THE APPLICATION OF BLENDED WASTE ROCK AND TAILINGS FOR COVER SYSTEMS IN MINEWASTE MANAGEMENT[1]

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Abstract: Waste rock, tailings, and slag from a mine in Sudbury, Ontario were blended to create a material with superior physical and hydraulic properties for the potential construction of a cover system on a large tailings impoundment. The new material, termed Co-Mix, has a low hydraulic conductivity, a high Air Entry Value, and low compressibility. These properties indicate that the Co-Mixed waste rock, tailings, and slag can be used to restrict oxygen entry and water seepage, thus minimizing acid generation and metal leaching within the sulfide bearing mine tailings. The results of laboratory testing for various blend ratios together with soil cover model simulations are used to design a field scale experiment.

Field scale test trials using selected Co-Mix blends of waste rock, tailings, and slag were constructed in October, 2004 at the Copper Cliff mine in Sudbury, Canada. The field scale test trials consist of 5 lysimeters measuring 15x15 m, with a total depth of about 2500 mm. These test trials are currently being used to evaluate the performance of the new material for cover systems that may potentially be constructed on the tailings impoundment upon closure. The lysimeters were constructed with thicknesses of Co-Mix cover material ranging between 600 mm and 1000 mm along with various blend ratios of waste rock, tailings, and slag. The lysimeters will be used to measure seasonal net infiltration rates together with oxygen fluxes to the underlying tailings. The construction of the lysimeter was recently completed and early results with respect to field performance during the spring snow melt period and summer months are presented in this paper for comparison with model predictions.

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Introduction

Construction descriptions of four test trials for Co-Mix waste rock and tailings material, used as a cover for tailings impoundment, together with theoretical considerations regarding the predicted performance of such covers, are presented in this paper. Conventional mine waste management systems produce a wet tailings stream and a dry waste rock stream. Tailings and waste rock have strikingly different properties with respect to texture and soil behavior. Fine grained tailings tend to feature low permeabilities but are commonly discharged at high water contents with low shear strength and have slow consolidation properties with high volume change characteristics. Alternatively, the dry waste rock stream is typically coarse rock, cobbles and gravel that offers high physical stability; but also permits high water infiltration and oxygen entry for sulphide oxidation and acid generation. In general, neither material is suitable for cover construction and long term reclamation.

Cover systems constructed on potentially acid forming tailings impoundments or waste rock dumps must function as oxygen and water barriers in order to minimize acid rock drainage. 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 grained matrix such as the glacial till material used at Equity Silver Mine in British Columbia have been proven to be excellent materials for the construction of barrier type cover systems.

Inco has initiated a field and laboratory study to investigate the potential of blending tailings, waste rock and slag at the Copper Cliff Mine in Sudbury, Canada to produce a suitable material for the construction of a barrier cover system. A preliminary laboratory test program was conducted that indicated it should be possible to produce a high quality cover material. The decision was subsequently made to proceed with the construction of field scale lysimeters to measure the performance of cover systems constructed using blended waste rock, tailings and slag as Co-Mix material. The design, construction and predicted performance of the lysimeters are described herein.

Theoretical considerations over the concept of Co-Mixing Tailings and Waste Rock

In order to be effective, a cover system should have hydraulic properties that limit oxygen infiltration and/or water seepage into the tailings impoundment or waste rock dump. This will ensure that oxidation of the sulphidic minerals is minimal, and consequently, a lower volume of acid drainage is produced with much more benign chemical properties. The physical properties of a cover material that are required to produce adequate barrier characteristics are presented in this section.

The parameter used to quantify the saturated/unsaturated hydraulic performance of different types of materials is the Soil Water Characteristic Curve (SWCC). The SWCC illustrates how water will be retained within the matrix of the material under negative pore water pressure or matric suction. It is known that there is a direct correlation between grain size distribution and pore size distribution, and that the shape of the SWCC is a consequence of the size distribution (Fredlund, 2000). Figure 1 illustrates typical grain size distributions for waste rock and tailings.

Also show is the grain size distribution for Equity Till, a well graded material that has proven to provide excellent performance as barrier cover material.

The SWCC for the waste rock, tailings and glacial till are presented in Fig. 2. Upon comparison of the SWCC for the three different types of materials shown in Fig. 1, it becomes apparent that the most desirable hydraulic characteristics are provided by the Equity Till, (Wilson et al, 2003). The grain size distribution of the well graded Equity Till ensures a high Air Entry Value (AEV) and a low hydraulic conductivity with excellent water retention characteristics. As a consequence of this observation, the primary objective of this study is to produce an engineered material by blending waste rock, tailings, and slag together from INCO's Copper Cliff Mines, near Sudbury, Ontario. The material is referred to as Co-Mix.

Furthermore, Wilson et al (2003) describes that the Co-Mix material combines the physical stability of the waste rock with the low hydraulic conductivity of the tailings, producing a material well suited for cover purposes. The new material has low compressibility with respect to consolidation and soil matric suction, greatly reducing the cracking associated with drying and dessication. At the same time, the Co-Mix material is capable of maintaining high saturation under negative pore waster pressure above the water table.

