THE INFLUENCE OF CLIMATE, VEGETATION, LAYER THICKNESS, AND MATERIAL PROPERTIES FOR PERFORMANCE OF THE COVER SYSTEMS AT THE GOLDEN SUNLIGHT MINE[1]

Fernando F. Junqueira, G. Ward Wilson, Craig Nichol, and Shannon Dunlap[2]

Abstract. Golden Sunlight mine is located northeast of Whitehall, MT. Two cover systems were installed on the west waste rock complex and tailings area in order to minimize water infiltration and acid drainage. The covers were designed to function as a store-release system and are composed of coarse and fine materials being 0.80 m thick on the waste rock and 1.8 m thick at the tailings area. In order to study the influence of thickness, material properties, vegetation and climate on the performance of the cover systems, a laboratory testing program was carried out to identify the properties of the cover at different depths. In addition, thermal conductivity sensors were installed at three field monitoring stations located on the waste rock dump and tailings area in order to evaluate the variation of suction in the cover profiles. These data were used to calibrate a numerical modeling program that assessed infiltration rates through the covers under different vegetation and climate conditions. The simulation results were used to correlate internal variations in grain size and hydraulic conductivity with cover performance in terms of measured suction profiles and infiltration rates.

The results show that vegetation plays a critical role in cover performance and becomes most important during wet and very wet years. The simulations and field measurement also revealed that the internal properties of the cover control infiltration patterns, showing upward and downward fluxes at different zones within the cover. It is shown that while increasing layer thickness reduces the dependence of cover performance on vegetation conditions, the establishment and sustainability of vegetation remains most important with respect to satisfactory long-term performance of store-release cover systems.

Additional Keywords: Store-release cover, numerical modeling

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[2] F. Junqueira, Geologist. Golder Associates Ltd. 500 - 4260 Still Creek Drive, Burnaby, B.C. Canada V5C 6C6, Email: fjunqueira@golder.com., G. Ward Wilson, Professor and Chair. The University of British Columbia, Department of Mining Engineering. 517 - 6350 Stores Road. Vancouver, BC. V6T 1Z4 Canada., Craig Nichol, Department of Geological Sciences, University of Saskatchewan, Saskatoon, SK, S7N 5E2 Shannon Dunlap, Environmental Superintendent. Golden Sunlight Mine. 453 MT Hwy 2 East. Whitehall, Montana 59759

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Introduction

In arid and semi-arid climates, the design of store-release cover systems has proven to be the most efficient method to reduce acid drainage. Nevertheless, the performance of this type of cover system is strongly associated with the presence of vegetation, the properties of the material used to construct the cover and the thickness of the cover itself (Durham et al. 2000, Williams et al. 2003). The influence of these parameters becomes most important during wet and extreme wet years, and different configurations must be attempted to optimize the performance of the cover system.

This paper presents the results of a three year research program carried out on the Waste Rock Dump and Tailings area at the Golden Sunlight Gold Mine located northeast of Whitehall, MT in a semi-arid climate. The research aimed to evaluate the current and long term performance of the store-release cover system installed at both locations, as well as to predict the performance of the cover systems during typical, wet and extremely wet years, along with different vegetation conditions. The covers were designed to store rainfall and snow melt, and release it through evapotranspiration after the rainy season. The main objective of the store and release cover system was to prevent water infiltration through the rock piles and minimize the generation of acid drainage.

A laboratory testing program was carried out on the soil cover, waste rock and tailings materials. Field monitoring stations were installed to monitor matric suction and temperature. The results were used as input for numerical modeling, which in turn was used to evaluate current and long-term performance of the cover systems.

Site Description

The Golden Sunlight Mine is owned by Placer Dome Inc. and operated by Golden Sunlight Mines Ltd. The site is located in Jefferson Country, Montana, near Cardwell at approximately 46 degrees north latitude (Fig. 1). Gold ore is extracted from open pits and waste rock from the open pits is stored in waste rock dumps deposited by end dumping.

The site is located in arid climate with average annual precipitation of 243 mm occurring throughout the year; while average annual pan evaporation being much higher, reaching 1048 mm. Average maximum temperature of 26ºC occurs in July; and average minimum temperature in January is -15ºC.

A layered cover system has been proposed and installed on inactive waste rock dumps and tailings area. On the waste rock dump the cover consists of approximately 80 cm of cover soil, while on tailings the cover consists of a 1 meter thick layer of oxidized waste rock material, overlain with 60 cm of cover soil, and topped with 20 cm of local soil. A vegetative cover provides the final component of the cover systems for protection against wind and water erosion. The vegetation is also designed to reduce both moisture and oxygen flux through root water and oxygen uptake. The characteristics of the cover systems materials are described in the followings sections.

The tailings impoundment 1 has surface area of approximately 187 acres, and preliminary reclamation works started in 1994 with the construction of test plots. Reclamation works began effectively in 1997, with completion of final soil capping occurring in 1999, and the entire surface being seeded in 2000.

At the East waste dump, sloping of the reclamation areas began in 1995. Some acreage was seeded in 1996 and the remaining areas were completed in 2000. Approximately 124 acres of the East dump have been reclaimed, but the mine is still using the East dump for waste rock disposal, and conducting concurrent reclamation.

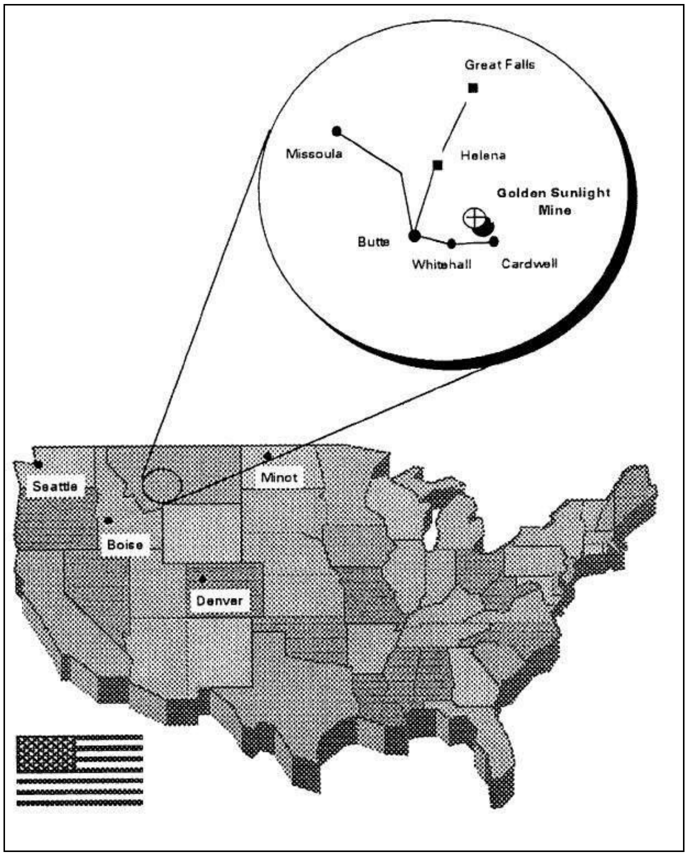


Figure 1. Location of the Golden Sunlight Mine

Materials and Methods

Laboratory Testing Program

A laboratory testing program was carried out on 18 samples of the soil cover, waste rock and tailings materials. At the waste rock dump, samples were collected from two test pits excavated adjacent to the main and satellite sensors location. Five bulk samples of material were obtained within the cover profile from 0 to 86 cm depth, and 7 samples of the underlying waste rock were obtained from 90 cm down to 180 cm. At the tailings area samples were obtained from selected test pits across the tailings facility cover. Five samples were obtained within the cover system from 0 to 180 cm, and one sample of the underlying tailings was collected.

