HYDRAULIC PLACEMENT OF A DRY COVER SYSTEM - DESIGN AND PERFORMANCE MONITORING OF THE KENNECOTT RIDGEWAY MINE TAILINGS DAM COVER SYSTEM[1]

R. Duckett,[2] and M. O'Kane[3]

Abstract. The Kennecott Ridgeway Mining Company (KRMC) tailings facility was built using run of mine waste and downstream embankment construction techniques. Approximately 60% of the 60 million tons of processed tailings have a negative net neutralization potential. KRMC conducted a cost-benefit analysis supported by a detailed cover system design and determined that a hydraulically placed cover system was the preferred closure option for the tailings facility. The tailings mass (124 ha, or 307 acres) was covered with 2.7 million tons of clay material (saprolite) using hydraulic placement from both centre-point and ring discharge points following cessation of operations in November 1999. Approximately 90% of the tailings surface area is now covered with greater than 90 cm (36 inches) of cover material.

Monitoring was initiated in September 2001 to evaluate the field performance of the tailings dam cover system. Three primary tailings monitoring sites were established to provide continuous measurements of *in situ* suction, moisture content, and temperature conditions. Sixteen secondary tailings monitoring sites were also installed. The secondary monitoring sites provide spatial coverage to evaluate cover system performance. Surface runoff across the cover surface during precipitation events is also monitored.

This paper summarizes the design and implementation of the hydraulically placed KRMC tailings dam cover system. The cost benefit of implementing this novel cover placement technique is discussed. The field performance monitoring system is described and field data is discussed and summarized in light of the cover system design objectives for minimizing oxygen ingress.

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[1] Paper presented at the 7th International Conference on Acid Rock Drainage (ICARD), March 26-30, 2006, St. Louis MO. R.I. Barnhisel (ed.) Published by the American Society of Mining and Reclamation (ASMR), 3134 Montavesta Road, Lexington, KY 40502

[2] Roy Duckett, Manager Projects, Kennecott Ridgeway Mining Company, 227 Summer Rd. Ridgeway, SC 29130, [3]Mike O'Kane, President, O'Kane Consultants Inc., Suite 1740 – 246 Stewart Green S.W., Calgary, AB, Canada, T3H 3C8.

7th International Conference on Acid Rock Drainage, 2006 pp 539-554
DOI: 10.21000/JASMR06020539
https://doi.org/10.21000/JASMR06020539

Introduction

The two principal design objectives of cover systems for reactive mine waste are:

1) To function as an O_2 ingress barrier for the underlying waste material by maintaining a high degree of saturation within a layer of the cover, thereby minimizing the effective O_2 diffusion coefficient and ultimately controlling the flow of O_2 across the cover; and
2) To function as a water infiltration barrier for the underlying waste material as a result of the presence of a low permeability layer and/or a moisture store-and-release layer (MEND, 2004).

Additional design objectives for cover systems placed on reactive mine waste can include:

1) Prevention of mechanical weathering of the underlying waste material;
2) Influenceof consolidation and differential settlement;
3) Oxygen consumption (i.e. organic cover materials);
4) Reaction inhibition (i.e. incorporate limestone at the surface to control the rate of oxidation (does not prevent oxidation)); and
5) Control of upward capillary movement of process water constituents/oxidation products (MEND, 2004).

It is difficult and usually not economically feasible in arid and semi-arid climates to construct a cover system that contains a layer that remains highly saturated to reduce O_2 transport. The cover system will be subjected to extended dry periods and therefore the effect of evapotranspiration will be significant. However, subjecting the cover system to evaporative demands can be beneficial in arid and semi-arid climates and result in a reduction of infiltration to the underlying sulfidic waste material. A homogeneous upper cover surface layer with a well-graded texture and possessing sufficient storage capacity can be used to retain water during rainfall events. The storage layer releases a significant portion of pore-water back to the atmosphere by evapotranspiration during extended dry periods, thereby significantly controlling the net percolation across the cover system and into the underlying waste material. The objective is to control acidic drainage as a result of preventing moisture movement into and through the waste material. A cover system with the above objectives is often referred to as a "moisture store-and-release" cover system (MEND, 2004).

Dry covers can be simple or complex, ranging from a single layer of earthen material to several layers of different material types, including native soils, non-reactive tailings and/or waste rock, geosynthetic materials, and O_2 consuming organic materials. Factors that control the economic and technical feasibility of a dry cover system for a particular site include, but are certainly not limited to (MEND, 2004):

- site climate conditions;
- availability of cover material(s) and distance to borrow source(s);
- cover and waste material properties and conditions;
- surface topography;
- soil and waste material evolution; and

- vegetation conditions.

Hydraulic placement of a capping, or cover, system over potentially hazardous waste material is generally undertaken in an aquatic environment, or open water disposal, using barges, hopper dredges, and pipelines, as well as diffusers and tremie approaches for submerged discharge. Examples include Morton (1983), Suster and Ecker (1972), and Brannon and Poindexter-Rollins (1990). However, hydraulic placement of cover material to construct a "dry" cover system is a novel concept for the mining industry and represents an opportunity to significantly reduce closure costs.

Background

The KRMC tailings facility was built using run of mine waste and downstream embankment construction techniques. The embankment was constructed in five phases with crest heights at +470, 500, 525, 540, and 560 above sea level (SL). The closure crest is at +570 SL. The embankment itself incorporated both waste classification and waste encapsulation techniques relevant to O_2 transport and acid rock drainage (ARD). The facility is lined with 60-mil HDPE liner and contains 60 million tons of processed tailings of which 25% are oxidized and 75% are sulfidic with pyrite as the primary ARD component of the unoxidized tailings. The tailings mass was converted from a concave to a convex surface during the final two years of operation using centre-line and centre-point hydraulic deposition.