Laboratory Testing

Field samples of tailings, waste rock and slag were obtained for blending trials. Waste rock was collected from fresh production rock produced by 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 Tailings Area R3 as well as whole

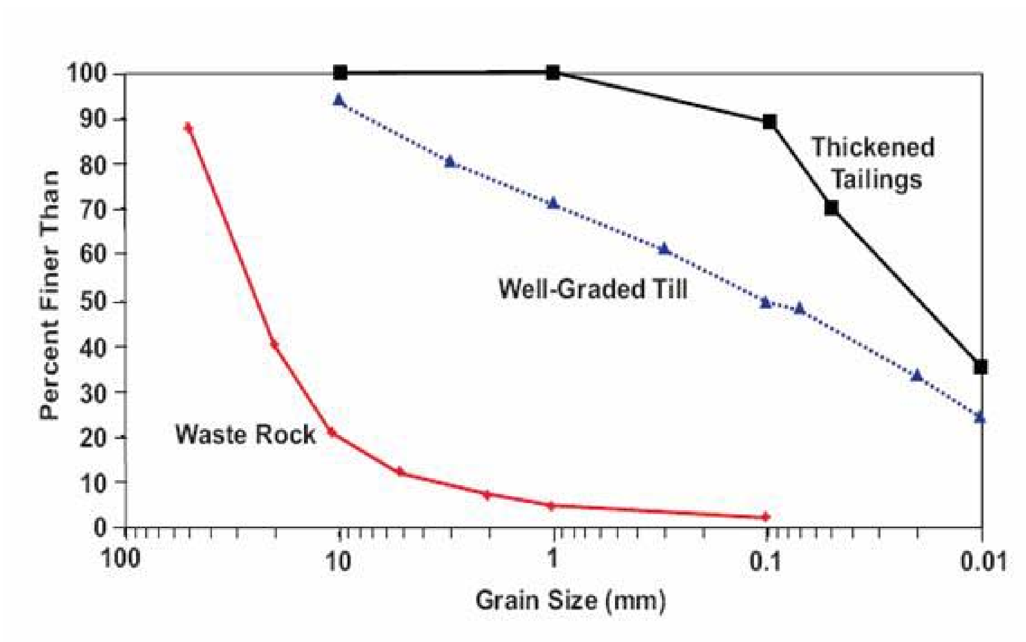

Figure 1. Typical grain size distribution for tailings, waste rock, and well graded Equity till.

tailings directly from the mill. The grain size distributions for various blend ratios of waste rock, slag and tailings are designated with numbers such as: 1:1:2 indicating 1 waste rock, 1 slag, and 2 tailings on a dry weight basis. It was found that Blend 1:1:2 produced a grain-size distribution similar to that for the Equity Till shown in Fig. 1. Equity Till has proven to be an excellent cover material at the Equity Silver Mine in British Columbia.

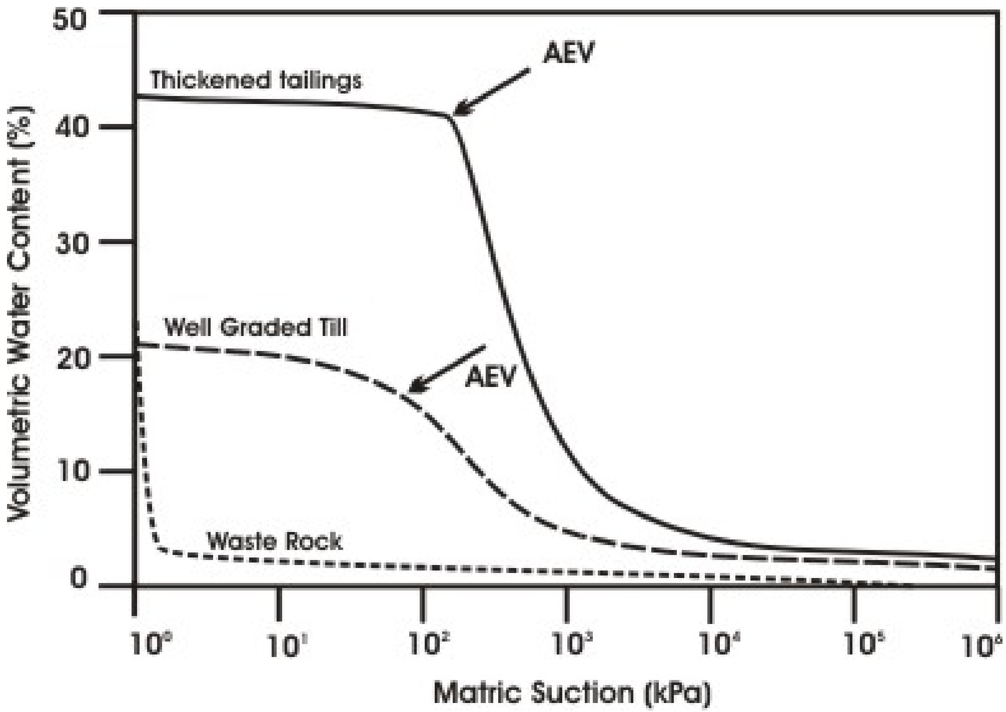

Figure 2. Typical Soil Water Characteristic Curves for tailings, waste rock, and well graded Equity till.