Samples were characterized by grain size, saturated hydraulic conductivity and specific gravity. In addiction, the soil water characteristic curve of the samples was estimated by using the software SoilVision v.3.34 (SoilVision Systems Ltd., 2004).

The grain size tests were performed using mechanical sieve and hydrometer analysis according to the ASTM standard D422-63.

The hydraulic conductivity of the samples was determined by performing a falling head permeability test using a 10.5 cm height and 14.5 cm diameter stainless permeameter; following the procedures described in the ASTM standard D5856-95.

The Specific gravity and water contents were determined according to the ASTM Standards D854-02 and D2216-98.

Field Instrumentation

In 2001, Golden Sunlight mine determined to install instrumentation on the cover systems constructed on the waste rock dumps as well as the Tailings Impoundment No. 1. Two monitoring stations were installed on the waste rock dump and tailings area to evaluate the variation in matric suction with time and to monitor temperatures in the covers profile by means of thermal conductivity sensors (TC sensors). Thermal conductivity sensors are composed of a heating element and a temperature measurement device encased in a ceramic body. Matric suction outside the sensor is determined indirectly by using a calibrated relationship between output of the temperature sensing device, and the matric suction applied to the exterior of the sensor (Fredlund D.G. 1992). The use of TC sensors has become more common because they provide long term measurements without the need of regular maintenance (O'Kane et al. 1998, Marjerison et al. 2001, Nichol et al. 2003).

The monitoring station at the waste rock facility was installed in November, 2001, and consisted of five sensors installed in a test pit immediately adjacent to the monitoring station at the up-hill edge of the bench (Main location), at depths of 20, 75, 106, 123 and 176 cm. At the tailings area, the monitoring station was also installed in November, 2001 and consists of five TC sensors installed at 23, 45, 78, 105 and 145 cm in depth.

In addiction to the TC sensors data, weather data were obtained from a weather station located northwest of the reclaimed Tailing Impoundment #1. At the site, wind speed, peak wind gust, wind direction, air temperature, relative humidity, and precipitation can be monitored.

Numerical Modeling

Numerical modeling was used to evaluate the performance of the cover systems installed on the waste rock and tailings. The modeling was carried out by using the one-dimensional finite element model SoilCover (Unsaturated Soils Group, 1997). Input data were obtained from different sources: weather data from the weather station at the mine site, suction and temperature values from the TC sensors at the monitoring stations and, material properties obtained from the laboratory testing program.

The model was used to predict the performance of the cover systems under three different climate conditions based on an 18-year return period. a typical year, a wet year and an extreme wet year were considered. Furthermore, taking into account the great importance of vegetation in the evapo-transpiration process (Van Haveron and Brown, 1971, Saxton k., 1982), the effect of vegetation was also considered. The model accounts for the effects of canopy cover, root depth and density, and water stress. Four cases were simulated: no vegetation and, vegetation at poor, good and excellent condition. The model uses different leaf area index functions to differentiate each vegetation condition, and the efficiency of the numerical algorithm was experimentally proved by Trach (1995). The climate and vegetation parameters used are presented in Table 1, and Fig. 2 shows the configuration of the profiles simulated for the waste rock dump at the main and satellite monitoring stations, and for the tailings area.

Table 1. Climatic and vegetative parameters used in the numerical modeling.

Case	Year of reference	Rainfall / snow melt (mm)	Vegetation condition
Typical	1995/96	348.0	No, poor and good
Wet	1996/97	423.0	No, poor, and good
Extreme wet	1992/93	540.0	No, poor, good and excellent

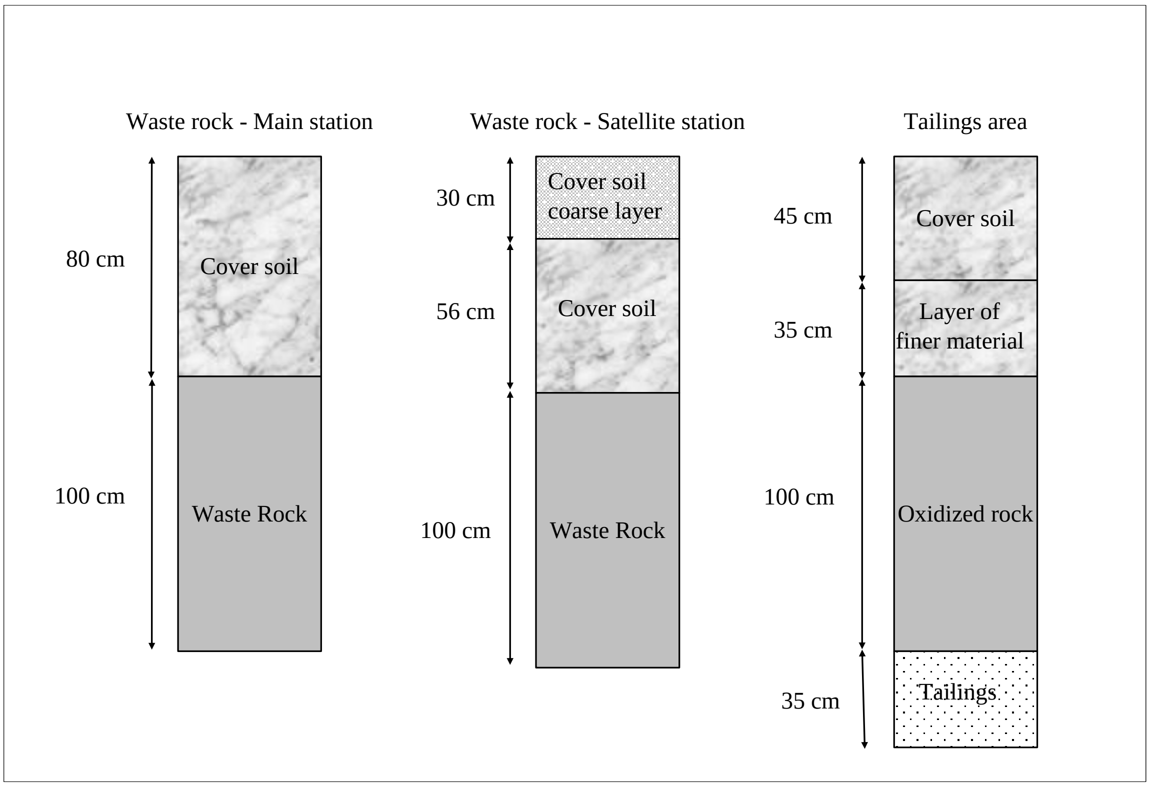


Figure 2. Basic profiles used in the numerical modeling for the waste rock dump and tailings area.

The simulations spanned a period of 214 days from April 1st to October 31st. The snow melt runoff was assumed to occur between April 1st and April 15th. It was also assumed that the snow pack accumulated from October 31st in the previous year to April 1st of the year modeled.

Two sets of simulations were performed using different initial suction profile. For the first one, the initial suction profiles at tailings and waste rock were calculated by the SoilCover Model. Another set of simulations was carried out for the main station location at the waste rock dump. In this second group, the actual suction profile measured by the TC sensors on April 1st, 2003 were used as initial suction input. It was important to use real TC sensors measurements as well as calculated suction data, to allow for a comparison between the two different methods.

