

**LABORATORY EVALUATION OF
CO-MIXED TAILINGS WASTE ROCK
AND SLAG FOR THE CONSTRUCTION OF
BARRIER COVER SYSTEMS
AT COPPER CLIFF**

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TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
1.0 INTRODUCTION.....	1
2.0 PRELIMINARY ON SITE BLENDING TRIALS.....	2
3.0 LABORATORY TESTING: UBC.....	6
4.0 CONCEPTUAL DESIGN & OPTIONS EVALUATION (PERFORMED BY GOLDER PASTE TECHNOLOGY)	13
4.1 Overview.....	13
4.2 Cover Materials	13
4.2.1 Waste Rock	14
4.2.2 Slag.....	14
4.2.3 Tailings	14
4.3 Options Descriptions	15
4.3.1 Tailings Dewatering Equipment	15
4.3.2 Mixture Delivery Method	15
4.3.3 Plant and Deposition Area Operation	16
4.4 Options Summary	16
4.4.1 Dry Placement of Cover Mixture – Summer Only	16
4.4.2 Dry Placement of Cover Mixture – Placement Year Round, Compaction in Summer Only.....	16
4.4.3 Wet Placement of Cover Mixture – Summer Only	17
4.4.4 Wet Placement of Cover Mixture – Placement Year Round.....	17
4.4.5 Wet Placement of Cover Mixture – Placement Year Round and Rehandling in Summer	17
4.5 Cost Estimate	17
5.0 CONCLUSIONS AND RECOMMENDATIONS	19

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

Table 2.1	Co-Mix Blends Mixed With Tailings from Area R3
Table 2.2	Co-Mixed Blends Using Whole Mill Tailings
Table 3.1	Summary of Laboratory Test Results Completed at UBC
Table 3.2	Summary of Soil-Water Characteristic Curve Testing
Table 4.1	Capital and Operating Cost for 1:1:2 Waste Rock : Slag : Tailings Mixture with 1.5% Bentonite
Table 4.2	Operating Cost for Alternate Waste Rock : Slag : Tailings Mixtures

LIST OF FIGURES

Figure.2.1	Grain size distributions for materials used in the blending trials
Figure 3.1	Proctor Compaction Curve for Blend 1:1:2 (Mill Tailings)
Figure 3.2	Proctor Compaction Curve for Blend 1:1:2 (R3 Tailings)
Figure 3.3	Proctor Compaction Curve for Blend 1:1:1
Figure 3.4	Grain Size Distribution for Co-Mix Blends Analysed at UBC
Figure 3.5	Soil-Water Characteristic Curves for the Tailings and 1:1:2 Co-Mix with Whole Tailings
Figure 3.6	Soil-Water Characteristic Curves for Non Compacted and Compacted Co-Mix Blends

1.0 INTRODUCTION

Cover systems constructed on potentially acid forming tailings impoundments or waste rock dumps must function as oxygen and water barriers in order to minimize ARD. The barrier system within a cover profile must also provide physical stability with respect to deformation, shear strength and erosion. Long-term integrity of cover systems is a critical issue due to extreme variations in climatic and environmental conditions associated with temperature, freezing, wetting and drying, and vegetation. These variations may cause volume change and cracking leading to failure associated with excessive infiltration and /or oxygen entry. In general, well-graded soils with a fine grain matrix such as the glacial till material used at Equity Silver Mine have been proven to be excellent materials for the construction of barrier type cover systems.

INCO Limited sponsored a literature review and theoretical study through the International Network for Acid Prevention, INAP, (Klohn Crippen, 2001) to investigate the potential of blending tailings, waste rock and slag to produce a suitable material for the construction of a barrier cover system. The study concluded that it should be possible to manufacture a high quality material suitable for the construction of an oxygen and infiltration barrier within a cover profile. INCO has elected to proceed with a second laboratory test program for the Copper Cliff Mine to evaluate the blending of tailings, waste rock and slag. The broad objective of the study presented herein is to verify the preliminary conclusions outlined in the literature review and theoretical study. The specific objectives of the study are as follows:

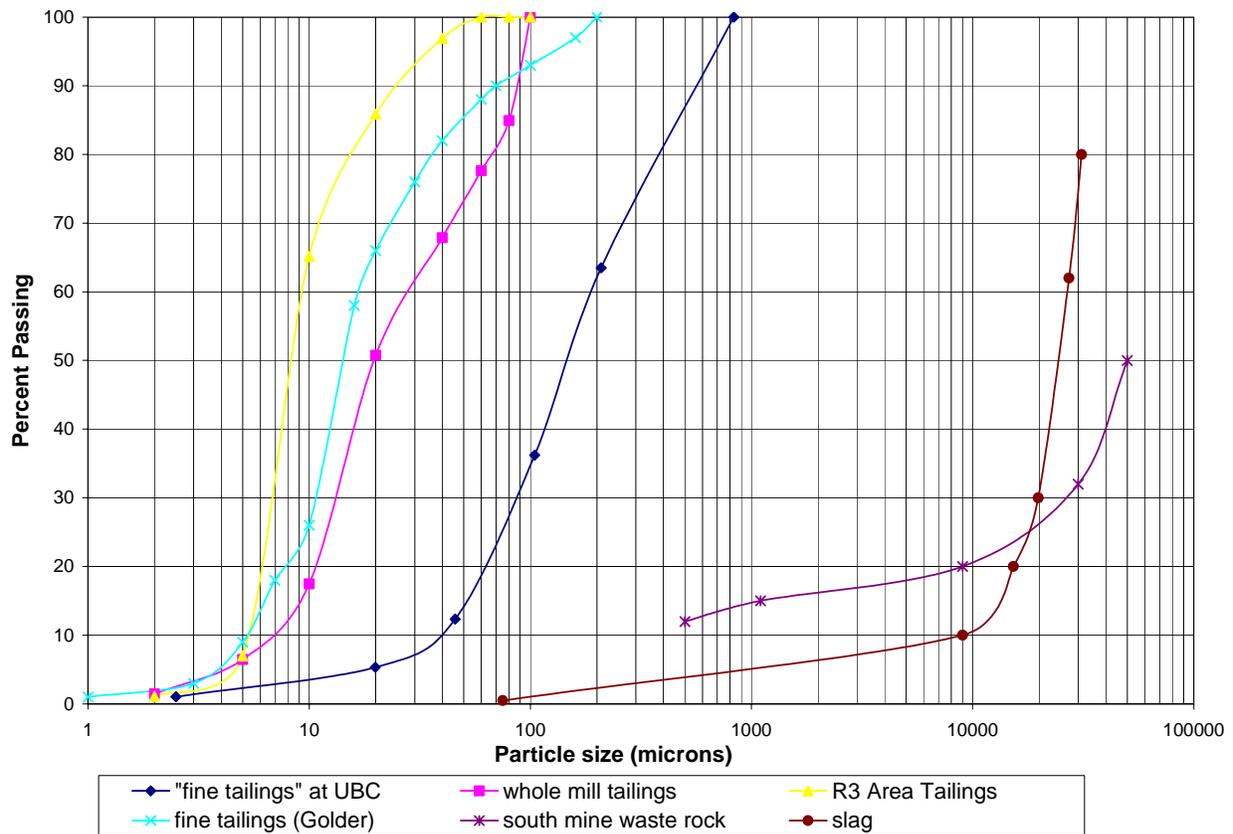
1. To conduct laboratory testing examining differing blends of tailings and waste rock material to ascertain optimal geotechnical and geochemical mixes that should be tested further in the field;
2. To give consideration to the need to desulphurize any tailings material that is to be used in the blended materials;
3. To address the issue of how to achieve mixing under field conditions; and
4. To provide a general assessment with respect to the potential for successfully capping acid generating materials with co-mixed materials.