Climate Conditions

KRMC is located near Columbia, South Carolina, USA in the north central portion of the state. The average annual rainfall in the area is approximately 1270 mm (50 inches). The average annual potential evaporation is approximately 1015 mm (40 inches), with nearly 70% occurring from May to October, inclusive. Rainfall typically exceeds potential evaporation except for the months of April, May, June, September, and October.

Cover System Design

KRMC completed cover system design modelling for the purpose of determining whether existing design parameters were both achievable and sufficient to meet physical and chemical requirements pertaining to O_2 transport and prolonged mass saturation, as well as surface water management as described in the KRMC closure plan. In summary, based on the numerical modelling completed, the tailings closure cover system design called for hydraulic placement of a 90 cm (36 inches monolayer of clay saprolite at a 0.33% to 0.66% slope, without the need for detailed saturated hydraulic conductivity QA/QC.

Cover System Construction

KRMC ended gold production in November 1999. Following a two-month period during which the mill and crusher circuits were modified with a view to processing clay and a second tailings centre-point barge ramp was constructed, production of the final saprolite cover system began in January 2000. Placement of cover material was completed in July 2000 after a total of 2.7 million tons of saprolite was placed using hydraulic deposition and standard mechanical placement. All saprolite materials used in the cover system were mined in conjunction with creation of the North to South Pit ultimate drainage channel, or from clean fill material pulled back from the upper tailings embankment slope during construction of the final embankment crest ring dike. Milling was performed using a conventional crushing and grinding circuits. The clay slurry, at densities between 45 and 55% solids, was pumped using the existing tailings circuit to the tailings area via 460 mm (18 inch) SDR-17, HDPE pipe to single point dumps configured and moved in a manner necessary to achieve the design parameters set out by the KRMC Engineer-Technical Superintendent. Lime was added at the secondary conveyor system in order to maintain pH values within a range of 7.5 to 8.5. Densities and pH measurements were completed up to 10 times per 12-hour shift each day as standard operating practice by the KRMC grinding operator. KRMC tailings closure technicians at the direction of KRMC management performed daily pipe movement and facility inspections. Survey control was performed by KRMC using GPS equipment and hovercraft. Beginning in June 2000, foot surveys across the cap were performed to physically measure cap thickness.

The tailings surface now covers 124 ha (307 acres) and has slopes that vary from 0.46 to 0.69% on the centre dome, to 0.0 to 0.15% on the wetland surfaces, and 0.4 to 0.6% on the perimeter inward slopes. The cover material thickness achieved across the 124 ha (307 acres) hydraulically placed surface is summarized in Table 1.

Table 1. Summary of cover material thickness and surface areas.

Cover Thickness	Percent of Total Surface Acreage	Total Area (ha (acres))
> or = to 120 cm (48”)	60%	75 (186)
90 cm (36”) to 120 cm (48”)	33%	40.5 100)
< or = 90 cm (36”)	7%	8.5 (21)
total cover material > or = to 90 cm (36”)	93%	116 (286)
total cover material > or = to 110 cm (43”) (saprolite material plus original plan calling for a 18 cm (7”) topsoil layer)*****	74%	92 (228)

***** No topsoil was placed over the cover material following successful vegetation of the saprolite using standard commercial fertilizers.

Source of Cover Material - Saprolite Geology

The saprolite material mined and placed during cover construction consists of weathered, massive to thinly laminated siltstone and fine to medium grain massive greywacke consistent with Richtex Formation volcanoclastic sediments found within the eastern Carolina Slate Belt. The sediments have undergone supergene weathering to depths of 15 to 30 m (50 to 100 feet) such that sulfides, present in unweathered core samples as fine to coarse euhedra in amounts of less than 1%, are no longer present. Fine sub-micron size pyrite, characteristic of the alteration zones hosting the ore bodies, is absent in the sediments. Carbonate, as calcite, is also weathered but begins to survive as veining at depths approaching 15 m (50 feet). Standing rain pools, located in the cover material borrow area making up the drainage channel, have basic pH values of 7 to 7.5 and alkalinity values of 10 to 15 ppm consistent with the weathering of weakly altered to unaltered sediments in the area.

The oxidized material used in construction of the embankment ring dike consists of weathered, altered sediments associated with the upper pit levels. This material is consistent with oxide rock used for inert armoring during encapsulation of sulfide waste.

Cover System Field Performance Monitoring System

KRMC installed three primary tailings monitoring sites (PTMS) in September 2001, each including profiles of suction / temperature sensors, volumetric water content sensors, and gas sampling ports. Sixteen secondary tailings monitoring sites (STMS) were also established in September 2001, each consisting of a PVC access tube for insertion of a portable moisture sensing probe. An automated data acquisition system was installed at each PTMS to monitor the sensors. A tipping bucket rain gauge was also installed at each PTMS. The gas sampling ports at each PTMS are used to measure *in situ* gaseous O_2 and carbon dioxide concentrations, using a portable analyzer, within and below the cover material. The portable moisture-sensing probe used at each STMS and PTMS is connected to a portable datalogger that stores the moisture data. Figure 1 shows the STMS and PTMS locations for the tailings dam cover performance monitoring system.