Results and Discussions

Laboratory Testing Program

Grain Size Analysis. The grain size distribution of the cover systems and waste rock materials at the main and satellite locations are shown in Fig. 3 and 4.

Figure 3 shows that all cover material samples present a similar trend of grain size distribution except for the first layer at the satellite location (WRS1), which is markedly coarser. All samples present more than 50% gravel and cobble, with the coarsest layer presenting 69% gravel and cobble.

From Fig. 4 it can be seen that the waste rock material become coarser in depth and this is associated with migration of finer material from the cover above into the shallow waste rock. After this 40 to 80 cm transitional zone, the grain size of the waste rock is noticeably coarser than the cover materials.

For the tailings area, the results showed that although the cover system is made up of finer particles than at the waste rock dump, the variation of grain size distribution among the layers in the tailings area is greater. From Fig. 5, it can be seen that the first two layers in the profile down to 45 cm in depth present very similar curves. These layers are underlain by a finer one that goes to 80 cm, and then two coarser layers of oxidized rock down to 180 cm in depth complete the cover profile.

Saturated Hydraulic Conductivity. The saturated hydraulic conductivity (Ksat) of the cover systems, waste rock and tailings materials is presented in Fig. 6. For the cover system at the waste rock dump, the first layer at the satellite location (WRS1) presented the highest Ksat among the samples tested, with a value of 6.2×10^{-4} cm/s. This is compatible with the grain size distribution presented in the former section. The higher permeability of this layer allows water to infiltrate faster into the cover system and makes ponding or runoff less probable. Since the underlying layers are less permeable, water infiltrating into this first layer will tend to accumulate until saturation occurs. After that, the water may either infiltrate into the lower layers or form ponds on the surface, depending on weather conditions. The Ksat of the lower materials at both locations were very similar and ranged between 2.4×10^{-4} and 1.4×10^{-4} cm/s.

At the tailings area, the surface materials have lower Ksat values than at the waste rock dump. The first sample of the tailings cover system (TPB51 at 15 cm depth) has a Ksat of 7.3×10^{-5} cm/s, which is approximately 3 to 8 times lower than the surface samples at the main and satellite location at the waste rock dump. From the surface to about 80 cm depth, the Ksat of the tailings cover system remains below the values found at the waste rock dump for the same depths. The finer constitution of the upper material at the tailings cover system causes the water to be held longer than at the waste rock site. This is favorable to the tailings cover performance, because the unsaturated hydraulic conductivity of the material remains close to the saturated

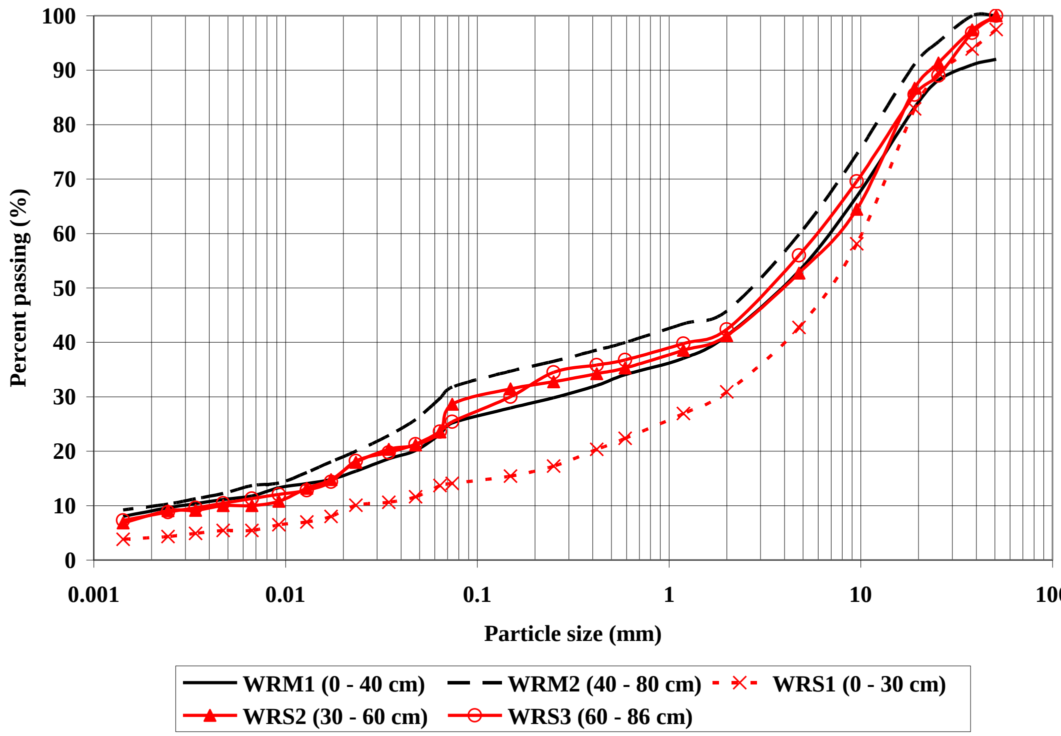


Figure 3. Grain size distribution of the waste rock cover material at the main (WRM) and satellite locations (WRS).