The laboratory test program was initiated 26 November, 2001. Representative samples of tailings, waste rock, and slag were obtained. These materials were blended at ratios selected on the basis of preliminary modelling completed for the previous INCO study. Initial testing was carried out at Golder Associates' laboratory in Sudbury, Ontario. Samples collected were shipped to the University of British Columbia (UBC) for further testing and analyses upon completion of the initial testing phase. Laboratory measurements for grain size distribution, density, hydraulic conductivity, the soil-water characteristic curve and volume change characteristics were carried out.

2.0 PRELIMINARY ON-SITE BLENDING TRIALS

Field samples of tailings, waste rock and slag were obtained November 26 and 27, 2001. Weathered waste rock was obtained from the open pit area for the North Mine while fresh production rock was obtained from the underground operation for the South Mine. Slag samples were collected from a stockpile of fine-screened material (approximately 25 mm and finer). Tailings samples were obtained from the R3 tailings area as well as whole tailings directly from the mill. Figure 2.1 shows typical grain size distributions for each of the materials used in the test program. The grain size analyses for the tailings were completed at the CANMET laboratory, while the slag and waste rock samples were conducted at Golder Associates' facility in Sudbury.

**FIGURE 2.1
GRAIN SIZE DISTRIBUTIONS FOR MATERIALS USED IN THE BLENDING TRIALS**



The hydraulic conductivity of the blended Co-Mix samples of tailings, waste rock, and slag were measured in a 150 mm diameter permeameter using the falling head test method. Blend ratios equal to one waste rock, one slag and two tailings (1:1:2) were initially created using a tailings sample obtained from Tailings Area R3. The blended samples were mixed at a gravimetric water content of approximately 10 percent to produce a slump of 4 inches; as well as at a higher water content of 12 percent to produce a paste like consistency having a slump of 8 inches. The higher water content materials were blended and placed directly into the permeameter ring for measurement of the hydraulic conductivity without compaction. Additional samples were also compacted at a lower water content (i.e., approximately 8 percent) using a Standard Proctor compactive effort in order to determine the reduction in hydraulic conductivity associated with increased density. The influence of the addition of a small percentage of bentonite (equal to 1.5 percent based on the dry weight of waste rock, slag and tailings) for non-compacted and compacted samples was also evaluated. The results for the measured values of hydraulic conductivity are shown in Table 2.1, which summarizes the test results for the samples blended with tailings obtained from Tailings Area R3. Table 2.2 presents the results of tests conducted for samples blended with whole tailings obtained directly from the mill. The influence of decreasing the blend ratio for tailings from 1:1:2 to 1:1:1 (WR:Slag:Tailings) as well as increasing the tailings ratio to 1:1:3 was also measured.

TABLE 2.1
CO-MIX BLENDS MIXED WITH TAILINGS FROM AREA R3

Mix (WR/Slag/Tails)	Waste rock	Slump	Compaction	Bentonite	K (m/s)
1:1:2	South Mine	4"	None	None	2×10^{-7}
1:1:2	South Mine	8"	None	None	2×10^{-7}
1:1:2	South Mine	n/a	Standard Proctor	None	4×10^{-8}
1:1:2	South Mine	4"	None	1.5%	3×10^{-8}
1:1:2	South Mine	n/a	Standard Proctor	1.5%	5×10^{-9}
Waste Rock	North Mine	n/a	Standard Proctor	None	3×10^{-6}

TABLE 2.2
CO-MIXED BLENDS USING WHOLE MILL TAILINGS

Mix (WR:Slag:Tails)	Waste rock	Slump	Compaction	Bentonite	K (m/s)
1:1:2	North Mine	>10"	None	None	3×10^{-7}
1:1:2	North Mine	7"	None	None	1×10^{-7}
1:1:2	North Mine	Zero	Standard Proctor	None	1×10^{-7}
1:1:2	North Mine	7"	None	1.5%	1×10^{-8}
0:1:1	n/a	>10"	None	None	1×10^{-7}
0:1:1	n/a	Zero	Standard Proctor	None	1×10^{-7}
1:1:1	South Mine	2"	None	None	1×10^{-7}
1:1:1	South Mine	Zero	Standard Proctor	None	5×10^{-8}
1:1:2	South Mine	4"	None	None	2×10^{-7}
1:1:2	South Mine	Zero	Standard Proctor	None	2×10^{-7}
1:1:3	South Mine	7"	None	None	2×10^{-7}
1:1:3	South Mine	Zero	Standard Proctor	None	2×10^{-7}

It can be seen in Table 2.1 that Co-Mix materials with a low hydraulic conductivity can be achieved by blending waste rock with slag and tailings. A blend ratio of 1:1:2 for R3 tailings produced a material with a hydraulic conductivity of 2×10^{-7} m/s without compaction (i.e., loose, semi-fluid state). The value of hydraulic conductivity was found to decrease to 4×10^{-8} m/s (i.e., approximately one order of magnitude) after compaction with Standard Proctor effort. Furthermore, the hydraulic conductivity was found to decrease to 3×10^{-8} m/s with the addition of 1.5% bentonite. A more striking and significant benefit was found with the combination of 1.5% bentonite and compaction to produce a material with a hydraulic conductivity of 5×10^{-9} m/s. This material is considered to be an excellent candidate for the construction of a barrier cover system.

Similar results can be seen in Table 2.2 for whole tailings blended with North Mine waste rock. A hydraulic conductivity of 1×10^{-8} m/s was obtained for a blend ratio of 1:1:2 without compaction and 1.5% bentonite. The value of hydraulic conductivity for blend ratios of 1:1:1 to 1:1:3 using whole tailings and South Mine waste rock are typically in the range of 2×10^{-7} m/s. Less benefit associated with compaction was observed for the South Mine waste rock and whole tailings. In general, the whole tailings were found to be slightly coarser than the R3 tailings; hence, the values of hydraulic conductivity for the blended Co-Mix materials were slightly higher compared to those blended with tailings from Tailings Area R3.