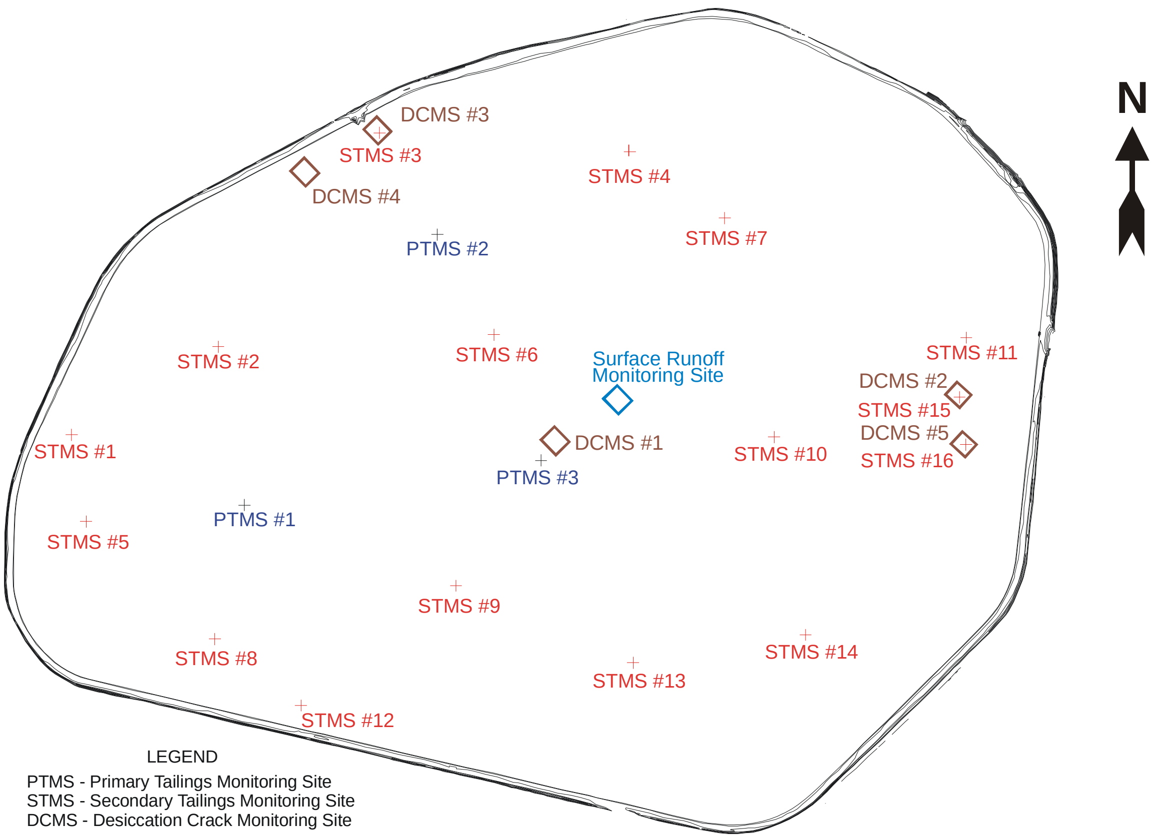

Figure 1. Schematic showing location of the tailings dam cover system performance monitoring system.

Surface runoff for the entire tailings facility is monitored using a broad crested weir (location noted in Fig. 2). Initially, water level depths were measured manually using a staff gauge. An automated depth level monitoring system was installed in April 2005. In addition, a Bowen

Ratio (BR) system was installed adjacent to PTMS #3 in April 2005 to measure actual evapotranspiration from the cover system.

Each of the monitoring sites varies in thickness due to the processes of hydraulic placement. The resulting cover system acquires deltaic sedimentary features, as the sedimentary grading reflects energy levels and cover material viscosities at the time of deposition. The maximum, minimum, and mean thickness of cover material observed at the PTMS locations were 142 cm (56 inches), 79 cm (31 inches), and 113 cm (44.5 inches), respectively. The maximum, minimum, and mean thickness observed at the STMS locations were 168 cm (66 inches), 71 cm (28 inches), and 113 cm (44.5 inches), respectively. This cover layer will help to reduce the percolation of meteoric waters to the underlying tailings through storage and subsequent release of moisture to the atmosphere as a result of evapotranspiration. In addition, O_2 ingress will be a function of the depth of the cover material, the maintenance of tension-saturated conditions, and the presence, and characteristics, of any cracks in the cover material.

Figure 2. Aerial photograph of the tailings dam (note surface runoff spillway / monitoring location).

Field Sampling Program during Installation of Monitoring System

The sampling program involved collecting samples of all cover and tailings materials encountered during installation of the KRMC tailings dam cover performance monitoring system. Samples were collected for the purpose of either geotechnical (i.e. physical and hydraulic characteristics) or geochemical testing (paste pH and paste EC (electrical conductivity)). Laboratory testing included specific gravity, particle size distribution, Atterberg limits, x-ray diffraction, triaxial permeability, consolidation-falling head permeability, soil water characteristics, and O_2 diffusion cell analysis.

Field and Laboratory Characterization

The KRMC tailings dam cover material is predominantly "silt loam" (approximately 10% clay, 65% silt, and 25% sand) according to the USDA soil classification system. The remaining cover material is classified as "sand" (approximately 10% silt and 90% sand). The predominant tailings material is also classified as a "silt loam" (approximately 5% clay, 70% silt, and 25% sand), but contains less clay-sized particles than the cover material. The remaining tailings material is characterized as a "sand loam" (approximately 3% clay, 34% silt, and 63% sand). The clay size particle mineralogy of the tailings and cover materials are different. The cover material predominantly consists of montmorillonite and vermiculite, which are classified as active minerals (i.e. are subject to swell when brought into contact with water), whereas the tailings material is composed of inactive clay minerals.

A nuclear densometer was used to assess variations of the *in situ* density and moisture conditions of the cover surface, as well as during development of the trenches used to install the monitoring sensors. One-hundred and forty-nine nuclear densometer measurements were taken across four grid lines to determine density and moisture variations across the cover system. Figure 3 shows the frequency distribution over a range of densities, while the trend between moisture content and dry density is shown in Fig. 4. Note that all dry density values shown in Fig. 3, 4, and 5 are corrected, based on gravimetric moisture content measurements of grab samples obtained immediately following the *in situ* density measurement. Figure 5 is a generated plan view of the spatial dry density distributions measured on the surface of the cover system.