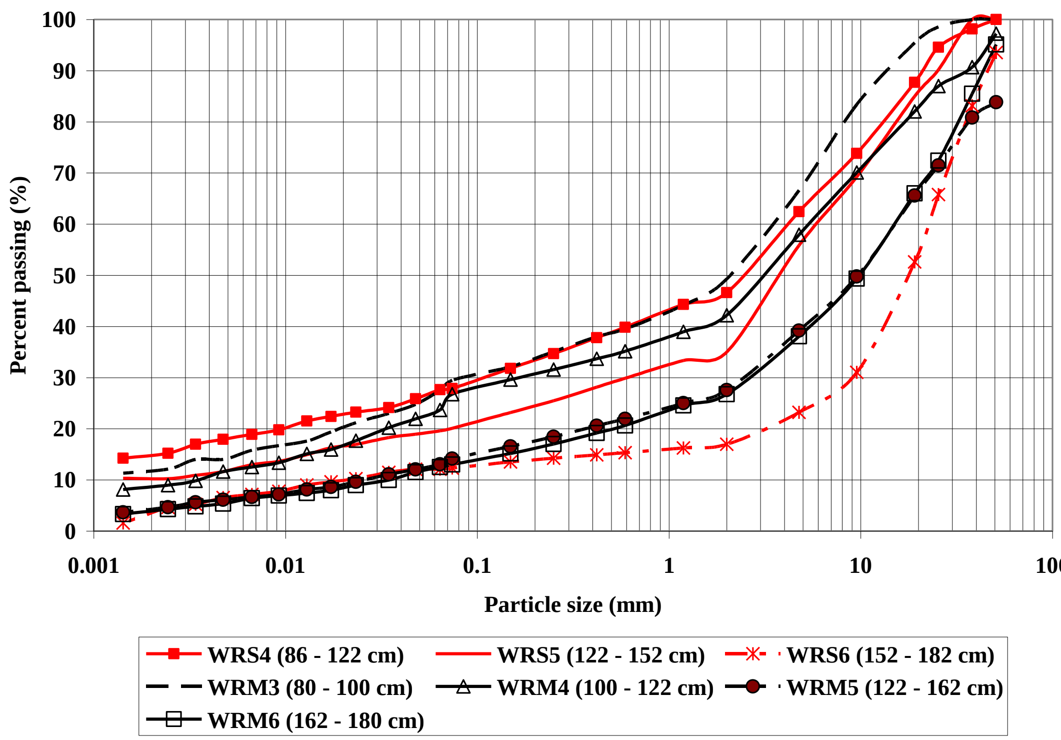


Figure 4. Grain size distribution of waste rock materials

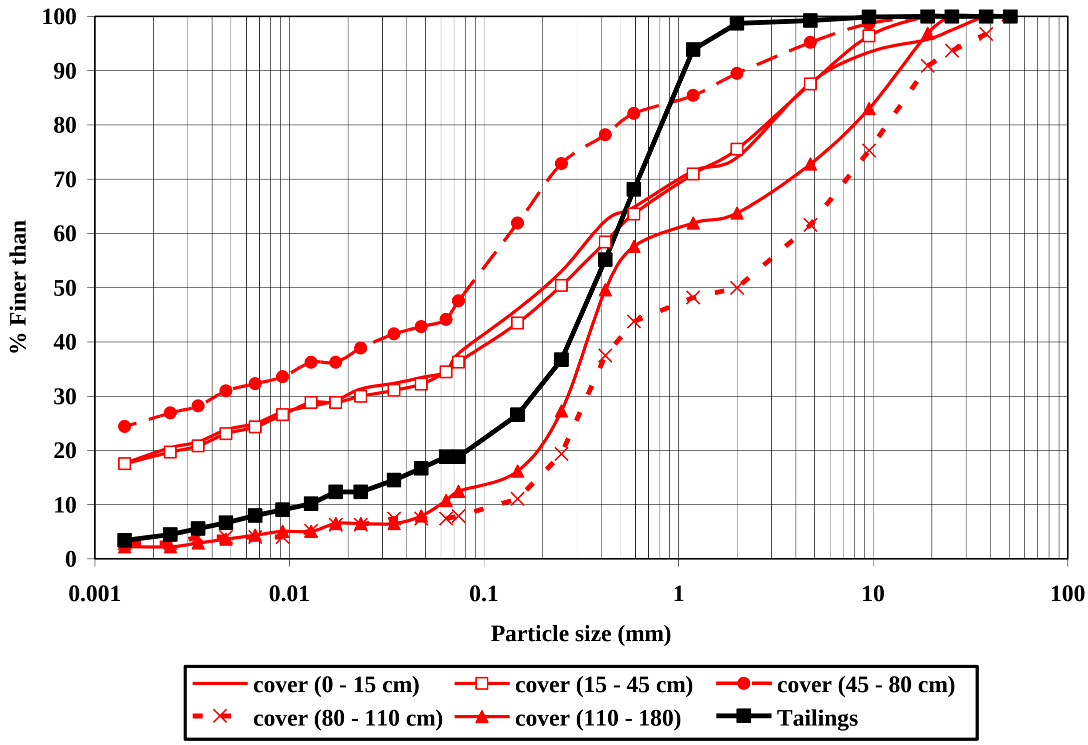


Figure 5. Grain size distribution of the cover system at tailings area.

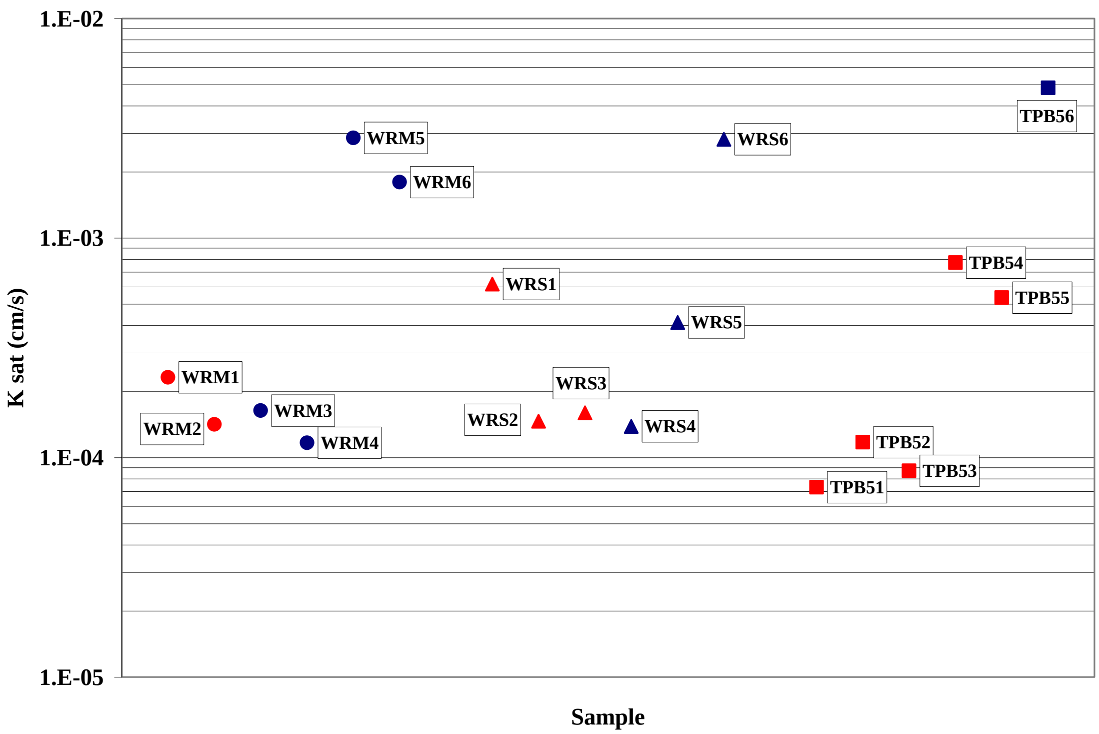


Figure 6. Saturated hydraulic conductivity of the cover systems, waste rock and tailings. Red marks are cover materials and black marks are waste rock and tailings.

value, even when the suction increases as the material dries out. The tailings cover is completed by two layers of oxidized rock from 80 cm down to the bottom of the cover system (180 cm), and the Ksat in this zone increases between 7 and 10 times as much as compared to the upper layers. These values reflect the coarser constitution of the oxidized rocks as presented in the former section.

Soil Water Characteristic Curves. The soil water characteristic curve of the samples was estimated by using the software SoilVision v.3.34. Figures 7a and 7b show the estimated soil water characteristic curves for the waste rock dump, as well as for the tailings area.

The results showed that the air entry value (AEV) of all samples at the waste rock dump, including both the cover system and the waste rock, is close or less than 1 kPa, influenced by the predominance of coarse particles in the entire profile. For the tailings cover, the AEV's for all samples are higher than the waste rock dump reflecting the finer constitution of the material. From Fig. 7b it can be seen that the curve for the tailings sample TPB56 is steep, revealing its sandy constitution and higher homogeneity as compared to the other samples. This sample's AEV at 0.7 kPa is also the smallest among all the samples in the tailings area, which, in general, present an Air Entry Value between 2 and 6 kPa.