The possibility of incorporating fine fraction tailings from the sand plant at Hill Station was suggested. Fine fraction tailings were collected and shipped to UBC for analysis. It can be seen in Figure 2.1 that the sample received is not representative of the fine fraction tailings since the grain size distribution is coarser than that for the whole tailings. A grain size distribution for the fine tailings provided by Golder Associates is also shown in Figure 2.1

3.0 LABORATORY TESTING: UBC

Samples were shipped to UBC for further comprehensive testing. The first stage of the testing was to repeat the hydraulic conductivity testing completed for the compacted samples to assure that the values were reproducible. Standard Proctor compaction curves were generated for blend 1:1:1, and 1:1:2 with both whole tailings and tailings from Area R3. Blend 1:1:3 was not evaluated due to the fact that the volume of tailings needed to blend the materials at a ratio of 1:1:3 was considered to not be sustainable on a year-round basis. Hydraulic conductivity tests were subsequently carried out on the samples compacted at the optimum water content. Analyses for measurement of the Soil-Water Characteristic Curve (SWCC) and grain size distribution of the blended materials were also completed. Table 3.1 presents a summary of the testing that was completed at UBC.

TABLE 3.1
SUMMARY OF LABORATORY TEST RESULTS COMPLETED AT UBC

Blend	Hydraulic Conductivity	Grain Size Distribution	Proctor Density	SWCC
1:1:2 R3 tailings	4×10^{-8} m/s compacted	Complete	2400 kg/m ³ at 9.5% w.c.	Compacted Sample
1:1:2 mill tailings	1×10^{-7} m/s compacted	Complete	2115 kg/m ³ at 9.6% w.c.	Loose and Compacted Samples
1:1:2 mill tailings and 1.5% bentonite	1×10^{-8} m/s compacted	Complete	As Above	Loose and Compacted Samples
1:1:1	1×10^{-7} m/s compacted	Complete	2155 kg/m ³ at 8% w.c.	Compacted Sample

Figure 3.1 shows the compaction curve for the 1:1:2 blend using whole mill tailings while Figure 3.2 presents the compaction curve for the 1:1:2 blend with the tailings obtained from Area R3. Figure 3.3 shows the compaction curve generated for the 1:1:1 blend mixed with whole mill tailings.

FIGURE 3.1
PROCTER COMPACTION CURVE FOR BLEND 1:1:2 (MILL TAILINGS)

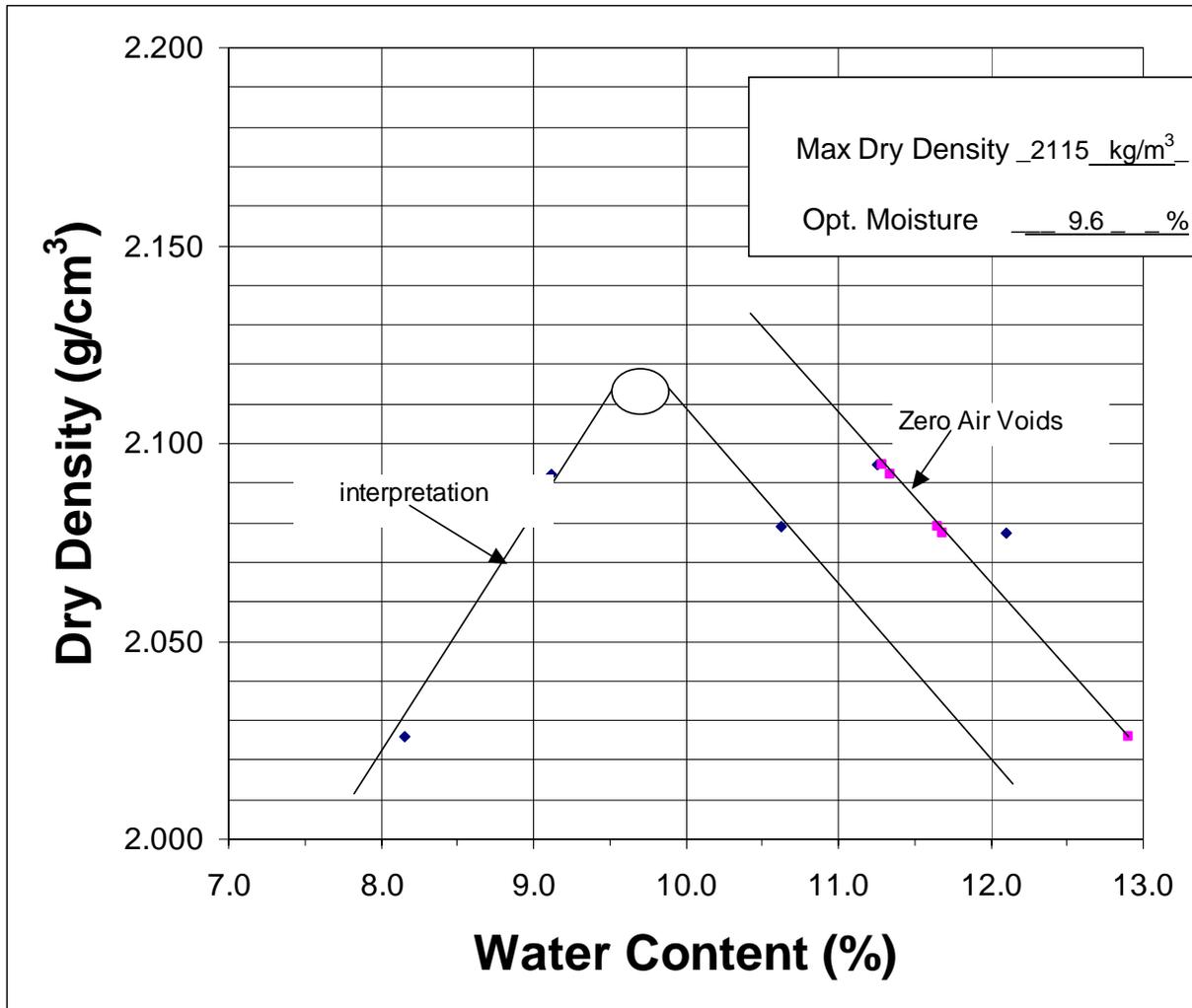


FIGURE 3.2
PROCTOR COMPACTION CURVE FOR BLEND 1:1:2 (R3 TAILINGS)