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 1:1:2 were 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 100 mm, as well as at a higher water content of 12 percent to produce a paste like consistency having a slump of 200 mm. 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) to non-compacted and compacted samples was also evaluated. The results for the measured values of hydraulic conductivity are shown in Table 1, which summarizes the test results for the samples blended with tailings obtained from Tailings Area R3 as well as fresh or whole tailings.

Table 1. Hydraulic conductivity values for selected Co-Mix blends.

Blend	Tailings	K_{sat} (m/sec)	Comments
1:1:2	R3	2 x 10^{-7}	100 mm Slump
1:1:2	R3	2 x 10^{-7}	200 mm Slump
1:1:2	R3	4 x 10^{-8}	Standard Proctor
1:1:2	R3	3 x 10^{-8}	200 mm Slump with 1.5% Bentonite
1:1:2	R3	5 x 10^{-9}	Compacted with 1.5% Bentonite
0:1:1	Fresh	1 x 10^{-7}	> 250mm Slump
1:1:1	Fresh	1 x 10^{-7}	50 mm Slump
1:1:1	Fresh	5 x 10^{-8}	Standard Proctor

Table 1 shows 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 x 10^{-7} m/s without compaction (i.e., loose, semi-fluid state). The value of hydraulic conductivity was found to decrease to 4 x 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 x 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 x 10^{-9} m/s. This material is considered to be an excellent candidate for the construction of a barrier cover system.

Figure 3 shows the soil water characteristic curves for typical tailings and Co-Mix blends. Tailings Type 2 and Co-Mix 2 correspond to Blend 1:1:2 mixed with R3 tailings. It can be seen that the AEV for the Type 2 tailings (R3 tailings) is approximately 30 kPa. The AEV for the Co-Mix 2 (1:1:2 blend) placed in a loose state is approximately equal to that for the tailings (i.e., 30 kPa). In summary, the results of the hydraulic conductivity testing together with the soil water characteristic curves show that the hydraulic properties of the Co-Mix materials are similar to those for the tailings used for blending.

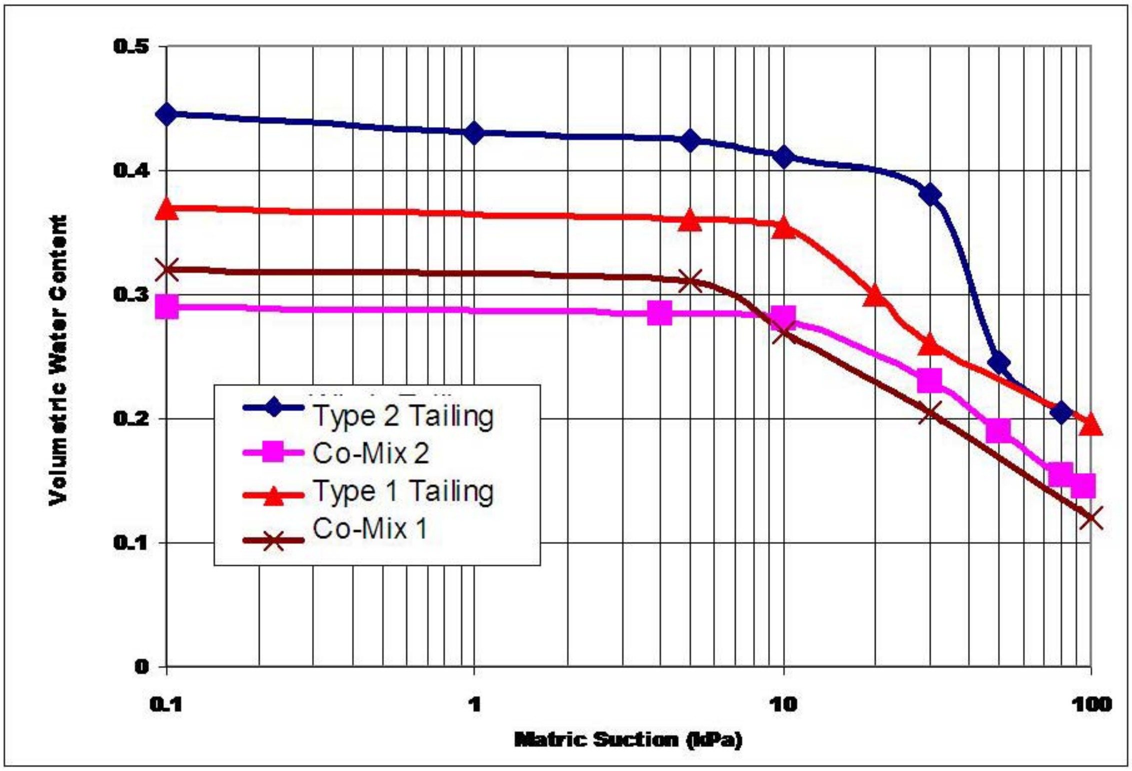

Figure 3. Typical Soil Water Characteristic Curves for select Co-Mix blends.