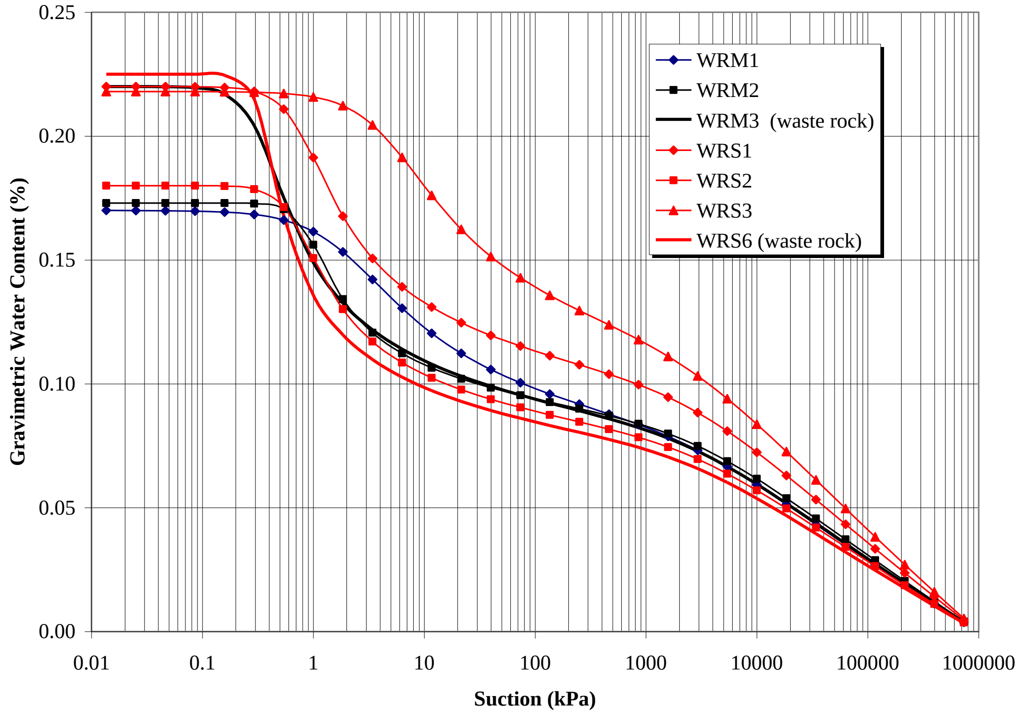
Thermal Conductivity Sensors

The results of calculated matric suction measured by the TC sensors at the waste rock and tailings areas from October 2002 to November 2004 are presented in Fig. 8 and 9.

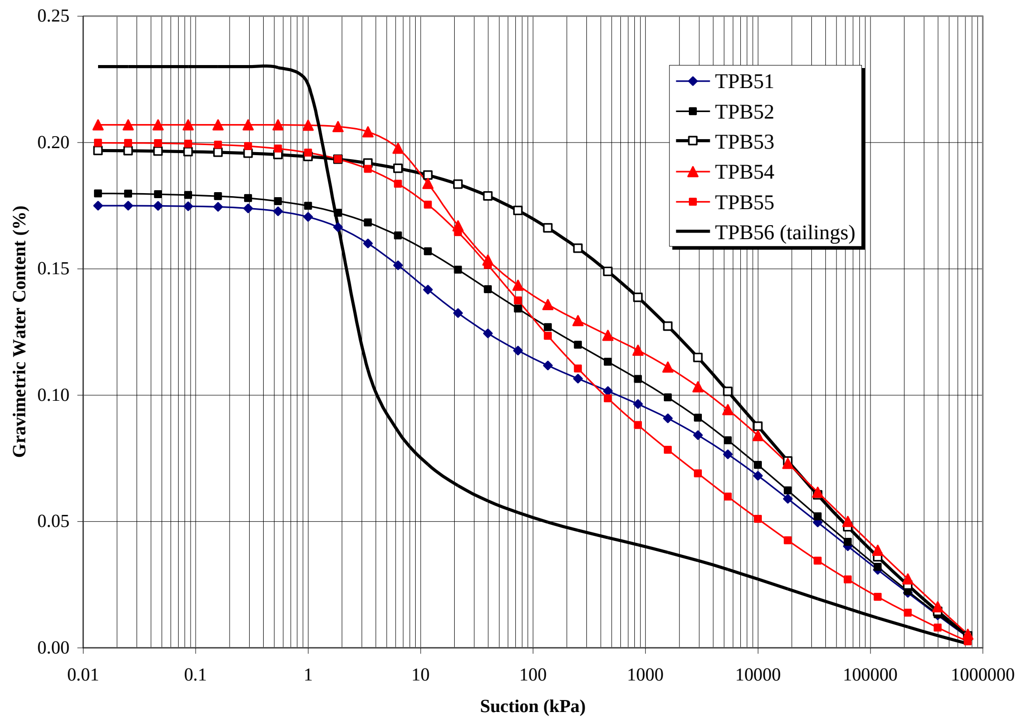
Figure 8 shows that all sensors at the main test pit on the waste rock site presented a decreasing suction between March and June associated with scatter rainfall events. The sensors results also showed that the cover dries out during the remainder of the year raising the suctions again. The 20 cm sensor presented the largest variation in suction among all of the sensors, revealing that the greatest water flux occurs near the surface rather than at depth, where the variation in suctions is less accentuated (106 and 129 cm deep sensors). It should be noted however, that the plant roots also play an important role in drying out the upper portion of the cover system.

The TC sensors at the tailings area shown in Fig. 9 also indicated periods of drying and wetting associated with the rain/snow melt and drying seasons (Fig. 8). The upper 45 cm sensor did not show an expressive variation in suction like the top sensor at the waste rock site. This difference is associated with the finer constitution of the surface material at the tailings cover system, which retains water longer and has a greater potential for moisture storage and release than the coarser cover material at the waste rock site.

The increase in suction seen for all sensors between December 2003 and February 2004 clearly indicates that the cover is drying out during this period, decreasing the volumetric water content and making room for water to be stored during the rains season.



(a)



(b)

Figure 7. Estimated Soil Water Characteristic Curve of the material at the Waste rock dump (a) and tailings area (b)

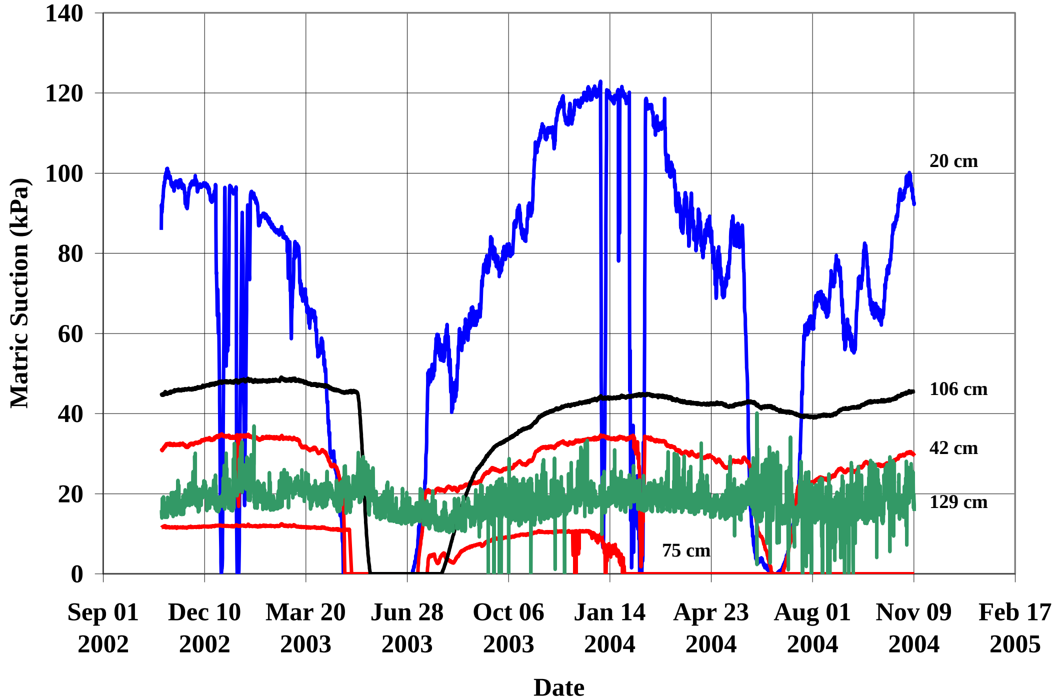


Figure 8. Matric suctions in the cover for the waste rock dump.