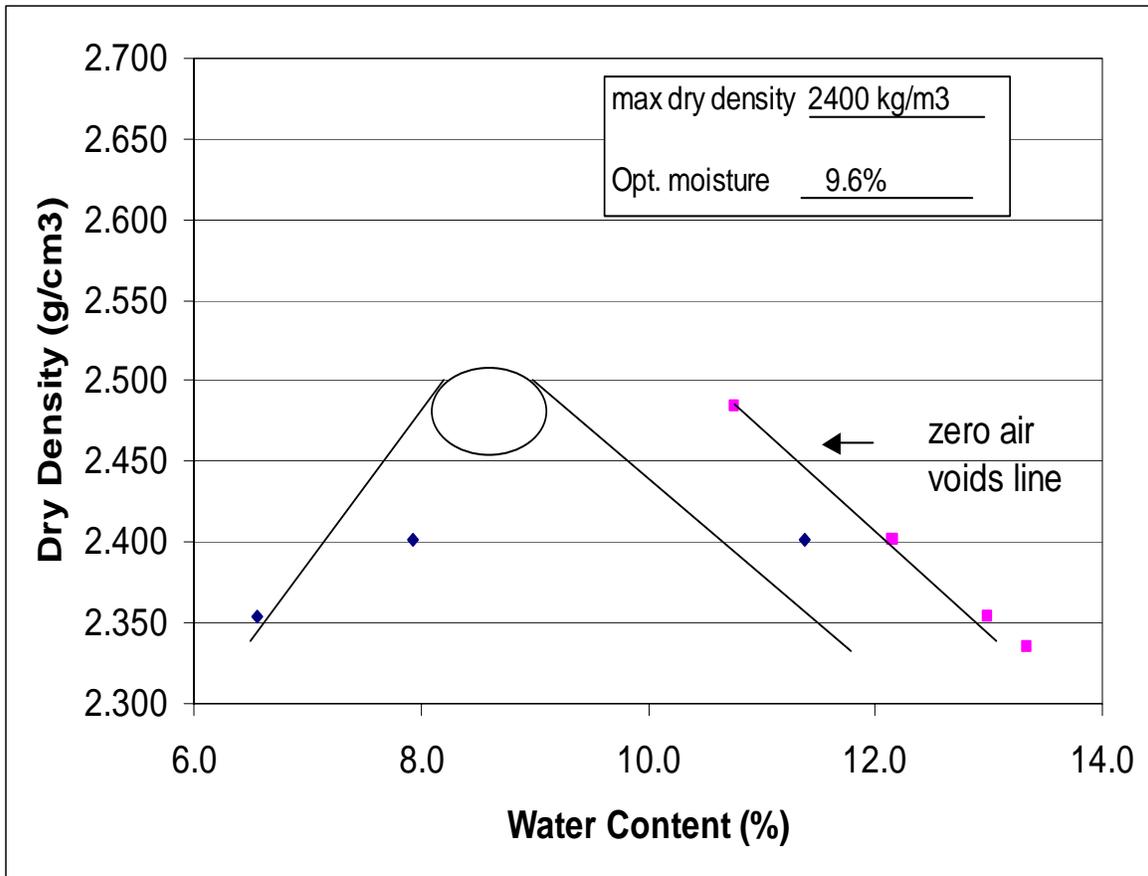
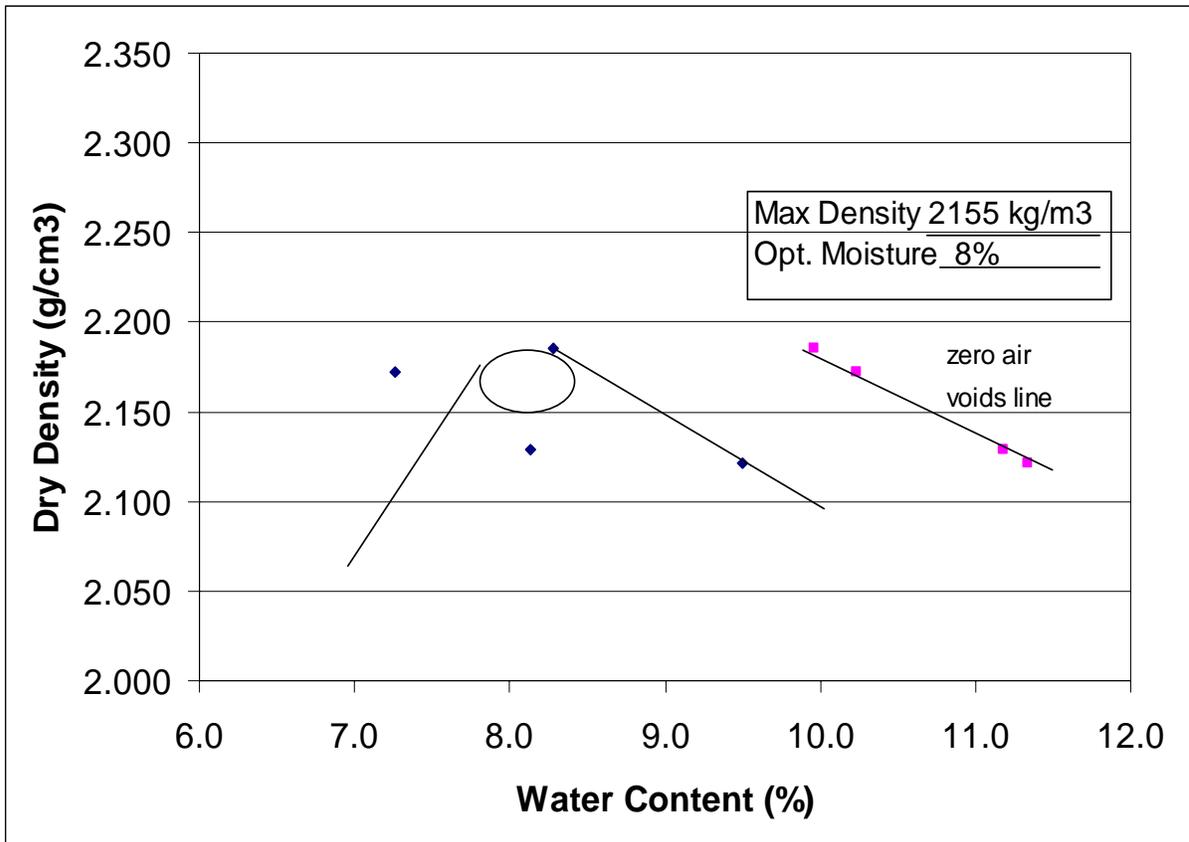