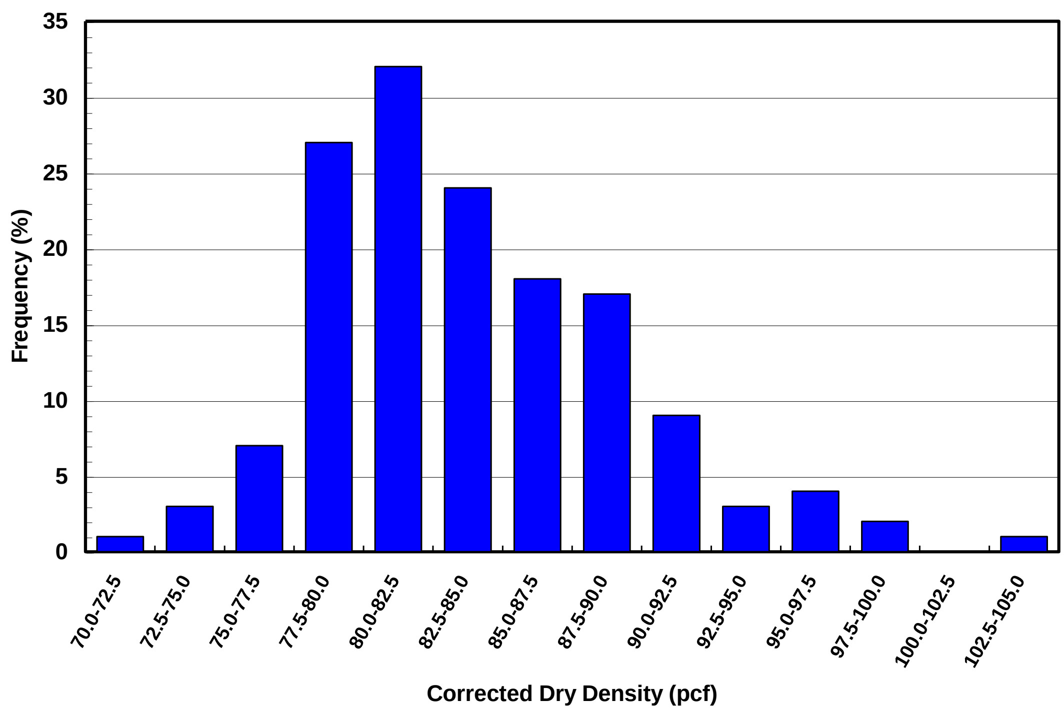

Figure 3. Frequency distribution of corrected *in situ* density conditions for the near surface cover material.

Samples for saturated hydraulic conductivity testing were prepared to reflect the most predominant *in situ* density and moisture conditions. The highest saturated hydraulic conductivity (1 x 10^{-4} cm/sec) was measured for the "sand" cover material. The orange coloured "silt loam", representing the most predominant cover material, had a laboratory measured saturated hydraulic conductivity of 5 x 10^{-6} cm/sec. The saturated hydraulic conductivity was measured at 1 x 10^{-6} cm/sec for the grey "silt loam" cover material. These laboratory tests were conducted on samples prepared at *in situ* moisture and density conditions, and then saturated. Note however, that any soil structure developed under field conditions would not be replicated in the laboratory. A comparison of "mechanically" placed cover material to hydraulically placed cover material was not within the scope of the project. The saturated hydraulic conductivity measured for the tailings material ranged from approximately 2 x 10^{-6} cm/sec to 6 x 10^{-5} cm/sec.

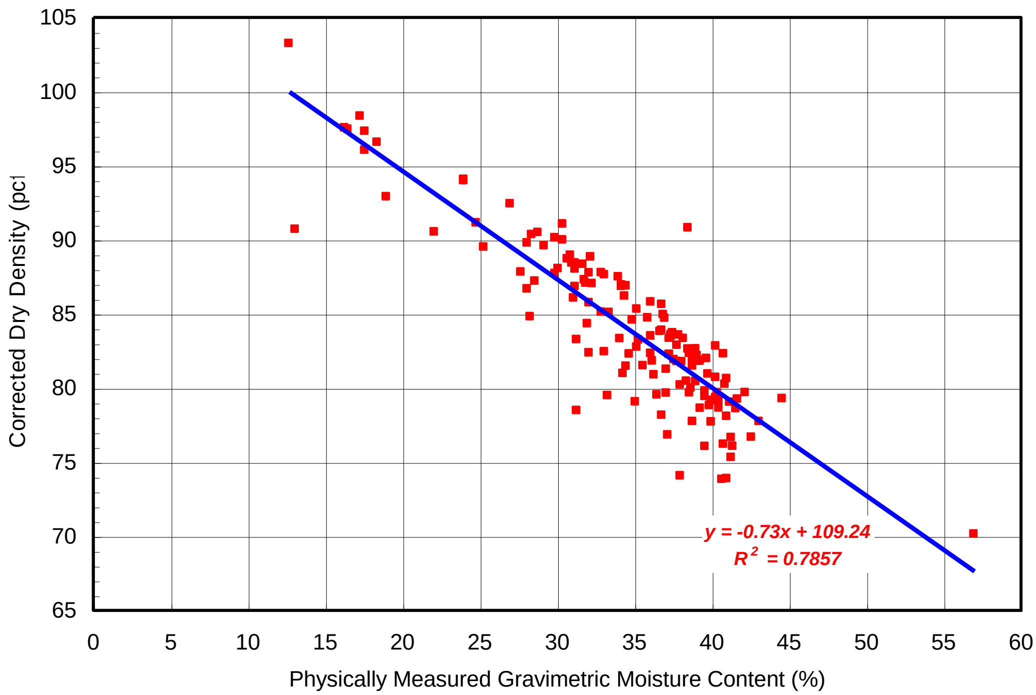

Figure 4. Relationship between corrected dry density and physically measured gravimetric moisture content for the near surface tailings dam cover material.