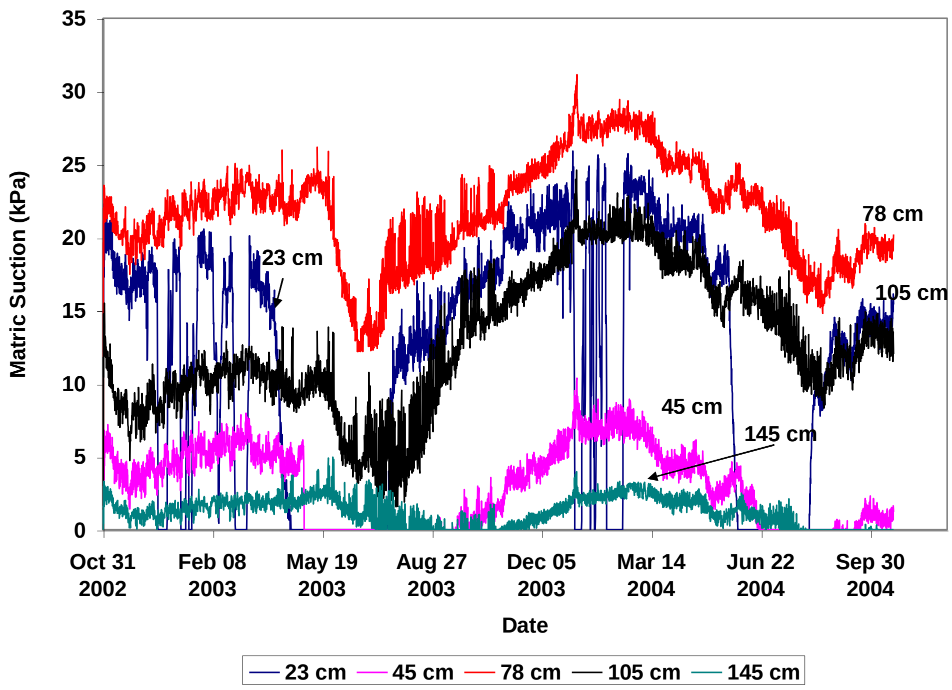


Figure 9. Matric suctions at the tailings monitoring station.

Numerical Modeling

Results from calculated initial suction profiles. According to the simulations using the initial suction profile calculated by the model, the infiltration through the cover system at the waste rock dump is strongly influenced by the presence and the condition of the vegetation. Figure 10 shows the variation in infiltration for the different vegetation and climate conditions analyzed.

For all climate conditions analyzed, infiltration decreases as the vegetation varies from the “no-vegetation” to the “excellent” condition. For “poor” vegetation, the simulations indicate an infiltration of about 4%, versus the estimated 15% for the case where the “no vegetation” condition is used. When “good” vegetation is used, infiltration approaches zero for all years, and is negative when “excellent” vegetation is established, even during a very wet year.

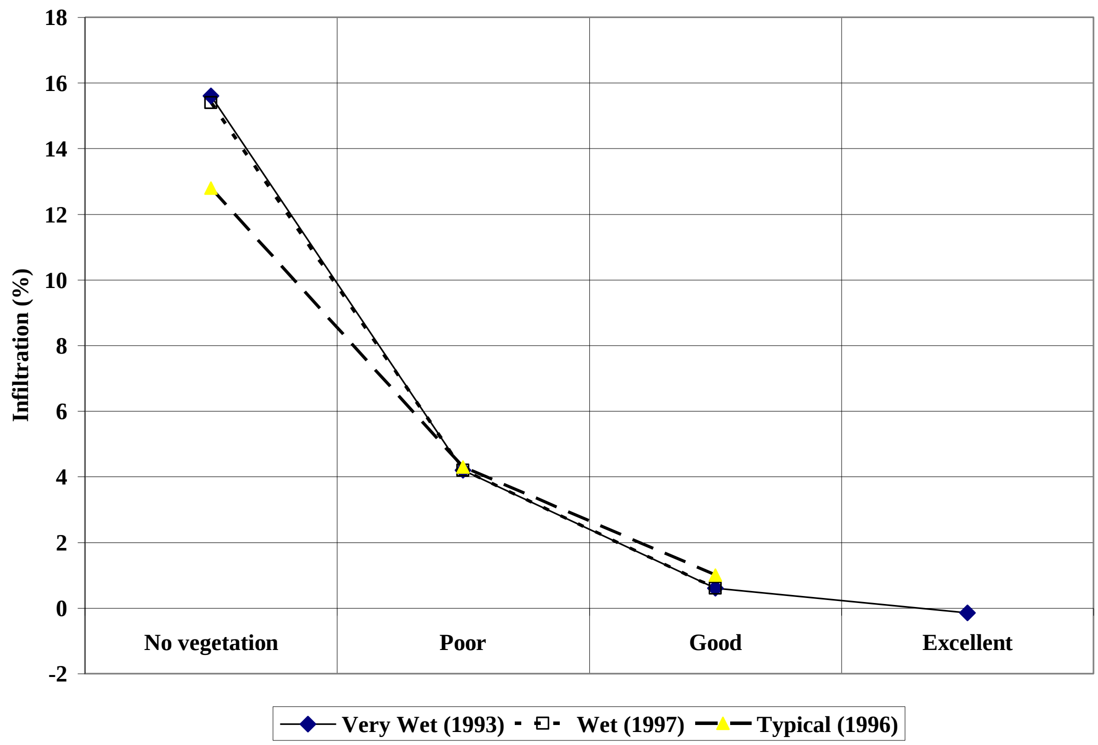


Figure 10. Cumulative infiltration through the cover at the Main monitoring station on the waste rock dump.

At the satellite location on the waste rock dump, the vegetation was assumed to be in poor condition during typical years, good during wet years, and excellent during very wet years. The results showed an infiltration even lower than that at the main station, with about 2% for typical dry years and poor vegetation, 0.5% for wet years with good vegetation, and no infiltration (0%) for very wet years with excellent vegetation.

For the tailings area, the thicker cover systems and the finer material caused water infiltration to be less dependent on the vegetation condition. However, as can be seen in Fig. 11, it is still necessary to establish vegetation to ensure a good performance for the cover. Simulations showed that for the “no vegetation” condition, the infiltration rate would be about 2% during typical dry years, and around 5 to 6% during wet and very wet years. If vegetation is established, even in poor condition, the simulations showed that no infiltration would happen no matter what the climate considered. In fact, when vegetation is present, the results point to a negative net infiltration. Negative infiltration is only possible if adequate moisture is available within the cover profile. A net negative water balance will lead to continued drying until evapotranspiration becomes moisture limited and thus net negative fluxes will tend to zero..