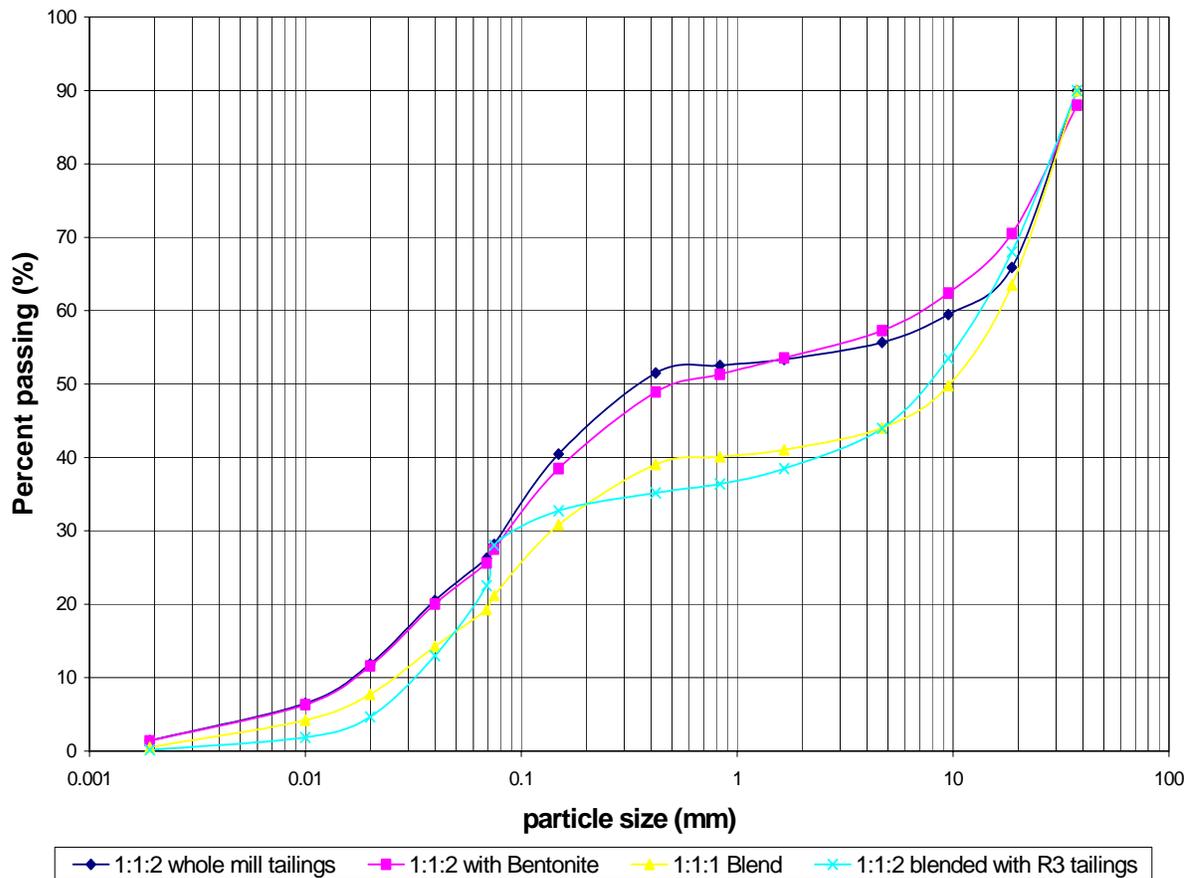
FIGURE 3.3
PROCTER COMPACTION CURVE FOR BLEND 1:1:1



The maximum density obtained for the 1:1:2 blend was $2,115 \text{ kg/m}^3$ at a water content of 9.6%. The density achieved for the 1:1:2 blend that was mixed with tailings from Area R3 achieved a density of approximately $2,400 \text{ kg/m}^3$ at a water content of 9.8%. The value of $2,400 \text{ kg/m}^3$ measured for the dry density of 1:1:2 (R3) blend is unusually high. The reason for this is the R3 tailings have a high specific gravity equal to 3.6, which is believed to be due to a higher concentration of pyrite associated with segregation during deposition. It can also be seen that the increased density results in lower value of hydraulic conductivity for the compacted blend with R3 tailings compared to that for the whole mill tailings (i.e., $4 \times 10^{-8} \text{ m/s}$ versus $1 \times 10^{-7} \text{ m/s}$). The 1:1:1 blend achieved a density of 2155 kg/m^3 at a lower optimum water content of 8% due to the reduced volume of tailings in the blend.

Grain size distribution analysis for the blended materials was conducted upon completion of the density, hydraulic conductivity and SWCC testing. Figure 3.4 shows the actual grain size distribution for the blended materials. The figure shows that a reasonably well-graded texture was achieved for each blend.

FIGURE 3.4
GRAIN SIZE DISTRIBUTION FOR CO-MIX BLENDS



Upon completion of the compaction and hydraulic conductivity testing, specific blends were selected for soil-water characteristic curve analysis. Table 3.2 shows a summary of the SWCC tests conducted. The soil-water characteristic curve of the whole tailings and the tailings from Area R3 were also evaluated. A standard size Tempe Cell with a cell diameter of 50 mm was utilized for all but two tests. The SWCC for the 1:1:2 blend with and without bentonite was repeated using a large Pressure Plate with a diameter of 150 mm. These tests were conducted to determine the influence of particle sizes greater than 5 mm.

TABLE 3.2
SUMMARY OF SOIL-WATER CHARACTERISTIC CURVE TESTING

Blend	Compaction	Pressure Plate	Bentonite
1:1:1	Yes	Small	n/a
1:1:2	No	Small	n/a
1:1:2	No	Large	n/a
1:1:2	No	Small	1.5%
1:1:2	No	Large	1.5%
1:1:2	Yes	Small	n/a
1:1:2	Yes	Small	1.5%
1:1:2 (R3 tailings)	Yes	Small	n/a

Figure 3.5 shows the soil water characteristic curves for the two tailings samples and the 1:1:2 blend mixed with whole mill tailings. Figure 3.6 shows the soil-water characteristic curves for the remainder of the tests.

It can be seen on Figure 3.5 that the Air Entry Value (AEV) for both the whole tailings and the R3 tailings is approximately 30 kPa. The AEV for the 1:1:2 blend, placed in a loose state is approximately equal to that for the whole tailings (i.e., 30 kPa). An interesting observation that can be drawn from the SWCC test results is that compaction of the material does not appear to increase the AEV. Alternately, the addition of bentonite significantly increases the AEV. It can be seen on Figure 3.6 that the AEV for the 1:1:2 blend with bentonite is greater than 50 kPa. It was also observed that the Co-Mix blends showed no measurable volume change associated with drying.

The reduction in volume change due to drying or desiccation is a paramount issue with respect to cover performance. Clearly, non-blended tailings have a low hydraulic conductivity and high AEV without the addition of waste rock and provide suitable hydraulic properties required for the construction of barrier covers. However, tailings are highly susceptible to shrinkage and cracking during drying cycles, which leads to failure in barrier cover systems. The Co-Mixing of waste rock and/or slag greatly reduces the compressibility and volume change characteristics of the matrix. In summary, the Co-Mix blends offer the hydraulic sealing characteristics of tailings together with a relatively low compressibility associated with granular materials. Furthermore, the integration of coarse waste material into the Co-Mix blend increases shear strength and resistance to erosion for the cover system.