The coefficient of diffusion measured at 85% saturation for the cover and tailings material is 9 x 10^{-8} m^2/sec and 2 x 10^{-8} m^2/sec, respectively. The coefficient of diffusion as a function of degree of saturation decreases significantly at a degree of saturation greater than 85%. The coefficient of diffusion is lower for the tailings material as compared to the cover material. The main factor contributing to this difference is considered to be the lower porosity that the tailings material was prepared at (0.46), in relation to the cover material (0.48). The O_2 consuming potential of the tailings may also have played a role in the lower coefficient of O_2 diffusion.

Cover Material Evolution

Measurements of saturated hydraulic conductivity in the unsaturated zone are referred to as the "field-saturated" hydraulic conductivity (K_{fs}) (Reynolds et al., 1983). Various methods exist for measuring the K_{fs} of soil, ranging from *in situ* to laboratory procedures. In this study *in situ* measurements of hydraulic conductivity were obtained with a constant head well permeameter (Guelph Permeameter).

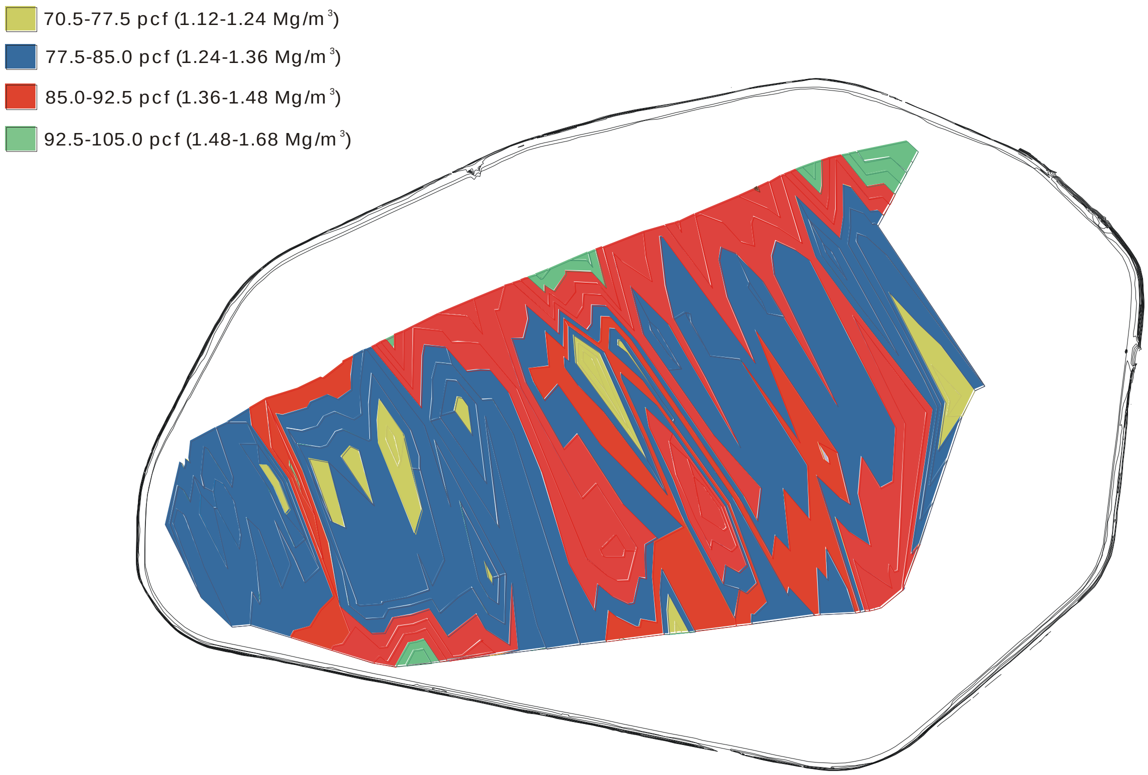

Figure 5. Tailings dam cover system plan view of the spatial distribution of corrected *in situ* density conditions for the near surface cover material.

The objective of this component of the monitoring program is to evaluate any changes in the saturated hydraulic conductivity of cover materials, which may have occurred since placement. In general, physical, chemical, and biological processes will affect the long-term performance of a dry cover system (INAP 2003). These processes will act to change the key properties of the cover materials, such as the saturated hydraulic conductivity and moisture retention characteristics. Soil structure (i.e. cover materials that have developed of cracks, worm holes, root channels, etc.) will provide the dominant flow path in the cover materials. The evolution of soil structure with time will significantly alter the saturated hydraulic conductivity of the cover materials.

Figure 6 shows K_{fs} values measured in 2002 and 2004 at PTMS #2. Of note, is that in 2002 field saturated hydraulic conductivity of the cover material was one, to one-and-one-half orders of magnitude higher than that measured in the laboratory. This is attributed to soil structure that had developed in the field, which cannot be replicated in the laboratory, particularly for non-compacted conditions. Furthermore, while the number of tests conducted in 2004 was not sufficient to determine whether the measured increase in K_{fs} was significantly higher than in 2002, it would appear that the K_{fs} of the cover material increased by another one to two orders of magnitude. The implication is that it is difficult to envisage that laboratory saturated hydraulic conductivity testing of non-compacted or "loosely" placed growth medium material would be representative of field conditions.

