed and compacted was $16.66.

Table 1. Calculation of repository cost per cubic yard of waste material placed based on truck counts and surveyed volume following compaction.

Repository Activity	Dates	Time & Materials Cost	Yardage Placed	
Base Preparation	7/13-7/29/05	$52,702		
Closure	8/24-10/26/05	$102,278	Truck Counts (yd^3)	Surveyed (yd^3)
Total		$154,980	12,947	9,301
Repository Cost per yd^3			$11.97	$16.66

4.1.2 Alluvium Sorted: Truck counts indicate that 14,119 cubic yards of alluvium from the floodplain was sorted during the project. The 25-

mm minus material removed totaled 6,655 cubic yards (47%), while the oversized material was 7,464 cubic yards (53%).

4.1.3 Sorting Cost: Sorting was completed on a time and materials basis. Sorting was associated with removal from project areas 4 and 5, occurring over the very specific dates of August 11, 2005 to August 24, 2005. Sorting costs include all equipment based to haul to the sorter (12 yard dump trucks), load the sorter (excavator), sort and load the 25-mm (1–inch) minus material for haul and redistribute the oversized material (five-yard loader). The cost of the equipment and its operation is provided in Table 2. A total of 14,119 cubic yards of contaminated alluvium from removal areas 4 and 5 was sorted. The cost of the sorting mill was $4.79 per yard, which included a lack of full efficiency. The sorting mill was obtained for a fixed cost for a fixed period. Sorting was completed well before the expiration of the equipment lease. If rental cost of the sorting mill was pro-rated for the actual period during which it was used, sorting mill cost would be $15,330, reducing the cost per yard sorted to $3.34 per cubic yard.

Table 2. Sorting costs from August 11 to August 24, 2005 and cubic yards of alluvium sorted.

Equipment	Hours Used	Unit Cost	Total Cost
12 Yard Dump Trucks	173.5	$83.04	$14,407.44
Excavator	95.5	$123.19	$11,765
Sorter Fixed Cost			$32,850
5 yard Loader	83	$104.27	$8,654.41
Total			$67,676.50
Cubic Yards Sorted			14,119
Sorting Cost per cubic yard			$4.79

4.1.4 Cost to Excavate, Haul, Place, and Compact: The cost to excavate, haul, place, and compact a cubic yard of material in the repository was set by the contractor's bid at $10.84 per cubic yard.

4.1.5 Cost Differential Between Dig and Haul and Sorting Approaches: The differential costs between the dig and haul and alluvium sorting approaches are compared in Table 3. Sorting cost $4.79 per yard, requiring $67,676 to sort the 14,119 cubic yards removed from areas 4 and 5 of the floodplain. This cost is not incurred with a dig and haul approach. Removal, haul, placement, and compaction costs were contractually set at $10.84 per cubic yard. The dig and haul only approach would have required 14,119 cubic yards to be removed from the site and placed in the repository, while the sorting approach required 6,655 cubic yards to be removed and placed. Repository space in this project cost $16.66 per cubic yard. The project attained an overall compaction in the repository of 28.2% of the truck count volume delivered. The waste volumes delivered to the repository do not change from those stated earlier. Based on the values measured, the sorting approach provided considerable savings to the project. Based on the entire project construction cost of $458,406, a 22% savings was attainable if the oversize material from the sort were disposed of at no cost.

Table 3. Cost Differential between dig and haul and sorting approaches to alluvium removal.

Approach	Sort Cost [1]	Removal & Haul Cost [2]	Repository Cost [3]	Total
Dig and Haul	0	$153,050	$168,890	$321,940
Sorting	$67,676	$72,140	$79,606	$219,422
Difference	+$67,676	-$80,910	-$89,284	-$102,518

[1] Added costs to sort 14,119 yards of alluvium at $4.79/yd3 (section 4.1.3)

[2] Cost to dig materials, haul to the repository, place and compact; 14,119 yd^3 * $10.84/ yd^3 = $153,050 and 6,655 yd^3 * $10.84/ yd^3 = $$72,140

[3] Cost to build and close repository based on $16.66/ yd^3, (Section 4.1.1) and the 28.2% compaction attained; 14,119 yd^3* 0.718 * $16.66/ yd^3 = $168,890 and 6,655 yd^3* 0.718 * $16.66/ yd^3 = $79,606