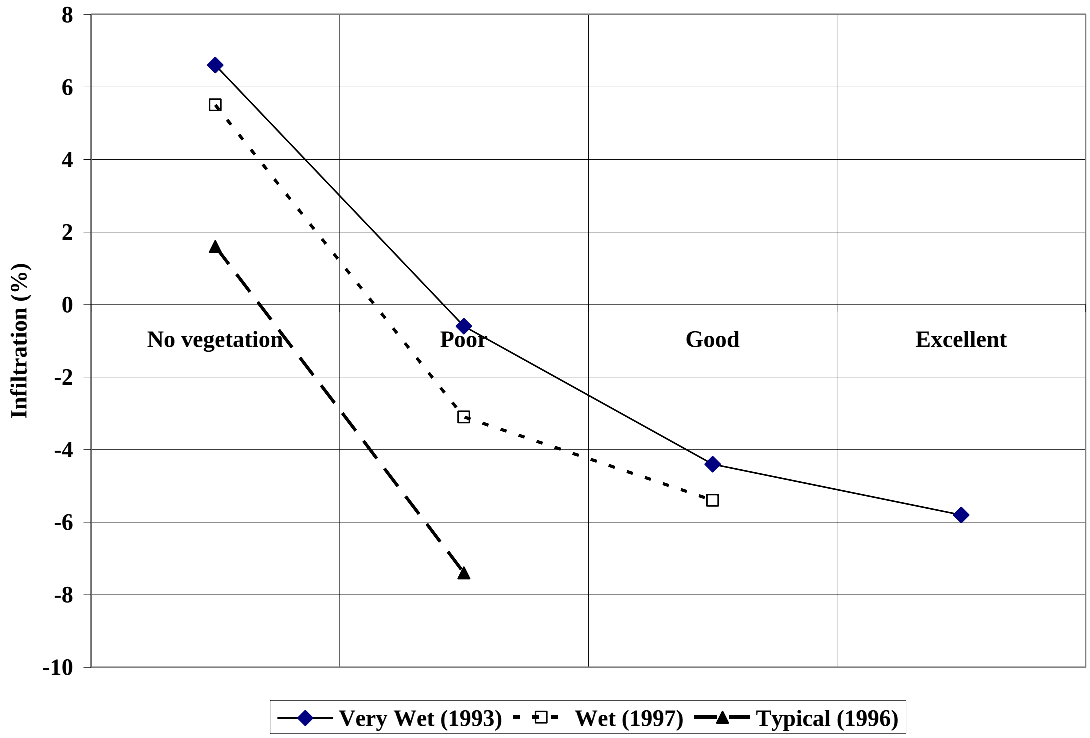


Figure 11. Infiltration rates at the tailings area for different climate and vegetation conditions.

Results using the April 1st, 2003 TC sensors suction profile. When the April 1st, 2003 measured profile was used as model-input to simulate the infiltration in the waste rock dump at the main station, the results showed a small amount of infiltration through the bottom of the cover system (0.8 m in depth), but also revealed the existence of upward flux from the material 1 meter below the cover. Table 2 summarizes the calculated total infiltration through the two boundaries. It was considered poor vegetation condition for typical dry years, good vegetation for wet years, and excellent vegetation for the very wet year case study.

Combining the simulated downward (positive) and upward (negative) infiltration values shown in Table 2, it can be noticed that infiltration through the waste rock pile would happen only during atypical wet years, and the amount of infiltrating water would be very small (1.8 mm). A comparison between the infiltration occurred through the bottom of the cover, and through the bottom of the simulated profile (1 m below), shows that the negative upward flux is greater then the downward flux from the bottom of the cover system. This suggests that, although some infiltration might occur through the bottom of the cover system, infiltrated water would not actually continue to move down through the waste pile, since one meter below the total upward flux is higher.

Table 2. Summary of flux through the bottom of the cover system and the bottom of the simulated profile. Negative values mean upward flux and positive values mean downward flux.

Year	Rain/snow (mm)	Flux at the bottom of cover (0.8 m)		Flux at bottom of profile (1.8 m)	
		mm	%	mm	%
Typical -1996	348.5	11.4	3.27	-12.0	-3.44
Wet – 1997	423.7	13.5	3.18	-11.7	-2.76
Very wet-1993	539.8	0.23	0.05	-12.4	-2.31

Thus, according to the simulations, although some small infiltration might occur through the cover system, the final flux direction is upward from the waste rock material to the cover. This suggests the existence of different hydraulic heads along the profile, which govern the direction of the flux. The pattern of different hydraulic heads that arises from the modeling is confirmed by the actual TC sensors data at the waste rock main monitoring station and tailings. Figures 12 and 13 present the calculated hydraulic head at different depths, based on the measured matric suction values.

At the waste rock dump, the higher head observed at 75 cm (approximately the bottom of the cover system) causes the flux to move down to 106 cm in the waste rock, while the higher head observed at 129 cm causes the flux to be upward to 106 cm. The simulations showed that the combination will result in upward flux from the waste rock to the cover material.

At the tailings, the same pattern of infiltration is suggested by the estimated hydraulic head profile in the cover system. Figure 12 shows that the hydraulic head at 75 cm is the lowest among all sensors, while it is the highest value is found at 45 cm. This suggests that water flows downward from 45 to 75 cm and upward from 106 to 75 cm. As the head at 23 cm is also lower than at 45 cm, it indicates an upward flow from 45 cm to the surface but, in this case, the flux is likely to be influenced by the presence of vegetation.

The simulations and the field instrumentation suggest a complex mechanism of infiltration where the flux in the profile takes opposite directions depending upon the hydraulic head existing at different depths. The variation in hydraulic head is directly associated with the grain size distribution and the water contents of the materials at different depths.

Conclusions

Based on the laboratory testing program, field instrumentation and monitoring program, together with the numerical modeling carried out on the cover systems for the waste rock dump and tailings area, the following conclusions are presented.

The three-year monitoring program to evaluate suction variation in the cover systems installed on the waste rock dump and tailings area, showed that the cover materials are storing water during the rain fall events and dessicating when the dry season starts. This behavior was predicted, and indicates that the store-release covers are working properly. The sensors also

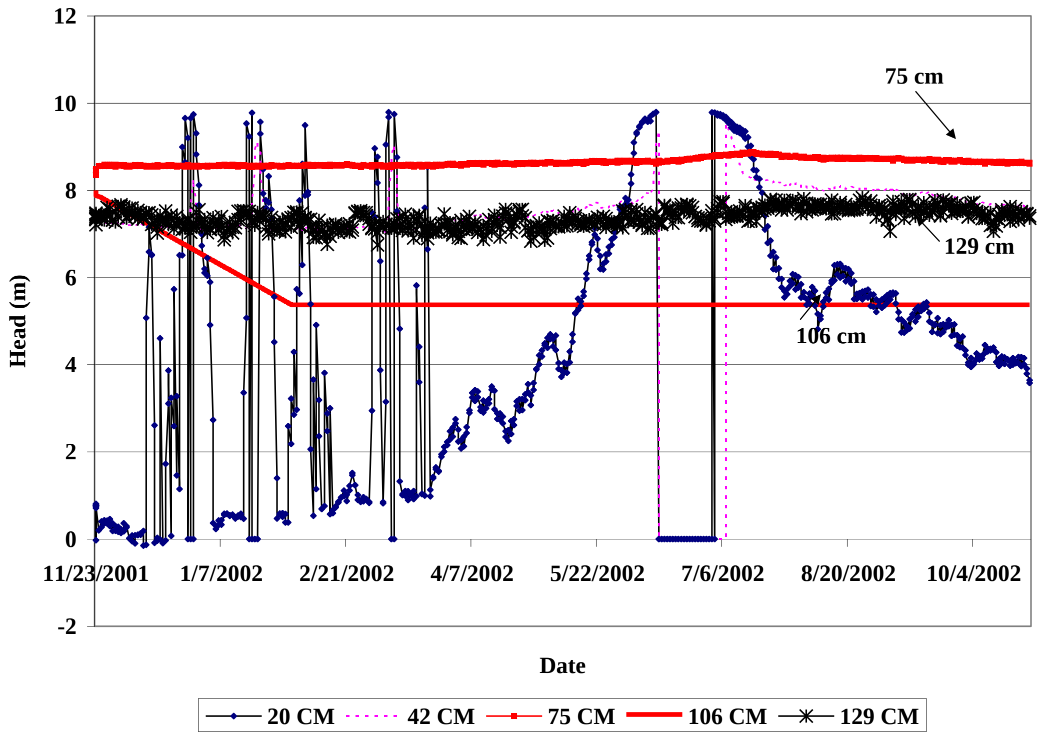


Figure 12. Hydraulic head for the profile at the *Main* monitoring station on the *waste rock* dump.