<u>Construction of field experiment</u>

<u>Field Lysimeters</u>

Five large field lysimeters were constructed in October 2004 to test the performance of the Co-Mix materials used for the construction of barrier type cover systems. The surface of each lysimeter measured 15 m x 15 m and the lysimeters had a total depth of 2.5 m. The lysimeters were lined with HDPE and the base was graded to a central collection sump for the measurement of vertical seepage due to infiltration. Approximately 1.5 m of coarse sand tailings was placed into the base of each lysimeter. The purpose of the field lysimeters were to measure net infiltration and drainage rates for each tailings profile with different cover systems constructed using various Co-Mix materials and layer thickness. Furthermore, the ability of each cover profile to maintain high saturation, for minimizing oxygen diffusion, will also be evaluated. The first phase of construction is presented in Fig. 4.

The five test pads include one control section with a lysimeter filled to full depth with coarse sand tailings (i.e., no cover) along with four Co-Mix test cover plots, as presented in Table 2. The first Co-Mix cover for Lysimeter L2 was constructed with a thickness of 1000 mm using 200 mm minus ROM waste rock and a blend ratio of 1:1:1 (tailings: slag : waste rock) Lysimeter L3 was also constructed with 1000 mm thick Co-Mix cover but a blend ratio of 2:1:1, using 50 mm minus waste rock. The primary difference between L2 and L3 is that the cover material placed in L2 was at low slump (i.e., 50 mm), while L3 was placed at high slump (i.e., 150 mm) to simulate a mixture that may by pumped. Lysimeter L4 was constructed using the same

Co-Mix blend as L2 but with the cover thickness reduced to 600 mm. Likewise, Lysimeter L5 was also constructed similar to L3 with a reduced cover thickness of 600 mm, but in addition, the high slump Co-Mix blend was modified with the addition of 1.5% bentonite

Figure 4. Aerial view of the first phase of construction.

The original plan for the construction of the Co-Mix covers included a layer of top soil as a growth medium and evaporation barrier. Due to the late start of the construction, the lysimeters were finished just prior to winter freeze in October 2004 and it was not possible to put in place the protective layer of top soil or to compact the covers.

During the spring snowmelt all the cells were draining water, as expected, since all cover systems were initially placed at high water content under flooded conditions. There was no possibility to quantify how much water was draining from each cell because the appropriate instrumentation was not installed at that time. The following summer of 2005 was extremely hot and dry. The average maximum temperature for the summer months was between 32 and 35 °C, compared to the 30 year average of 23 to 25 degrees centigrade. The total precipitation between 1st of June and 31st of August was 156 mm, compared to the 30 year average of 242 mm. Given these conditions, the Co-Mix covers were exposed to severe conditions for drying and desiccation. It was observed that, even under these extreme drying conditions, the Co-Mix in Cell # 2 and Cell#3 did not crack; however, cracks were noted in Cell #4 and Cell #5.

Table 2. Characteristics of the Co-Mix cover systems.

Cell #	Tailings thickness	Cover		Compaction	Topsoil	Placement	Bentonite
		Thicknes	Blend ratio				
1	2 m	--	--	--	No	--	--
2	1 m	1 m	1:1:1 200 mm minus WR	No	Yes	Dry	--
3	1 m	1 m	1:1:2 50 mm minus WR	No	Yes	Paste	--
4	1 m	600 mm	1:1:1 200mm minus WR	Yes	Yes	Dry	--
5	1 m	600 mm	1:1:2 50 mm minus WR	Yes	Yes	Paste	1.5 %

Generally, under operating conditions, the Co-Mix materials will not be exposed directly to the elements. Considering that the surfaces of the Co-Mix materials were allowed to desiccate extremely dry conditions that would not be expected under typical conditions, the decision was made to reinstate, as much as possible, the initial conditions in which the Co-Mix covers were put in place in the fall of 2004. To ensure that the potential cracks that formed as a result of the drying event were destroyed, the surface of the covers was scarified to a depth of 800 mm for the Co-Mix covers on L2 and L3, and 500 mm on L4 and L5. The surfaces of L2 and L3 were subsequently flooded with 15 cubic meters of water (Fig. 5), to produce a wet high slump material similar to the initial pumped condition. The surfaces were then graded with an excavator and finished with a small (80 Kg) plate tamper to eliminate the irregularities that may prevent water from running off.

In contrast to wet self-weight compaction, the Co-Mix covers on L4 and L5 were compacted in two layers. A layer of 250 mm depth was removed from the surface of the Co-Mix cover, and deposited in one corner of the cell to allow for access and proper compaction of the bottom layer, using a 500 Kg plate tamper; then the material was put back in place, and compacted. As a final step, the surface was graded with the excavator and finished with the same small 80 plate tamper used for the finishing of the surfaces on L2 and L3. Finally, in order to make the installation of the Thermal Conductivity sensors easier, and with minimum disturbance to the finished surface, sections of PVC pipe were installed in the cover prior to compaction.