4.1.6 Oversized Material Redistribution: The oversized material was the alluvium larger than 25 mm diameter. An estimated 7,464 cubic yards of oversized material was developed during the sorting. The oversized material is a potential threat to the floodplain as well. Although the metals contamination has been removed, if the oversized material were spread back across the floodplain, it would create a substrate with low water retention characteristics and virtually no cation exchange capacity. A substrate requires both of these characteristics to foster normal vegetation establishment and growth. Proper placement of the oversized material was necessary. For this project, the solution was to redistribute it to the vicinity of the mine waste rock dump, located on the hillside. The owner will grade the material into a veneer on the waste rock dump. Redistribution of the oversized material cost the project $9,629. As a result, the sorting approach provided a net savings to this project of $92,889 or 20% of the entire construction costs. If a no cost outlet for this material as aggregate could be developed in future projects, the sorting approach would provide additional project savings.

4.2 Compacted Waste Density and Permeability[1]: Nuclear density tests (ASTM D 2922-04) were completed at 13 locations of cell 2 of the Prichard Repository. Six of these locations housed compacted unsorted mine wastes removed from areas 2 and 3, while seven housed compacted sorted mine wastes removed from areas 4 and 5. As an alternative method, two sand cone density tests (ASTM D 1556-00) were conducted, but the two results were widely variable with one well above and the other well below the nuclear density values. Laboratory testing of representative

[1] ASTM numbers identify test methods approved by ASTM International.

samples of unsorted and sorted mine wastes included sieve analysis (ASTM C 136), standard test methods for laboratory compaction characteristics of soil using modified effort (ASTM D 1557), moisture content (ASTM D 2216), and standard practice for correction of unit waste and water content for soils containing oversize particles (ASTM D 4718). The range of permeability of the compacted material was estimated using particle size distribution information and survey of the existing literature.

4.2.1 Density: Nuclear density testing indicated little difference in the average dry density of unsorted and sorted mine wastes (Table 4). Unsorted material averaged 128.7 pounds per cubic foot, while sorted material averaged 127.3 pounds per cubic foot. Moisture content of unsorted material averaged 2.8%, while the sorted material averaged 4.9%. Statistical analysis of values (t-test) confirmed that the measurement sets were not significantly different. Sand cone tests provided results of 102 and greater than 150 pounds per cubic foot of the sorted and unsorted material, respectively. Since these values were, respectively, well below and above the nuclear density readings, they were determined by the contractor to be unreliable (Kleinfelder 2005).

Table 4. Results of nuclear density testing.

Test Number	Material Tested	Probe Depth (inches)	Dry Density (pounds per cubic foot)	Test Moisture (%)
1	Unsorted	0	128.7	3.0
2	Unsorted	10	140.0	3.7
3	Unsorted	0	117.9	2.3
4	Unsorted	10	132.8	2.6
5	Unsorted	0	120.9	2.3
6	Unsorted	8	133.6	2.7
7	Sorted	12	121.4	6.9
8	Sorted	10	127.0	4.8
9	Sorted	10	124.5	5.9
10	Sorted	10	123.0	5.7
11	Sorted	10	130.3	4.5
12	Sorted	10	129.1	5.3
13	Sorted	10	136.0	1.4

4.2.2 Size Distribution and Compaction: Sieving of the material in the laboratory demonstrated 25 mm minus material had lower percentage by weight of gravel fractions and higher percentage by weight of sand fractions than the unsorted material. Although both samples contained some cobble, the unsorted fraction contained boulder class material as well. These are expected results. Based on the maximum dry density values developed moisture content and nuclear density measurements, the unsorted material compaction range was from 87 to 93% of the laboratory maximum, while the sorted material compaction range was from 92 to over 100% of the laboratory maximum (Kleinfelder 2005).

Table 5. Summary of laboratory testing.

Material	Maximum Dry Density (pounds per cubic foot)	Optimum Moisture (%)	Gravel (%)	Sand (%)	#200 Mesh (%)	Unified Classification*
Unsorted	144.5	6.1	63	30	7	GP
Sorted	132.7	6.0	47	44	9	GW

* GP – gravel poorly sorted – ; GW– gravel well sorted

4.2.3 Permeability: The permeability range of the two material types was estimated based on the laboratory analysis of particle distribution and comparison of these values to permeability of referenced materials. The permeability range can be sufficiently established in this manner, but empirical testing would be necessary to establish the specific permeability of the materials. Unsorted material would be in a range of 1X10-3 to 2X10-1 centimeters per second (cm/sec), while sorted material was determined to be in the range of 1X10-4 to 1X10-1 cm/sec. Analysis by this method predicts the sorted material could be expected to have permeability that is lower by a factor of two- to ten-fold (Kleinfelder 2006). Empirical testing will be required in subsequent removals to establish actual values.