FIGURE 3.5
SOIL-WATER CHARACTERISTIC CURVES FOR THE TAILINGS
AND 1:1:2 CO-MIX WITH WHOLE TAILINGS

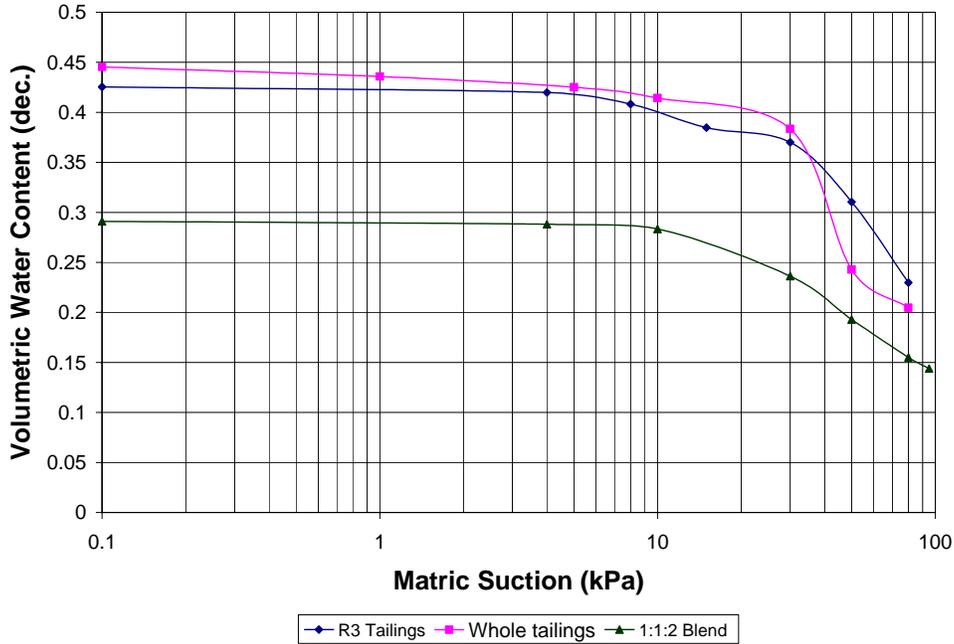
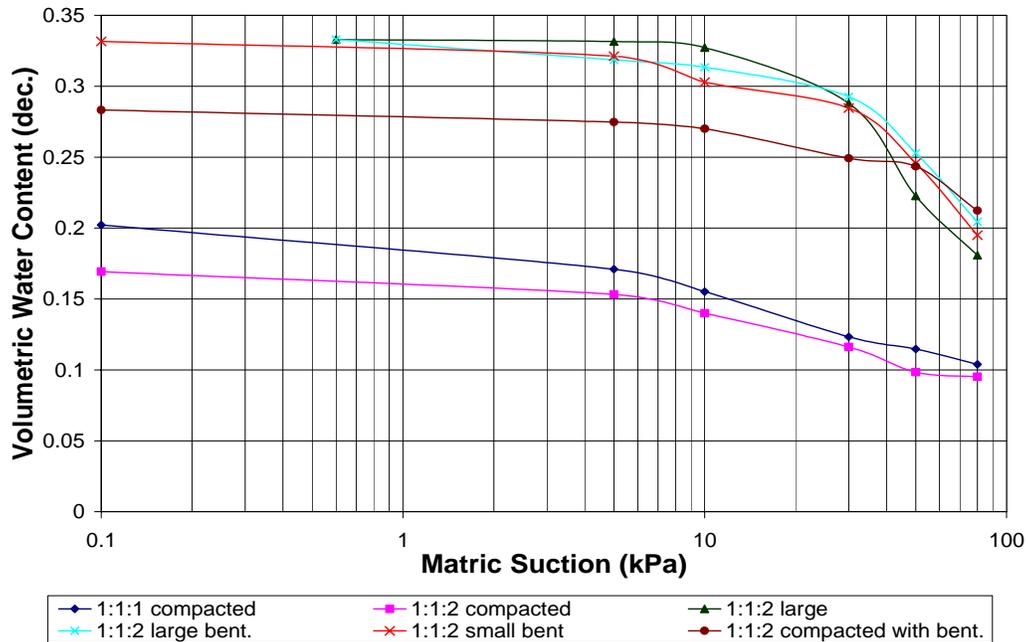


FIGURE 3.6
SOIL-WATER CHARACTERISTIC CURVES FOR NON COMPACTED AND
COMPACTED CO-MIX BLENDS



4.0 CONCEPTUAL DESIGN & OPTIONS EVALUATION (PERFORMED BY GOLDER PASTE TECHNOLOGY)

4.1 Overview

INCO requested Golder Paste Technology Ltd. (PasteTec) to complete a conceptual design and evaluate options for a cover material preparation and distribution system (Cover Plant). The design includes conceptual flowsheets and capital and operating cost estimates for 5 different placement options. These studies included details of the cost summaries for various placement and blending options with respect to tailings and blending ratios, as well as plant design and placement schedules. A summary of the costing study is provided here.

4.2 Cover Materials

The results of the testing described in previous sections indicate that the optimum mixture evaluated (in terms of hydraulic conductivity) was determined to be the following:

1. 1:1:2 mixture of waste rock, slag and tailings, respectively with 1.5% by weight of bentonite added and placed at zero slump. The mixture requires compaction to Standard Proctor before the optimum conductivity of 5×10^{-9} m/s is achieved.

It is understood that although these mixtures have the lowest hydraulic conductivity of the materials tested, alternative mixtures may be considered to reduce costs while still maintaining an acceptable hydraulic conductivity of less than 1×10^{-7} m/sec. Two alternative mixtures include:

2. Mixture without bentonite placed at zero slump and compacted (4×10^{-8} m/s or 8 times the hydraulic conductivity of the optimum mixture), and
3. Mixture with 1.5% bentonite placed at 7" slump and not compacted (1×10^{-8} m/s or twice the hydraulic conductivity of the optimum mixture).

A number of other mixtures are available and should be evaluated on a cost vs. benefit basis (ie. the expense of producing a mixture with a low hydraulic conductivity must be balanced against the benefit of doing so.)

A sensitivity analysis was prepared to address the sensitivity of the operating costs due to bentonite consumption and contractor costs for waste rock and slag supply. These two factors are the major contributor to the overall cost of the cover system and reductions in these costs must be balanced against the resultant hydraulic conductivity of the mixture. Waste rock/slag contents from 0% to 50% and bentonite contents from 0% to 1.5% were considered.

4.2.1 Waste Rock

It is assumed that waste rock will be available from the Copper Cliff North Mine area from existing stockpiles. The waste rock will require screening and/or crushing to minus 2" size before it is transported by truck to the Tailings Cover Plant location. Costs for delivering a sized waste rock product from the existing waste rock piles to the potential cover plant site at Hill Station were obtained from a local contractor familiar with the Inco site.

4.2.2 Slag

Slag will be available from the existing slag dump east of the Copper Cliff Smelter. The slag must be ripped, screened and/or crushed to minus 2" size before it is transported by truck to the Tailings Cover Plant location. Costs for delivering a sized slag product from the existing slag dump to the potential cover plant site at Hill Station were also obtained from a local contractor familiar with the Inco site.