Figure 5. Lysimeter L2 immediately after flooding.

Following the original plan of construction, a layer of top soil was put in place on top of the Co-Mix material. The soil is a locally acquired loam from a borrow source and consists of more than 80% particles finer than 74 microns. The thickness of the topsoil layer varies according to the level of compaction and settling observed in each lysimeter. The hydraulic conductivity of the topsoil is in the order of 5 x 10^{-6} m/sec. The aim was to construct the topsoil cover thick enough to provide a growth media as well as provide a graded slope such that surface run off is directed to the perimeter ditch around the lysimeters as illustrated on Fig. 6.

The protective layer of topsoil was hydroseeded with a mixture of grass seeds normally used by INCO in reclamation works.

The final density of the Co-Mix covers that was achieved subsequent to compaction (in the case of L 4 and L5) or drainage and self weight consolidation (in the case of L2 and L3) is presented in Table 3.

Figure 6. Lysimeter L3 with the topsoil cover.

Table 3: Density of the Co-Mix covers at 150 mm depth.

Lysimeter #	Density [Kg/m^3]	Water Content [%]	Standard Proctor Density [Kg/m^3]	Proctor [%]
1	1559	3.3	--	--
2	2080	9.9	2240	92.8
3	2087	10.3	2230	93.6
4	2151	9.4	2270	94.7
5	1936	11.9	1980	97.8

Observed Field Performance of Lysimeters

As a result of the unusually hot and dry weather, the Co-Mix cover placed on L5 and containing 1.5 % bentonite developed cracks during dessication, as shown in Fig. 7. The ponded water, resulting from a 12 mm torrential rain, was observed infiltrating in less then 10 hours. The Co-Mix covers on Cell #2, Cell #3, and Cell #4 showed only superficial cracks formed after prolonged drying. Ponded water from the same torrential rain was observed remaining on the surface for several days. The amount of infiltration water collected in 1000 L reservoirs at the bottom of each cell is perhaps the best method to compare relative performance of each Co-Mix cover. Compared to the total quantity of infiltration through the uncovered tailings in Cell #1, the relative quantity of infiltration through the Co-Mix cover of Cell #5 was almost equal, while the infiltration through the covers of cell # 3 and # 4 was approximately 50% less. Cell # 2 yielded no water throughout the summer.

Figure 7. Cracks on the Co-Mix cover of Cell #5.

Predicted Cover Performance

Construction and instrumentation of the lysimeters has only recently been completed and field performance with respect to net infiltration rates and saturation profiles will be observed over the next several years. While direct measurements of actual field performance are not yet available, it is possible to predict the performance for the lysimeters using the SoilCover numerical model (USG, 1997). Figure 8 shows the predicted surface fluxes (i.e., water balance) for the control cell with coarse sand tailings and no cover (L1). The hydraulic conductivity of the coarse tailings was set equal to 2.5×10^{-5} m/s. The simulation was conducted for a period corresponding to two years of a snow melt period followed by summer months. The total precipitation for the simulations was approximately 1800 mm with potential evaporation of slightly less than 1200 mm. The results of the numerical model show that approximately 1000 mm of net infiltration occurs. In other words, more than 50% of precipitation enters the surface of the uncovered tailings to form downward seepage. Figure 9 illustrates the predicted saturation values within the profile of the uncovered tailings. It can be seen that the degree of saturation in the profile is typically less than 50%. This indicates a corresponding high value for the diffusion coefficient of oxygen that drives sulfide oxidation and acid rock drainage (ARD).