4.3 Streambed Gravel Contamination Monitoring: Streambed alluvium samples were collected from the section of Prichard Creek traversing the Monarch project area. Six preliminary gravel samples were collected with a McNeil Core (Chapman and McLeod 1987) at locations shown in Figure 3. Preliminary samples were collected and analyzed to assess the number of samples necessary to establish a statistically significant data set. Samples were passed through 19-mm (3/4-inch) and 9.5-mm (3/8–inch) sieves to isolate the material previously shown to contain the most significant metals content. The 9.5-mm fraction was analyzed to better assess the winnowing of metals bearing particles from the stream bed. Samples were acid-digested and analyzed by inductively coupled plasma (ICP) for arsenic (As), cadmium (Cd), lead (Pb), and zinc (Zn) (EPA 3050/6010). The coefficient of variance was developed for use in determining sample size for additional sampling (Table 6).

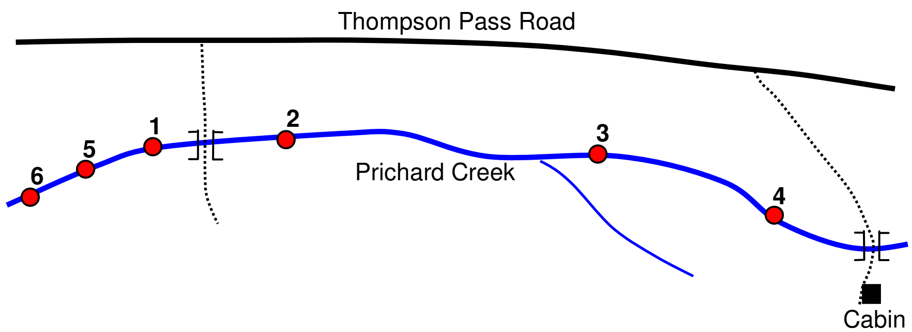


Figure 3. Sample collection locations of five preliminary streambed bed samples collected from Prichard Creek.

Table 6. Analysis of preliminary Prichard Creek streambed gravel samples

Sample	As	Cd	Pb	Zn
		----------- ug/g -----------		
1	11	4	590	1200
2	16	3	610	900
3	14	4	700	1200
4	10	6	2100	1900
5	7	2	640	780
6	20	3	570	1000
		mean:	868	1163
		std dev:	605	397
		CV:	70	34
		N:	13	3

Sample size was calculated based on equation 1.

Equation 1:

$$N = t^2CV^2/D^2$$

where: N = sample size
t (α = 0.05, n = 5) = 2.571
CV = coefficient of variation
D = desired accuracy = 50 ug/g

Based on these results, 13 gravel samples were collected from random locations between the upper and lower bridges that framed the length of the removal action (Figure 4). Thirteen samples is a sufficient sample population to determine lead and zinc concentration variability between sampling events. Samples were placed into clean plastic buckets and returned to the laboratory for subsequent sorting into fractions and analysis for metals. Field blanks of gravel were taken through the collection process to detect contamination sources for quality assurance purposes.

4.3.1 Streambed Gravel Metal Content: Total zinc and lead content of two sieve-size sub-samples (3-19 mm and < 3 mm) of Prichard Creek streambed gravel are provided in Tables 7 and 8. The 19- millimeter (3/4-inch) minus fraction includes the jig tailings entrained in the streambed. Arsenic and cadmium concentrations were consistently below detection limits.

Pre-removal zinc concentrations were 715 (3-19 mm) and 975 (<3mm) ug/g. Three channel-altering bank-full discharge events occurred during the two years after the removal action. These events should have mobilized the streambed sediments and washed out smaller particles. Statistical analysis demonstrated that the 3-19 mm fraction contained significantly lower zinc concentration after the three bank-full events (715+87 vs. 536+ 55; t= 0.02). The fraction less than 3 mm exhibited no significant change in zinc concentration 975+104 vs.1005+147; t= 0.85). Neither the 3-19 mm fraction nor the less than 3mm fraction had significantly different lead concentrations after the three bank-full events (3-19 mm: 316+63 vs. 327+53; t= 0.86; <3 mm: 665+101 vs. 550+77; t= 0.22). The t test of the less than 3 mm fraction indicated a much lower probability than the average of the two set of measurements were the same number, but was insufficiently low to draw the conclusion that the average of the two data sets represent different values. The most plausible explanation of the lack of significant difference observed is that an insufficient number of high discharge events have occurred to effect sufficient removal of the mine waste contaminants. Trend analysis of the data sets was conducted to assess the potential for statistically measurable declines in metal contaminants.