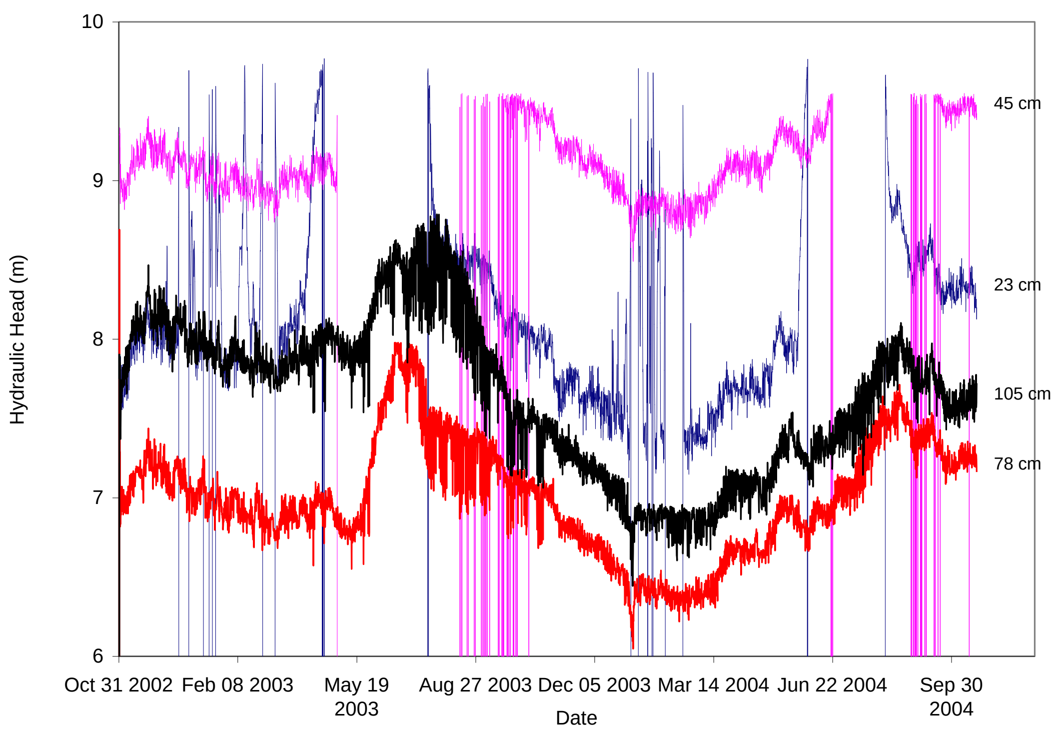


Figure 13. Calculated hydraulic head for the cover system profile at the *tailings* area using actual TC sensors data.

showed that most of water movement occurs close to the surface, and less moisture variation is observed at the lower part of the covers. The vegetation existing on the covers is assumed to play an important role to control water infiltration.

The numerical modeling showed that very small infiltration might occur through the cover systems at the waste rock site, while no infiltration is expected at the tailings area. The results suggest the existence of a complex mechanism of infiltration governed by the material properties and water contents in the profile, with downward and upward flux happening at different depths. The results showed that although small infiltration may occur through the bottom of the cover at the waste rock dump, the final water flux tends to be upward. This implies that superficial infiltrating water may not advance into the waste rock pile.

The simulations indicated that the vegetation condition is of utmost importance to ensure a good performance for the store-release cover systems. At the waste rock dump, no infiltration is expected if good vegetation is established. At the tailings area, the presence of vegetation, even at poor condition, is sufficient to prevent infiltration. The thicker cover system at the tailings area composed of finer material is less dependent on the vegetation.

The use of measured actual material properties as well as actual information from field instrumentation is of paramount importance to calibrate and confirm the results obtained from numerical modeling.

References

American Society for Testing and Materials. 2002. Standard Test Method for Specific Gravity of Soil Solids by Water Pycnometer. ASTM D854-02

American Society for Testing and Materials. 1998 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. ASTM D2216-98

American Society for Testing and Materials. 1995. Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter. ASTM D5856-95.

American Society for Testing and Materials. 1963. Standard Test Method for Particle-Size Analysis of Soil. ASTM D422-63.

Durham, A.J.P., Wilson, G.W., Bews, B.E., Currey, N. 2000. Evaluation of a Low Flux Cover System for Mine Waste Rock in an Arid Climate. Proceedings of the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000.

Fredlund, D. G. 1992. Background, theory and research related to the use of thermal conductivitv sensors for matric suction measurement, *In.* Advances in Measurement of Soil Physical Properties: Bringing Theory into Practice, SSSA Special Publication No. 30, pp.249-261

Marjerison, B., Richardson, N., Widger, A., Fredlund, D.G., and Berthelot, C. 2001. Installation of sensors and measurement of soil suction below thin membrane surface pavements in Saskatchewan. *In* Proceedings of the 54th Canadian Geotechnical Conference, Calgary, Alta., 16–19 September, pp. 1328–1334.

Nichol, C., Smith, L., and Beckie, R. 2003. Long-term measurement of matric suction thermal conductivity sensors. Canadian Geotechnical Journal, 40: 587-597. http://dx.doi.org/10.1139/t03-012

O'Kane, M., Wilson, G.W., and Barbour, S.L. 1998. Instrumentation and monitoring of an engineered soil cover system for mine waste rock. Canadian Geotechnical Journal, 35: 828–846. http://dx.doi.org/10.1139/t98-051.

Saxton, K.E. 1981. Mathematical modelling of evapotranspiration on agricultural watersheds. *In*, Modeling Components of the Hydrologic Cycle. Singh, H. (ed.), May 18 - 21, 1981. pp. 183-203.

SoilVision Systems Ltd. 2001. SoilVision Program Version 3.34. Saskatoon, Canada.

Tratch, D. 1994. Moisture uptake within the root zone. M.Sc. Thesis, Department of Civil Engineering, University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

Unsaturated Soil Group, 1997. SoilCover Program Version 4.01. Department of Civil Engineering, University of Saskatchewan. Saskatoon, Canada.

Van Haveron, B. P., and Brown, R. W. 1971. The properties and behavior of water in the soil-plant-atmosphere continuum. Psychrometry in Water Relations Research, Part I: Introduction. Utah Sate University. pp 1 - 27.

Williams, D.J., Currey, N.A., Ritchie, P., and Wilson, G.W. 2003. Kidston Waste Rock Dump Design and 'Store and Release' Cover Performance Seven Years On, Sixth International Conference Acid Rock Drainage, 14 – 17 July 2003.