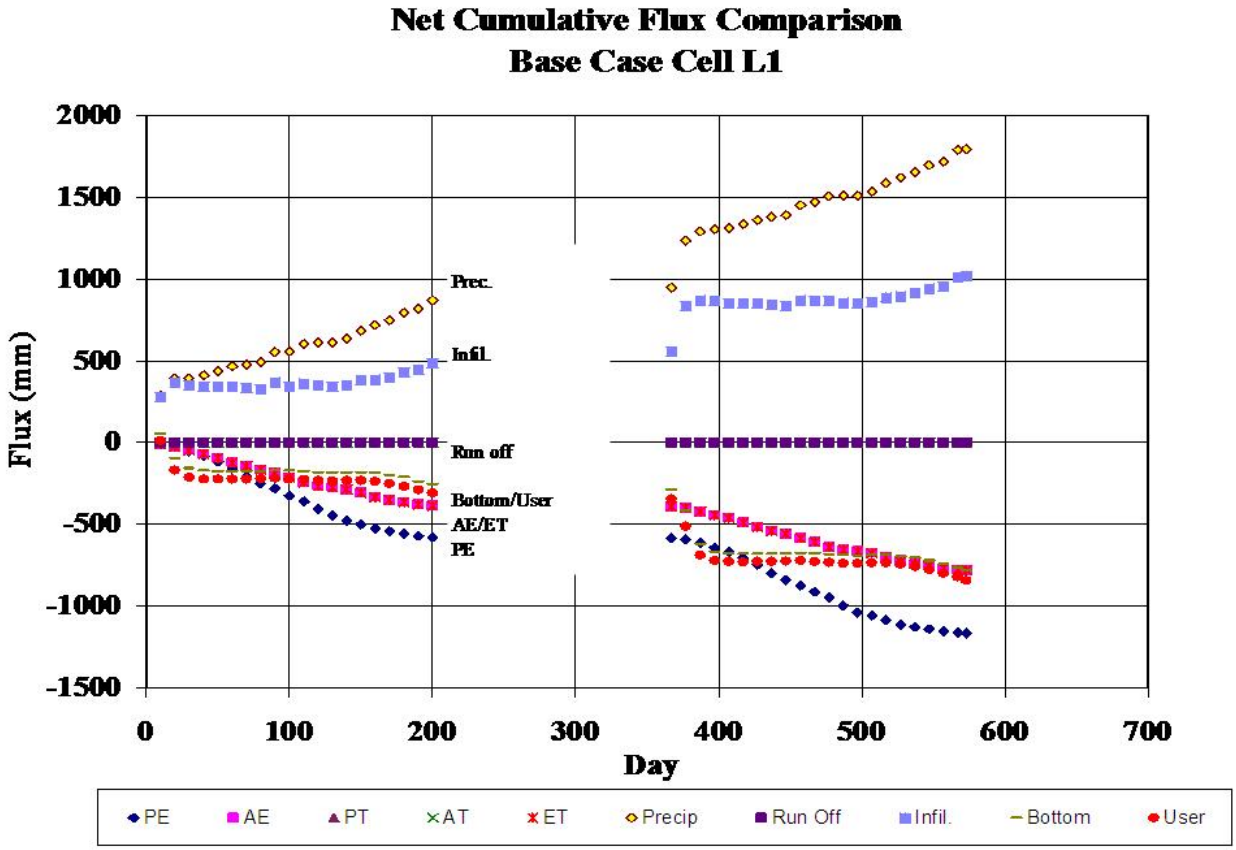

Figure 8. Flux summary for uncovered tailings.

In general, it is well known that a reduction in oxygen diffusion occurs only when saturation values exceed 85%. The results for the control lysimeter suggest that sulphide oxidation would not be restricted by diffusion. Furthermore, high infiltration occurs and the combined result with unrestricted oxidation rates could produce significant ARD. Figures 10 and 11 shows the predicted surface fluxes and saturation profiles for Lysimeter L2 with a 1000 mm Co-mix cover. The hydraulic conductivity for the Co-Mix cover material was set equal to 5.0 x 10^{-8} m/s. Figure 10 shows that the net infiltration rate is reduced to less than 400 mm compared to 1000 mm for the uncovered case. The reduction in hydraulic conductivity for the Co-Mix cover results in the ponding of precipitation and the subsequent generation of about 450 mm of surface runoff.

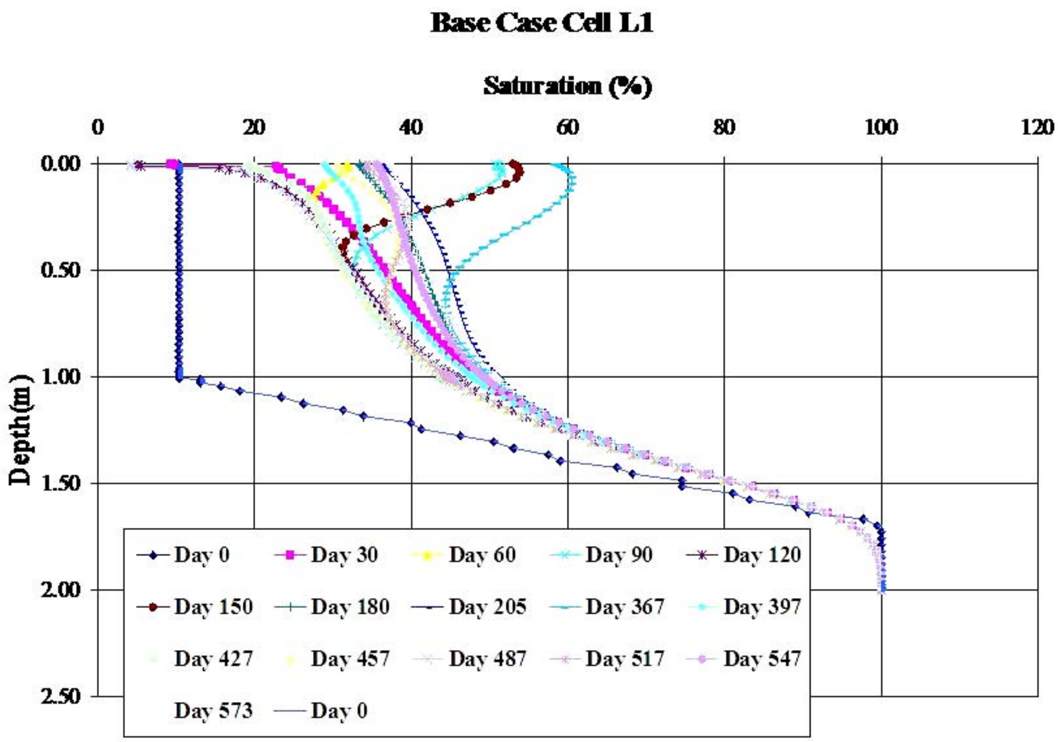

Figure 9. Saturation profile for Cell L1 with uncovered tailings.