4.3.2 Streambed Gravel Metal Content Trends: Although a statistically significant metal decline was noted in only one of four gravel fractions (zinc in the 3-19 mm fraction), declining trends were verified in three of the four data sets. Trend analysis using the FORECAST software on the existing data sets predicted that in the less than 3 mm fraction, the lead concentration would decline to 367 ug/g and the zinc concentration would decline to 453 ug/g five years after the removal. The zinc concentration in the 3-19 mm fraction is predicted to be 236 ug/g after five years. The lead concentration of the 3-19 mm streambed gravel was not predicted to decline in a five- or even ten-year horizon, based on the existing data sets. The average lead concentration in this fraction, based on all three measurements conducted, is 312 ug/g. This average is 137 ug/g higher than the background lead concentration (175 ug/g) estimated for the soils of the Coeur d'Alene Mining District (EPA 2001; Table 2-10). The concentration measured may be approaching a concentration that can be reasonably expected in the short term for a mineralized area where lead is prevalent and mining has occurred.

Figure 4. Streambed gravel collection locations from the Monarch Reach of Prichard Creek.

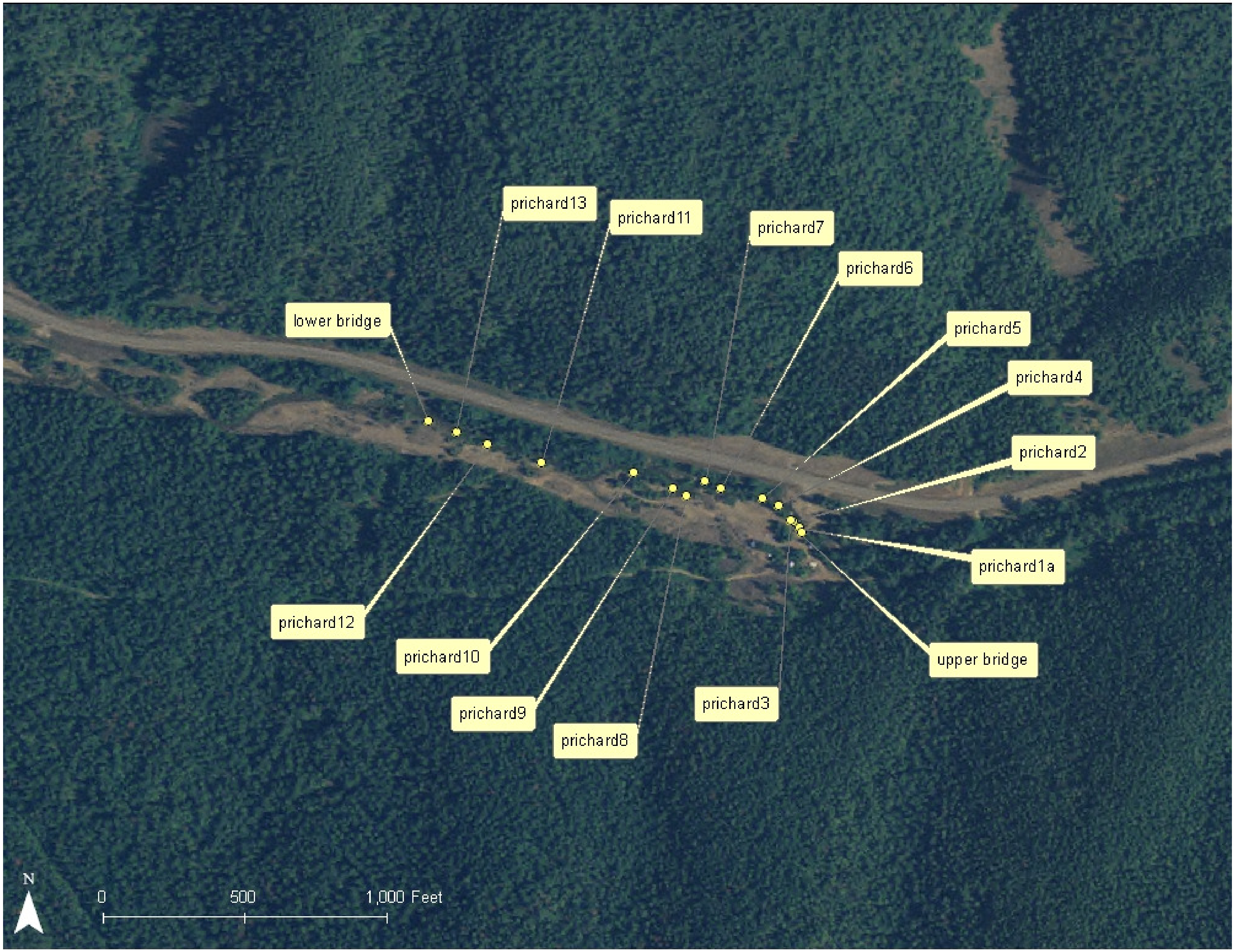


Table 7. Monarch Mine/Prichard Creek Alluvium Zinc Analysis

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	Ave	SE	t
3-19 mm Pre-removal	720	550	1000	1000	490	380	600	400	1100	1400	470	490	600	715	87	-
3-19 mm Year 1	400	860	420	230	250	320	390	850	610	990	510	540	540	532	67	-
3-19 mm Year 2	340	450	570	510	450	420	600	350	460	1100	420	660	640	536	55	0.02
<3 mm Pre-removal	790	630	910	900	800	810	850	870	1900	1700	860	840	820	975	104	-
<3 mm Year 1	540	630	510	490	560	1100	610	2300	790	1600	660	660	700	858	147	-
<3 mm Year 2	640	420	570	480	750	630	1300	2100	940	1800	840	1500	1100	1005	147	0.85

Note: All concentrations in ug/g. SE – standard error of the mean.

Table 8. Monarch Mine/Prichard Creek Alluvium Lead Analysis

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	Ave	SE	t
3-19 mm Pre-removal	280	99	190	120	170	110	350	210	550	930	320	420	360	316	63	-
3-19 mm Year 1	100	110	290	100	160	140	220	360	250	750	740	240	390	296	61	-
3-19 mm Year 2	230	96	140	210	140	180	350	680	360	670	300	460	440	327	53	0.86