4.2.3 Tailings

The tailings supply is more complicated than both the slag and waste rock since the available tailings stream will be variable depending on the demand from other tailings users. Additional demands on the tailings supply include:

- Dam raising during summer months (requires coarse fraction);
- South Mine hydraulic fill (requires coarse fraction);
- Creighton Mine hydraulic fill (requires coarse fraction); and
- Frood Stobie Mine hydraulic fill (requires coarse fraction).

It is unlikely that a reliable stream of total tailings will be available for a substantial portion of the time. Demands on the coarse fraction of the tailings stream will be particularly heavy in the summer months during tailings dam construction.

The fines fraction, however, is not typically used in any significant quantity and is available year round (except during mill shutdowns). Testwork was not reported for the combination of fines with waste rock and slag, however, for the purposes of this conceptual options evaluation, it is assumed that similar hydraulic conductivities will be obtained with the fines as compared to the total tailings.

4.3 Options Descriptions

In addition to the selection of the cover materials, several key parameters for the tailings area cover system that must be determined include:

- Tailings dewatering equipment (deep tank dewatering vs. thickener/filter);
- Mixture delivery method (truck delivery or pumping); and
- Plant and deposition area operation (summer only, year round or combination).

4.3.1 Tailings Dewatering Equipment

The choice of dewatering equipment is largely dependent on the requirement for more or less moisture in the mix.

For mix designs 1 and 2 where compaction is required, the tailings will need to have a dry, filter cake consistency before being blended with the waste rock and slag in order to produce a compactable material. Excess moisture will make the material sticky and too fluid like for truck transport, placement and compaction. In this case, a high rate thickener followed by a vacuum disc filter will likely be the most appropriate technology for the production of sufficiently dry tailings.

A more dilute mixture is acceptable for blend number 3 since the mixture will have a fluid like consistency that allows pumping. In this case, a deep tank thickener such as GL&V's Paste Production and Storage Mechanism (PPSM) or EIMCO's Deep Cone Thickener (DCT) would be appropriate since the power requirement and operating cost is significantly less than a thickener/filter.

It should be noted that testing is required to confirm the thickening, filtration and deep tank thickening rates available for the total tailings material as well as the tailings fines fraction only.

4.3.2 Mixture Delivery Method

The choice of delivery method is primarily dependent on the moisture content of the mixture.

For mix designs 1 and 2, the moisture content will need to be quite low in order for the material to be sufficiently dry for mobile equipment to travel on top of it. In this case, the material will be far too dry for any sort of pipeline transport. Due to the flexibility required by the delivery system to deliver the material to virtually every portion of the tailings area, stationary bulk handling systems such as conveyors are not considered practical. It is recommended that the dry

material be delivered by dump truck and rehandled by dozer into an evenly graded surface of uniform thickness before being compacted by a roller or dozer.

The moisture content of blend number 3 will be high enough for the mixture to be pumped via positive displacement pump for distances up to 2 km. Depending on the distance from the cover preparation plant to the cover locations, additional booster pumps may be required. Delivery of the paste in an even layer of uniform thickness may be via a truck mounted concrete pump with a PLC controlled boom traverse pattern or by rehandling desiccated paste deposited from a central discharge with a dozer and compacting into an evenly graded surface as previously described for the dry mixture.

4.3.3 Plant and Deposition Area Operation

Some of the deposition plans put forward in previous sections of this report require temperatures above zero. Other deposition plans can be performed all year long and still others can perform some functions year round while other functions can only be carried out in the summer. The timing of the deposition for various options is explained below:

4.4 Options Summary

4.4.1 Dry Placement of Cover Mixture – Summer Only

The cover material will be produced, deposited and compacted in the summer months for this option. A plant with a much higher capacity than one that operates all year long is required, but avoids problems with freezing of the material in the trucks or during dozing and compacting.

4.4.2 Dry Placement of Cover Mixture – Placement Year Round, Compaction in Summer Only

For this option, the cover material will be produced and deposited by truck at the tailings area year round, but will only be dozed and compacted during the summer months. This will allow the plant to be significantly smaller while still producing the same yearly tonnage and avoiding problems with dozing and compacting material in freezing temperatures. Handling of the mixture in dump trucks during the winter time will be more difficult with respect to freezing and hang-up, however, travelling over the tailings area will be easier when the ground is frozen.

4.4.3 Wet Placement of Cover Mixture – Summer Only

In this option, the cover material will be produced and placed only during the summer months. This will allow mobile equipment to move material around as required to produce a cover of uniform thickness, but will require a cover material plant with larger capacity.

4.4.4 Wet Placement of Cover Mixture – Placement Year Round

In this option, the cover material will be produced and placed all year round. No further rehandling of the material will be required. This option would require special equipment such as a concrete pumper truck equipped with a boom that is controlled to spread an even layer of paste over the pumper truck's area of influence

4.4.5 Wet Placement of Cover Mixture – Placement Year Round with Rehandling in Summer

In this option, the cover material will be produced and placed all year round at a central discharge location. The material will be allowed to dewater and, once sufficiently dry, will be rehandled by a loader into a dump truck for transport to the ultimate deposition area. The material will then be placed, dozed and compacted as dry material. The rehandling of the material will only be possible in the summer months. A number of central discharge points will be required so that one area can be in use, one area can be desiccating and one area can be available for rehandling of material.

4.5 Cost Estimate

The cost estimates were performed to an order of magnitude level of accuracy (+/- 30%) based on the 1:1:2 mixture of waste rock/slag/tailings and 1.5% bentonite. The cost summaries provided below are for the placement of 100 Ha of Co-Mix cover with a uniform thickness of 600mm.

Contractor costs for the crushing, screening, and handling of waste rock, slag and the cover mixture were obtained from Ethier & Son Construction. Equipment costs were obtained from suitable Vendors and from PasteTec's database from similar projects.

Power costs were assumed at \$0.06/kWhr, labour rates were assumed at \$80,000 per year and Bentonite costs were assumed to be \$200/tonne, including handling and transportation.

The capital and operating costs for the 5 placement options are summarized in Table 4.1 below:

TABLE 4.1
CAPITAL AND OPERATING COST FOR 1:1:2 WASTE ROCK:SLAG:TAILINGS
MIXTURE WITH 1.5% BENTONITE

	Capital Cost (CAN\$)	Operating Cost (CAN\$)
Dry Placement – Year Round	4,000,000	13,000,000
Dry Placement – Summer Only	7,300,000	12,100,000
Wet Placement – Year Round	6,800,000	11,400,000
Wet Placement – Summer Only	17,700,000	10,300,000
Wet Placement – Year Round with Summer Rehandling	6,800,000	11,500,000

The majority of the operating cost is a result of the bentonite and the contractor supply of waste rock and slag. .