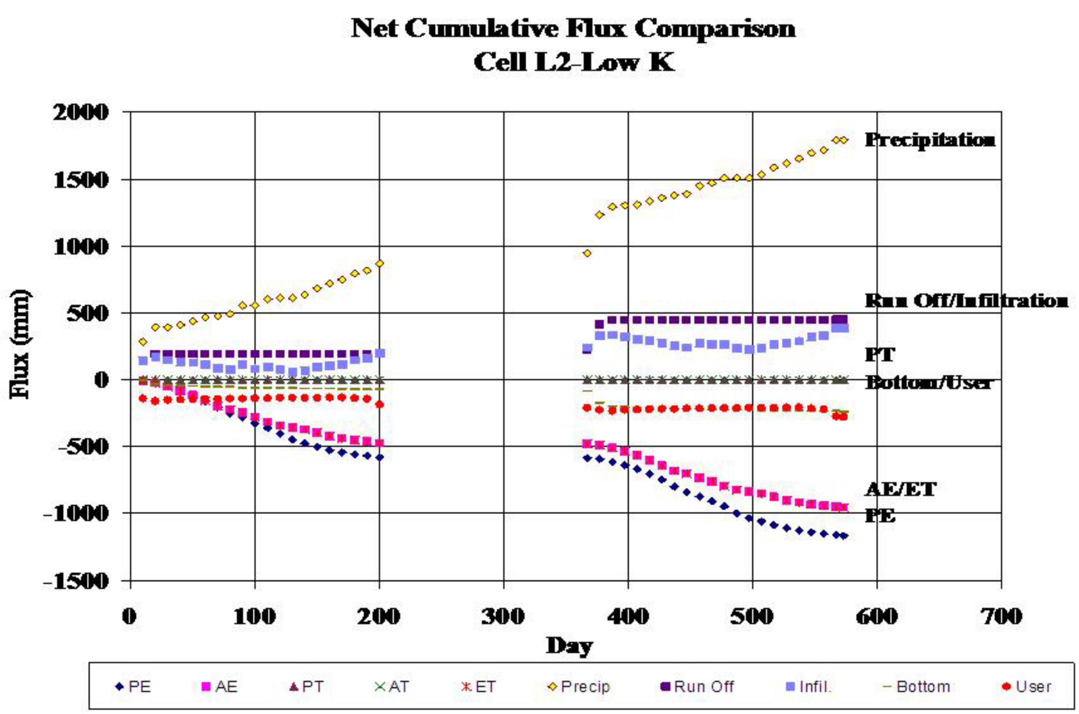

Figure 10. Flux summary for Cell L2.

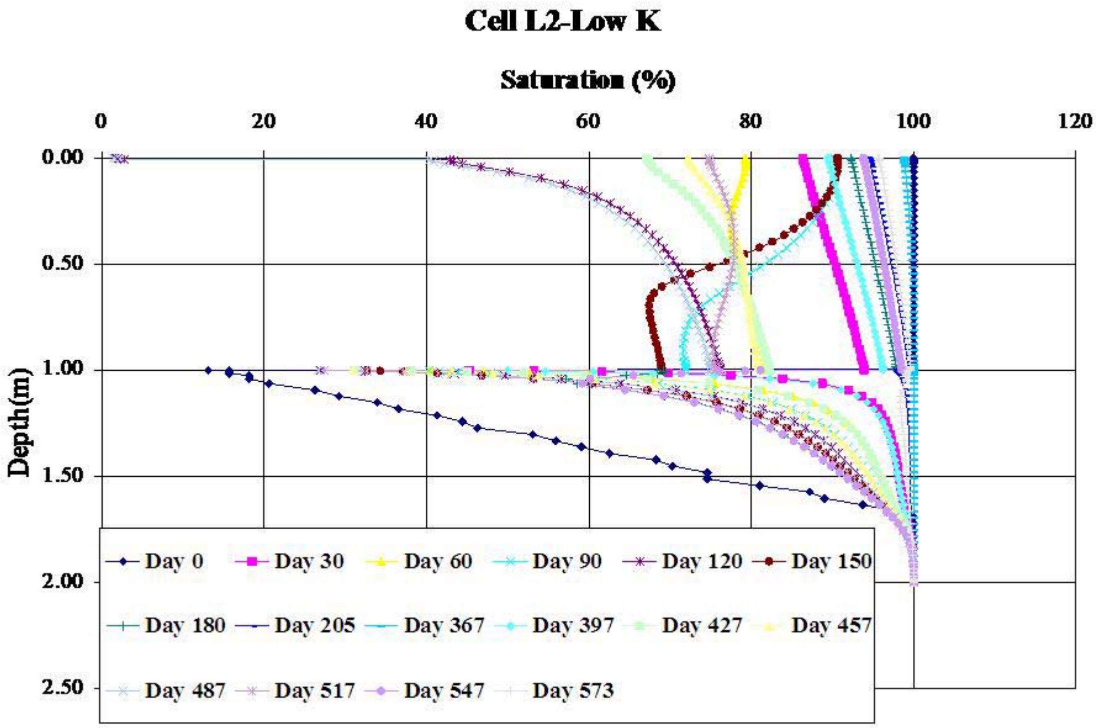

Figure 11. Saturation Profile for Cell L2.