<3 mm Pre-removal	520	340	450	480	470	400	600	550	1100	1700	640	650	750	665	101	-
<3 mm Year 1	390	250	240	350	470	390	400	1100	520	940	430	570	530	506	70	-
<3 mm Year 2	560	200	270	270	360	400	260	1000	590	860	690	780	910	550	77	0.22

Note: All concentrations in ug/g. SE – standard error of the mean.

5.0 Discussion

An alluvium sorting approach would be applied in those cases where mine tailings have been eroded, mixed with sediment from non-mining origins, and deposited. Tailings deposits unaffected by fluvial forces tend to be of the same size class, negating any advantage of sorting. Removal of mine wastes mixed with other sediment of larger size class raises the economic questions of the efficiency of removing all the material to a repository versus removing only the metals-contaminated fraction. Removal of mixed wastes also raises questions concerning the compaction that can be achieved with the sorted versus unsorted material and any improvement that could be achieved in lower permeability to water.

The results of the project-scale Monarch Removal Project clearly demonstrate the economic advantage afforded by sorting the material and placing only the metals-contaminated fraction in the repository. Sorting has a clear front end cost associated with screen mobilization and its additional operation and material handling. However, these costs are offset by the costs savings of transporting reduced amount of material to the repository. When the cost of creating repository space is assessed, the sorting approach provides a distinct economic advantage. In the case of the Monarch Removal Project, the savings provided was nearly $93,000 or roughly 20% of the entire project cost. An additional economic lesson learned during implementation of the Monarch Removal was that further savings could have been achieved if an economic outlet for the oversized material had been found. Nearly $10,000 was expended placing the oversized material in a location where it would not adversely affect revegetation of the floodplain. Even if the material had been given away to a productive use in the aggregate market, the additional expense to place it would have been avoided. Future projects that treat contaminated alluvium through a sorting approach should strive to find a productive outlet off-site for the oversized material.