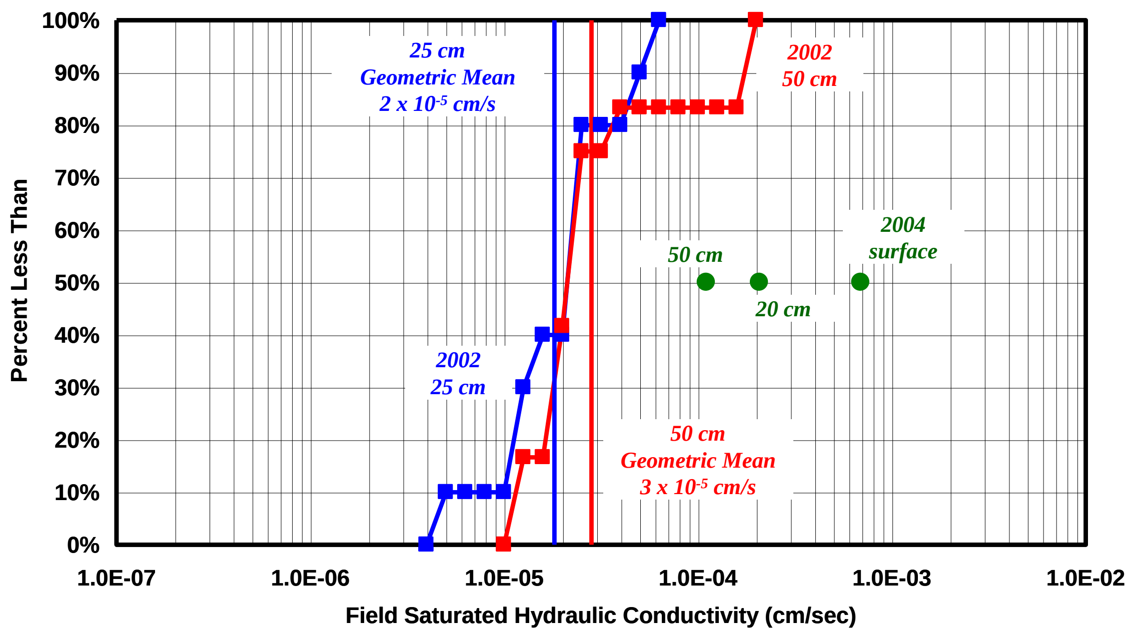

Figure 6. Field saturated hydraulic conductivity measurements at PTMS #2.

Figure 7 shows *in situ* moisture retention curves for the cover material at a depth of 20 cm (8 inches), as compared to the laboratory measured moisture retention curve. The field moisture retention curves were generated by plotting *in situ* volumetric water content data against *in situ* suction values, each obtained from sensors installed adjacent to one anther other at a depth of 20 cm (8 inches). The laboratory measurements indicate the cover material has an air entry value nearly an order of magnitude higher than that determined based on field conditions. The difference between field and laboratory conditions is attributed to the development of soil structure, which cannot be replicated in the laboratory on a reconstituted sample, making it difficult to develop laboratory moisture retention curves representative of field conditions for non-compacted, or loosely placed near surface cover material.

Cover System Field Performance Monitoring

Vegetation

Vegetation of the cover system began with test areas along the second centre point ramp in May 2000. Bermuda grasses, millet, and serecia lespedeza have proven adapt at growing in the saprolite without the use of topsoil placement. Vegetation of the surface has to date been completed using an LGP loader unit for scarifying and broadcast seeding. Desiccation cracks resulting from hydraulic placement of cover material and subsequent drying, as well as during dry climate conditions, are "healing", for the most part, during rain events and as a result of vegetation growth. Figures 8a and 8b are photographs of the same area (at STMS #3) in 2001 and 2004, respectively. The improvements in conditions as shown in Fig. 8a and 8b are representative of a large majority of the cover system. However, cover material in areas near the ring dike is slightly coarser textured (i.e. near the outer edges of the cover system), and as such the cracking in these areas, which was a result of placing the material hydraulically and its subsequent drying, has not healed to the same extent as shown in Fig. 8b.

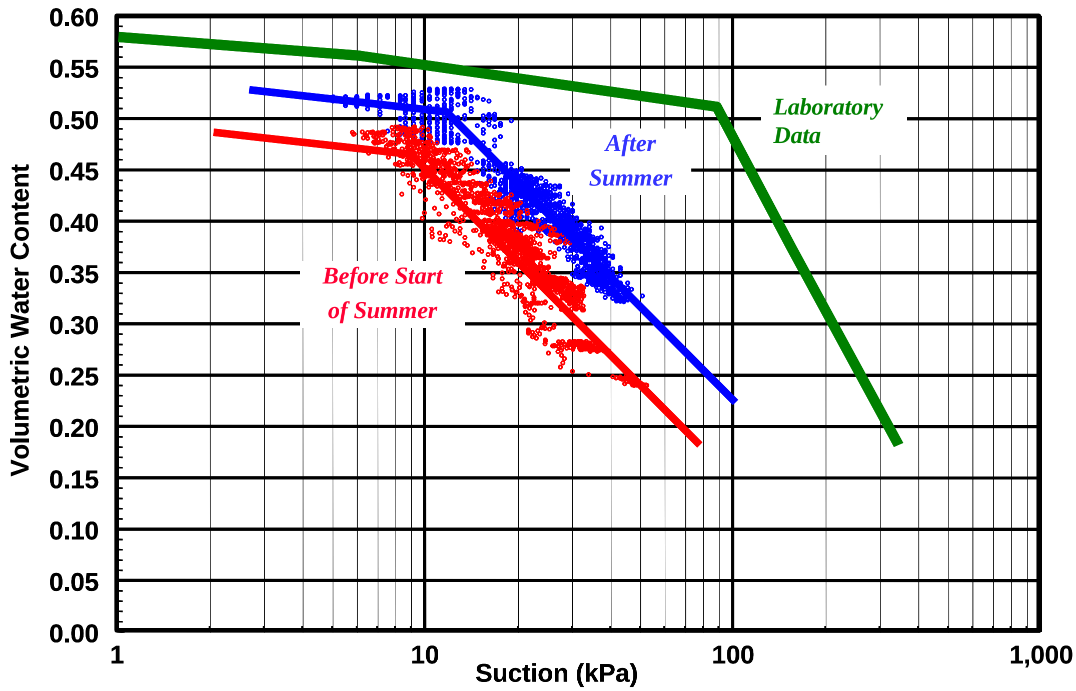

Figure 7. Field and laboratory moisture retention curves at a depth of 20 cm at PTMS #2.