The costs given here are considered conservative since it is likely that a significant reduction in the amount of bentonite and/or reduction in the amount of contractor supplied waste rock/slag can be obtained. The costs in Table 4.1 therefore represent the ‘worst case scenario’. The yearly operating costs alternate mixtures of bentonite and waste rock/slag are summarized in Table 4.2 below:

TABLE 4.2
OPERATING COST FOR ALTERNATE WASTE ROCK:SLAG:TAILINGS MIXTURES

	0% Waste Rock/Slag 1.5% Bentonite Operating Cost (CAN\$)	50% Waste Rock/Slag 0% Bentonite Operating Cost (CAN\$)	0% Waste Rock/Slag 0% Bentonite Operating Cost (CAN\$)
Dry Placement – Year Round	5,400,000	8,543,000	900,000
Dry Placement – Summer Only	4,987,000	7,618,000	487,000
Wet Placement – Year Round	6,410,000	6,852,000	1,910,000
Wet Placement – Summer Only	5,867,000	5,841,000	1,367,000
Wet Placement – Year Round with Summer Rehandling	7,650,000	8,092,000	3,150,000

From the table above it can be seen that the yearly operating cost savings are more pronounced for the dry placement options than for wet placement when bentonite, waste rock and slag are not added.

The Table 4.1 represents the most optimistic possibility for yearly operating cost. The benefits of adding bentonite and/or waste rock/slag must be measured against the increase in operating cost.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Laboratory testing conducted to date indicates that it is feasible to construct high quality sealing layers using blended Co-Mix tailings, slag and waste rock. A blend ratio of 1:1:2 WR: Slag: Tailings produced a dense, well-graded material with a low hydraulic conductivity. The hydraulic conductivity for the blended material is approximately equal to the value of hydraulic conductivity for pure tailings without the aid of compaction (i.e., 2×10^{-7} m/s). The value of hydraulic conductivity of the Co-Mix materials blended with whole mill tailings showed a reduction of approximately one order of magnitude with the addition of bentonite and compaction. The AEV of the Co-Mix material was found to be similar to the tailings in the range of 30 kPa. The addition of bentonite increases the AEV to approximately 50 kPa. In summary, the laboratory testing completed shows the Co-Mix material should provide excellent performance as a barrier layer within a cover system. Several key points and recommendations are outlined below:

1. Evaluation of the Co-Mix materials using the fine fraction tailings was not conducted. However, the blending of fine tailings within the Co-Mix materials should provide a somewhat lower hydraulic conductivity and higher AEV compared to the whole tailings. In general, it is expected that the value of hydraulic conductivity of a Co-Mix blend with fine tailings, bentonite and compaction will be similar to the value obtained for R3 tailings.
2. Wet placement year round provides the best economic value for the construction of a 600 mm barrier cover. The annual operating cost for the construction of 100 Ha of the 1:1:2 blend with 1.5% bentonite is estimated to be \$11.4 M or \$114,000 per Ha. Operating costs may be reduced by 40% to \$69,000 per Ha if bentonite is not required. Alternately, bentonite addition may be used only within the lower 200 mm of the 600 mm without significantly reducing hydraulic performance. It is expected the cost for this cover profile to be in the order of \$84,000 per Ha.
3. The optimum mix design consists of a waste rock, slag, and tailings ratio of 1:1:2 with bentonite. While this well graded mix design will provide the best geotechnical performance with respect to hydraulic conductivity, the SWCC and AEV, together with a high shear strength, low volume change characteristics and resistance to erosion; it should be possible to use alternate mixes at specific locations where significant cost savings can be achieved. For example it will be possible to use a simple Co-Mix blend of tailings and waste rock or tailings and slag at many locations. Further cost savings may be achieved by using South Mine waste rock and/or slag that requires only screening (i.e. no crushing).

4. Further to point No. 3, the construction of the highest quality 1:1:2 Co-Mix barrier will not be needed over the entire tailings impoundment. In general, it is expected the 1:1:2 Co-Mix system will only be required on the tailings dams and beaches where the high permeability of the sand materials results in free drainage with a low water table and a deep unsaturated zone. This would also be the case for the reclamation of the waste rock dumps at North Mine and the Slag dumps. Water covers and wetlands may be considered for the interior regions of the final impoundment thus eliminating the requirement for a Co-Mix profile. Alternately, paste tailings (i.e., 100% tailings with no waste rock or slag) may be used as cover for intermediate regions between the wetlands and beach areas. The cost of placing a 600 mm paste tailings cover is estimated to be \$140,000 per Ha. The reclamation of the North Mine dumps or Slag dumps could be carried out by simply pumping paste tailings directly on to the existing surface of the dumps and subsequently roto-mixing the paste into the in-situ waste rock or slag to form the Co-Mix cover. This method would eliminate the excavation, transportation, plant mixing and return pumping of the Co-Mix material back to the dumps. Saturated/Unsaturated Seepage analyses will be required to establish the appropriate regions for each cover type.
5. SoilCover modelling should also be completed to delineate the desired hydraulic properties needed for a cover system on waste rock piles and slag stockpiles. The desired hydraulic properties (i.e., AEV and hydraulic conductivity) may well be different for these varied uses.
6. Geochemical analysis for the Co-Mix materials must be investigated. In general, the acid generation potential of paste tailings may be reduced with either the addition of lime or the removal of the sulphide bearing minerals. A detailed estimate of cost for treatment for either method requires further geochemical analyses, however, a simple estimate based on 2% lime addition in the upper 300 mm of the cover would be approximately \$12,000 per Ha. It is important to note that the tailings obtained from the R3 area were observed to be highly reactive during the laboratory test program and are not considered suitable for blending with Co-Mixtures.
7. The construction of field scale test pad lysimeters is recommended. The following profiles may be considered:

I)	300 mm	Loose Growth Media
	600 mm	Paste Tailings
	2,000 mm	Reactive Tailings
II)	300 mm	Loose Growth Media
	600 mm	Co-Mix Blend 1:1:2
	2,000 mm	Reactive Tailings
III)	300 mm	Loose Growth Media
	600 mm	Co-Mix 1:1:2 (lower 200 mm compacted with 1.5% Bentonite)
	2,000 mm	Reactive Waste Rock

It is recommended that the test covers be constructed on lysimeters measuring 10 m x 10 m that have a HDPE liner and drainage collection for continuous flow measurement. Sensors for the measurement of oxygen concentration, water content and matric suction would be installed both

within the 600 mm barrier layer as well as the underlying reactive tailings and/or waste rock. Continuous measurements for flow/net infiltration, water content (i.e., degree of saturation), suction, and oxygen penetration will be used to assess performance of the Co-Mixed tailings, slag and waste rock barrier layer. It is recommended that the test covers operate for a period of at least three years. The covers would not be vegetated during the first year. Select vegetation would be seeded during years 2 and 3 to determine the influence of root penetration and water uptake. Furthermore, the barrier profiles would be subject to freeze/thaw along with wetting and drying cycles associated with spring melt and drying during the summer months.

Detailed specifications for the design and construction of the test cover lysimeters will be provided on the basis of Soil Cover modelling. The production and placement of the blended co-mix barrier will be conducted in conjunction with PasteTec.