Sorting did not develop a material that compacted to any greater density than the bulk unsorted material. Analysis demonstrated that sorted material did reach a higher range in percentage of maximum theoretical compaction. The difference between the two materials (sorted and unsorted) was sufficiently small that it made no difference in the field compaction achieved. Sorting has the potential to provide a compacted substrate with lower permeability due to the gradation of the particles. However, the key empirical analytical tests were not performed to demonstrate that the sorted material of the Monarch Removal Project was of lower permeability than the unsorted material.

Two years of post-removal field assessment have been completed to determine whether removal of the jig tailings and contaminated alluvium deposits at the Monarch site affect the concentrations of metals in streambed sediments. During the two years after removal, three bank-full channel-altering discharges occurred. The events should have winnowed metals-contaminated sediment from the streambed. Removal of a large part of the source material should retard replacement of metals-bearing particles in the streambed. Analysis of the existing data sets demonstrates that zinc concentrations did significantly decline in the 3-19 mm particle size range. Trend analysis indicates that zinc and lead are declining in the less than 3 mm particle size range. The trend analysis of less than 3 mm data sets predicts statistically significantly declines should be measurable five years after the removal. Lead concentration of the 3-19 millimeter fraction did not decline, but persisted in a range of 296-327 ug/g, averaging 312 ug/g. This concentration is lower than lead and zinc concentrations measured in the other fractions. This average is 137 ug/g higher than the background lead concentration (175 ug/g) estimated for the soils of the Coeur d'Alene Mining District (EPA 2001; Table 2-10). The concentration measured may be approaching a concentration that can be reasonably expected in the short term for a mineralized area where lead is prevalent and mining has occurred.

Although the observation is beyond the statistical scope imposed on the streambed monitoring, analysis of the data sets suggests the existence of a "metals hot spot" or "source" between stations 7 and 8 (Figure 4). A small tributary to Prichard Creek draining a portion of the Monarch Mill site enters the stream between stations 7 and 8. Although the area adjacent to this tributary was treated, no removal from the tributary, itself, occurred. It appears that this tributary is still yielding metals-contaminated sediments to the lower reach of the test area. The tributary metals source appears to be contributing metals that retard actual declines in metals of the Prichard Creek steam bed below station 7. The metals contribution confuses the interpretation of the data sets sufficiently to retard the development of statistically significant metals declines in two cases. Further monitoring of the bed sediments after additional high discharge conditions should better document the dynamics of the metals contribution and concentration decline.

6.0 Conclusions and Recommendations:

- An alluvium sorting strategy has an economic advantage in those cases where the removal of metals-contaminated alluvium is proposed.

- An outlet for the oversized fraction created by sorting should be sought to maximize the economic advantage of a sorting approach.

- The sorted fraction did not provide superior compaction, when compared to the bulk unsorted material, however laboratory analysis suggests superior low permeability might be achieved in the field, due to the more uniform grain size of the sorted material.

- Assessment of the in-stream effectiveness of the removal action has demonstrated the statistically significant decline of zinc in one particle-size fraction and declining trends in two additional.

- Additional streambed monitoring is warranted in the fifth year after the removal action to assess whether the declining trends result in statistically significant declines and to better document the interaction of the tributary suspected of yielding metals to Prichard Creek.

7.0 References:

Chapman, D.W. and K.P. McLeod 1987 Development of criteria for fine sediment in the Northern Rockies Ecoregion. EPA Report # EPA 910/9-87-162. 262p.

EPA 2001. *Coeur d'Alene Basin RI/FS, Basinwide Ecological Risk Assessment.* May 2001.

EPA 3050/6010. 1994. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW 846).

Kleinfelder 2005. Report on materials testing services Monarch Mill tailings compaction, Prichard Creek, Shoshone County, Idaho. Kleinfelder, 15320 E. Marietta, Suite 2 Spokane WA 99216. 6p.

Kleinfelder 2006. Response to comments materials testing services Monarch Mill tailings compaction, Prichard Creek, Shoshone County, Idaho. Kleinfelder, 15320 E. Marietta, Suite 2 Spokane WA 992169p.

Paulson, A.J., R. Balderrama E. Zahl and R.L. Cox 1996a. Treatment of fluvially deposited streamside mine waste – material from Ninemile Creek, Idaho. RI 9631 U.S. Department of Energy, Spokane Research Center. Spokane WA

Paulson, A.J., R. Balderrama and E. Zahl 1996b. Treatment of fluvially deposited streamside mine waste – material from Canyon Creek, Idaho. RI 9633 U.S. Department of Energy, Spokane Research Center. Spokane WA..