(a)

(b)

Figure 8. (a) Photograph of STMS #3 area in 2001, and (b) in 2004.

Climate Conditions

The total cumulative rainfall recorded at PTMS #1, PTMS #2, and PTMS #3 has varied over the monitoring period due to the loss of data resulting from the occasional malfunction of the dataloggers or tipping bucket gauges. However, during the periods when all gauges were functioning properly, there appears to be little spatial variation in rainfall across the cover system. Data recorded at PTMS #3 represents the only uninterrupted monitoring on the tailings facility. Approximately 1040 mm (41 inches) of rainfall was recorded during 2003 – 2004 monitoring period, compared to 1550 mm (61 inches) during the 2002 – 2003 period and 915 mm (36 inches) in 2001 – 2002. This is compared to an average annual rainfall of approximately 1270 mm (50 inches), making the first and third years of the monitoring period drier than average.

In Situ Moisture Conditions

In situ moisture conditions at each PTMS are measured by capacitance water content sensors (indirect measurement of volumetric water content) and thermal conductivity (TC) sensors (indirect measurement of matric suction). Sensors at each PTMS location were installed throughout the depth of the cover material and into the underlying tailings. Fourteen TC sensors were installed at PTMS #1 and #3 to depths of 173 cm (68 inches) and 152 cm (60 inches), respectively. Twelve TC sensors were installed at PTMS #2 to a depth of 127 cm (50 inches). Sixteen EnviroSCAN sensors at each PTMS location monitor *in situ* moisture content to a depth of 203 cm (80 inches). Moisture conditions at each STMS are measured with the Diviner 2000 system, a portable capacitance water content sensor, to a depth of 157 cm (62 inches).

Matric suction as a function of time for three TC sensors installed in the cover material and one TC sensor installed in the tailings material at PTMS #1 is shown in Fig. 9. The TC sensors located at depths of 132 cm (52 inches) (cover material) and 137 cm (54 inches) (tailings material) recorded constant matric suctions of approximately 0 kPa during the monitoring period (October 2002 to September 2004). This indicates that the base of the cover materials and the upper tailings profile are very near, or at, saturated conditions.

The sensor at a depth of 71 cm (28 inches) recorded suctions near 0 kPa for the entire monitoring period, except June 2004 when suctions of around 10 kPa were measured. This indicates a drying front reached a depth of at least 71 cm (28 inches) during the summer of 2004. The TC sensor located at a depth of 10 cm (4 inches) responded to atmospheric forcing during the month of October and November 2003 and then recorded a constant matric suction of approximately 0 kPa until late March 2004. Once again, the sensor at the 10 cm (4 inch) depth is responding to atmospheric forcing indicating that the upper layers of the cover system are beginning to de-saturate. Accuracy of the TC sensors reduces for suction conditions less than 10 kPa because the sensor operates on the principal of heat dissipation and the air entry value of the ceramic sensor is approximately 10 kPa. However, it is clear from the field measurements, that overall, near saturated conditions existed within the cover system and the underlying tailings at this location during the majority of the monitoring period. Although the data is not presented, the automated *in situ* volumetric water content sensors also indicate that near saturated conditions are prevalent. Similar *in situ* moisture conditions were measured at PTMS# 2 and

PTMS #3, as was presented in Fig. 9 for PTMS #1. In addition, the STMS monitoring locations consistently record high saturation conditions for the cover and underlying tailings material.

At the suction conditions measured, high saturation conditions exist, which implies that O_2 diffusion to the underlying tailings material is minimized, thereby controlling oxidation of the tailings material.

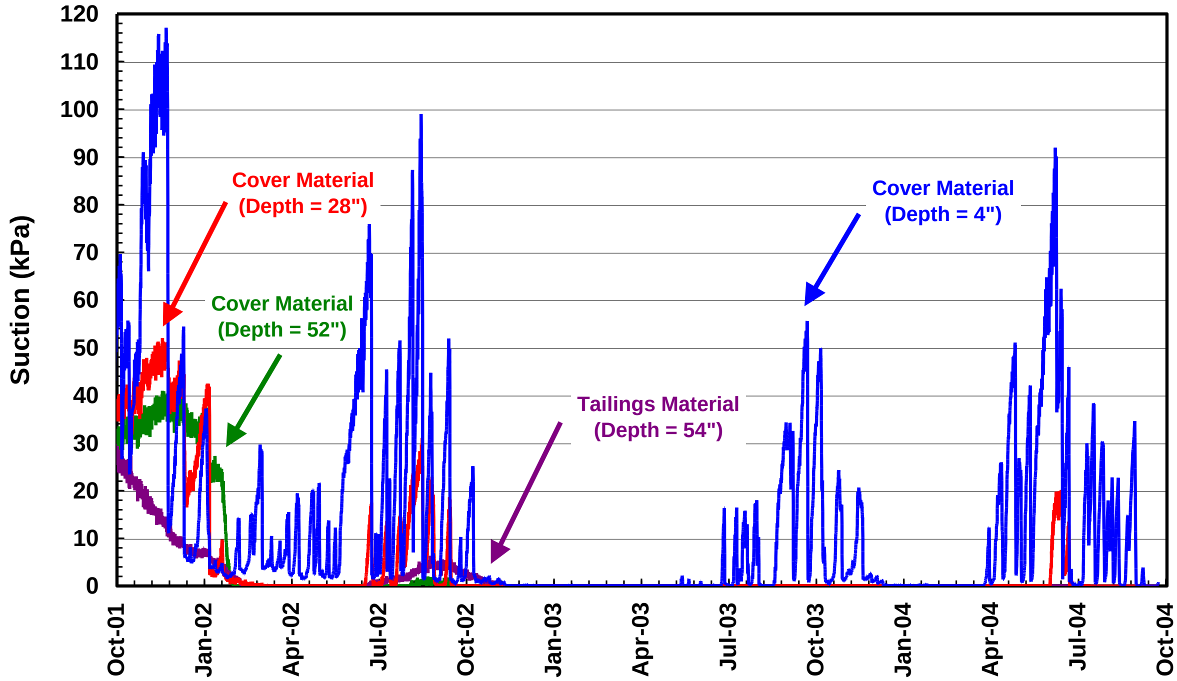

Figure 9. Field matric suction as a function of time for the sensors installed in the cover and tailings material at PTMS #1.