While direct field measurements are not available yet, surface ponding was observed on L2 during precipitation events that occurred at the time of construction, compared to the absence of ponding for the uncovered tailings. In addition to the reduction in infiltration, Fig. 11 shows high values of saturation, typically greater than 80% within the 1000 mm thick Co-Mix cover, which suggests oxygen diffusion and acid generation will be reduced within the coarse sand tailings below the cover.

Figure 12 shows the surface fluxes for Lysimeter L5 with a bentonite modified Co-Mix cover corresponding to a hydraulic conductivity of 2.0×10^{-6} m/s. The value of net infiltration is further reduced to approximately 250 mm, which is a reduction factor of 4 compared to the uncovered tailings. Furthermore Fig. 11 shows that the saturation values are maintained well above 85% and remain close to 100% most of the time.

In summary, the predicted performance for L5 indicates that this Co-Mix will provide excellent protection with respect to limiting water infiltration and oxygen entry for the reduction of acid generation. It is important to note that, while field observation showed L5 to produce rapid infiltration, the infiltration is attributed to the formation of desiccation cracks after prolonged exposure. The actual hydraulic conductivity for the matrix of the Co-Mix material with the addition of 1.5% bentonite should be significantly reduced compared to that for Lysimeters L2, L3 and L4. In general, it is anticipated that Lysimeter L5 will produce the lowest long term net infiltration rates following the recompaction work recently completed.

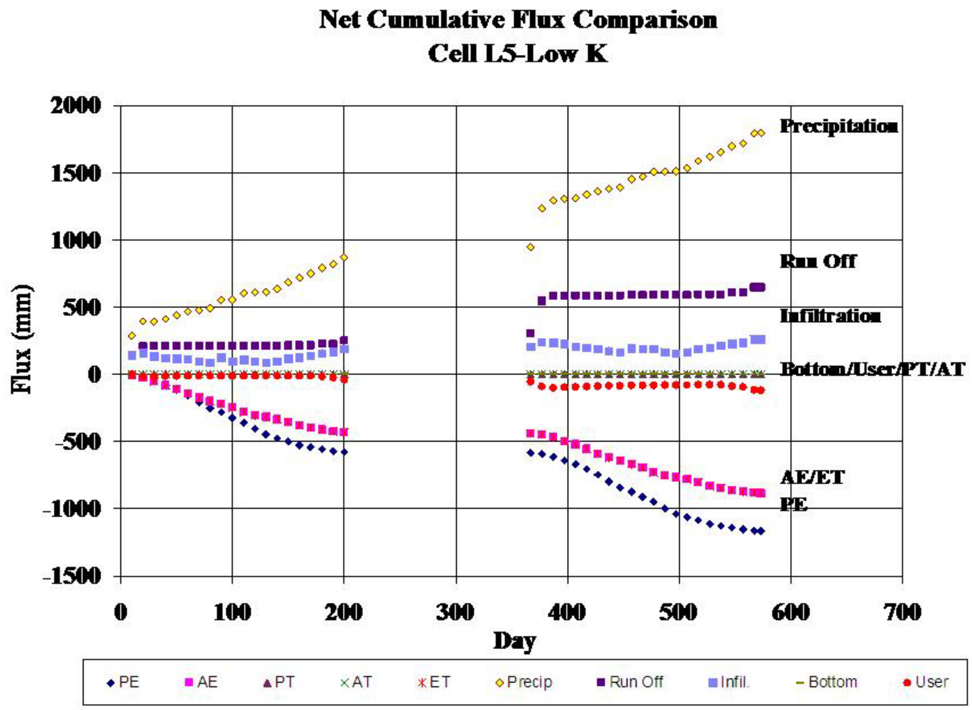

Figure 12. Flux Summary for Cell L5.

Summary and Conclusion

Laboratory testing results indicate that it is possible to construct high quality barrier covers using a mixture of waste rock, tailings, and slag in various blend ratios. A field scale experiment consisting of 5 large lysimeters was constructed at Copper Cliff, Ontario. The covers were put in place in different thicknesses and an additional top soil protective layer was constructed on top of the Co-Mix covers. Instrumentation for measuring infiltration and runoff rates, soil matric suction, net radiation, and precipitation are being installed at the test site. Data collected using these instruments were not available at the time this paper was written. Field observations confirm that the some of the Co-Mix blends have satisfactory performances even under unusually dry climatic conditions, while other blends show the development of cracks after prolonged drying under extreme conditions. The experiment is planned to continue for several years, and the long-time observations and results are expected to provide adequate data to evaluate the viability of Co-Mix covers constructed from waste rock, tailings, and slag.

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