Current and Future Activities

Current and future activities to evaluate current and long-term performance of the cover system include five components or phases as follows.

Evaluate Liner Seepage Rates

The tailings dam possesses multiple "levels of defense" to prevent migration of contaminants of concern to the receiving environment. A key to these levels of defense is the presence of the liner at the base of the tailings mass. Performance of the liner is being verified through an evaluation of the hydraulic gradient across the liner. KRMC have completed piezocone studies of the tailings mass, and have information with respect to tailings mass piezometric heads, as well as underflow and groundwater monitoring. This data is being used to determine the seepage rate across the liner.

Evaluate Long-Term Settlement and Consolidation of the Tailings

A consolidation analysis is in progress to assist with determining settlement rates of the tailings mass and hydraulically placed cover material. A key component of the tailings dam cover system design is the surface water management system, which is designed to direct surface runoff towards the runoff discharge weir / drainage structure. It is fundamental to evaluate the long-term settlement of the surface of the tailings dam cover system in order to determine whether the surface water management system will continue to function as designed. Should this not be the case, then the potential impact on vegetation communities, *in situ* moisture conditions, and overall performance of the tailings dam cover system would be determined.

Quantify Cover System Performance

The objective is to determine the elevation, or rather the range of elevations, for the phreatic surface within the tailings mass (and possibly the cover material), as well as the saturation profile above the phreatic surface. The elevation of the phreatic surface will change in response to climatic forcing (i.e. evapotranspiration and surface infiltration). Hence, the cover system water balance is required in order to predict the response of the phreatic surface.

The key question is: what is the probability that the phreatic surface (ideally), or tension saturated conditions as a minimum, will exist within the tailings under:

- extreme climate conditions;
- long-term climate changes; and
- changes with *in situ* conditions and material properties due to biological, physical, and chemical processes impacting on performance?

Monitoring has indicated that, in general, there are two cracking regimes, or areas, on the KRMC cover surface. It is hypothesized that the two regimes developed as a result of the proximity to the cover material discharge location. For example, it would appear that near the tailings dam wall, material is relatively coarser textured, as compared to other more central locations.

Volume change has occurred in these areas as a result of the cover material being placed hydraulically, but there has been less "healing" of the cracks that developed as a result of the volume change, as compared to more centrally located surfaces. At these centrally located surfaces, the material is finer textured and it appears that fine textured sediment has infilled many larger cracks that resulted from the material being placed hydraulically. Drying, cracking, and in general microstructure has developed in these areas in response to wetting and drying, but in general these cracks are of a significantly smaller scale than those that exist in material near to the tailings dam walls.

Field saturated hydraulic conductivity testing using a Guelph permeameter has been conducted for the cover material that has undergone "small-scale" cracking and desiccation. This data would be input during the field response modelling stage as a calibrated model is developed. However, the extent of the larger scale cracks is being evaluated in order to determine their impact on surface infiltration characteristics. KRMC has constructed a large-scale infiltration apparatus that is pushed into the surface at depths of 15 cm, 30 cm, and 45 cm (6, 12, and 18 inches). The objective is to determine whether a change in surface infiltration characteristics are observed as a function of the depth of the base of the box; and hence, the extent of the cracks within the confines of the surface area of the box.

Evaluate Geochemical Characteristics of the Tailings Material Placed at the end of Operations

It was determined that the tailings underlying the cover material, and overlying the potentially acid forming (PAF) tailings, should be considered a component of the cover system. This was decided because maintenance of tension saturated conditions within this material would ensure a minimal O_2 diffusion coefficient for this layer, and thus control of O_2 ingress to the underlying PAF material. This evaluation was initiated by collecting profiles of drill core material at a number of locations on the tailings storage facility. Analysis and interpretation of geochemical laboratory characterisation of the samples is in progress.

Evaluate Long-Term Vegetation Communities and their Link to Hydrologic Performance of the Cover System

KRMC is evaluating the impact on hydrologic performance of the cover system as a result of vegetation communities. It is anticipated that issues that would be addressed include:

- evaluating current conditions to use as input to cover system field response modelling;
- evaluating natural succession;
- evaluating grassland versus forest options / climax species; and
- evaluating impacts of physical and chemical processes on cover system performance, including:
  - tree uprooting;
  - bioturbation;
  - salt migration;
  - soil development and O_2 consumption; and
  - the physical weight of a forest on the cover system and tailings mass.

The natural succession of vegetation communities and/or passive / active management of the vegetation on the cover system will influence the predictive modelling scenarios to be completed. Hence, KRMC will determine the preferred cover system vegetation management strategy prior to commencing the predictive modelling.

Summary

Hydraulic placement of cover material over potentially acid forming mine waste material is a novel concept for the mining industry. However, it is a concept that represents a significant opportunity to reduce closure costs, as compared to using conventional methods to place cover material. Kennecott Ridgeway Mining Company has successfully placed a 90 cm (36 inch) thick saprolitic cover system using hydraulic placement methods. To date, performance of the cover system has met design objectives in that high *in situ* saturation conditions are prevalent at all locations monitored. This implies that diffusion of O_2 to the underlying potentially acid forming tailings material is minimized and that a “blanket of water” was maintained by the presence of the cover material.

Field performance monitoring indicates that the hydraulically placed cover system will provide long-term control on O_2 ingress. However, additional analysis and studies are in progress in order to increase confidence with respect to long-term performance.

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