Mine Closure 2012 — A.B. Fourie and M. Tibbett (eds)

doi:10.36487/ACG_rep/1208_36_O_Kane

Cover systems that utilise the moisture store-and-release concept – do they work and how can we improve their design and performance?

M.A. O'Kane *O'Kane Consultants Inc., Canada*

B. Ayres *O'Kane Consultants Inc., Canada*

Abstract

In general, the mining industry has 'labelled', or referred to, cover systems for mine waste storage facilities as per the cover system's primary function. Examples include: i) 'store-and-release' type cover systems, ii) 'water-shedding' and/or 'barrier' type cover systems, or iii) 'capillary break' type cover systems. This approach however, has led to a significant misunderstanding in regards to cover system performance expectations. For example, a 'water-shedding' cover system will typically include a barrier layer (low permeability layer) within the cover system and then an overlying growth medium layer. In reality, the growth medium layer is simply another label for a store-and-release cover layer because the functionality of the two is the same (i.e. store surface infiltration within the material, and then evapotranspirate moisture to release it back to the atmosphere). The underlying barrier layer is required to promote 'water-shedding' for conditions when storage is overwhelmed in the growth medium layer (e.g. periods of high rainfall).

This paper puts forth an approach to cover system design that focuses on developing cover systems that meet site-specific requirements and 'work' because a particular cover system has a high probability of meeting the design (or performance) criteria. For example, if it is determined that in order for a particular mine waste storage facility to be closed within the context of meeting site-wide closure objectives, that the average annual net percolation rate for the cover system must be less than 10% of rainfall, then a cover system is 'working' if there is a high probability of meeting this criterion for any given year. This would be determined on the basis of monitoring and modelling.

Hence, the fundamental first step in cover system design and performance is to determine, on a case-by-case basis, to what level, or extent, the cover system must 'work'. Only then can one determine whether a cover system is 'working', or not. This paper will first focus on discussion with respect to the need for developing site-specific cover system design criteria. Following this, discussion and examples will be provided on why and when cover systems do not 'work', with particular emphasis on cover systems that utilise, as their primary function, the moisture store-and-release concept to control net percolation rates. In addition, the need for developing a quality assurance program and implementing quality control for construction of moisture store-and-release cover layers will be discussed using field examples such that performance criteria can be met in the short-and long-term. In other words, to ensure the cover systems 'work'.

1 Introduction

The purpose of a mine waste cover system is restoration of the surface of a waste deposit to a stable, natural condition while minimising degradation of the surrounding environment following closure of the waste impoundment (MEND, 2012). Cover systems over waste material can have numerous objectives, including but not limited to:

- isolation of waste
- limiting influx of atmospheric oxygen

Contact author: M.A. O'Kane; mokane@okc-sk.com

- limiting influx of atmospheric water
- controlling erosion of waste material
- control upward movement of process-water constituents/oxidation products
- providing a medium for establishing sustainable vegetation.

One of the main purposes of placing cover systems over reactive waste material is to protect the downstream receiving environment following closure of the waste storage facility (O'Kane and Wels, 2003). This is achieved by reducing net percolation of meteoric water into the mine waste, which reduces effluent seepage volumes. This reduction in seepage volumes ideally limits peak concentrations of contaminants in receiving waters to levels that can be assimilated without adverse impact to the aquatic ecosystem. In addition to controlling contaminant releases, cover systems can also provide chemical and physical stabilisation of waste material and a growth medium for establishment of a sustainable vegetation canopy.

Cover systems can be simple or complex, ranging from a single layer of earthen material to several layers of different material types, including native soils, suitable overburden, non-reactive tailings and/or waste rock, geosynthetic materials, and oxygen-consuming materials (MEND, 2004). In general, the mining industry has 'labelled', or referred to, cover systems for mine waste storage facilities as per the cover system's primary function. Examples include: i) 'store-and-release' type cover systems, ii) 'water-shedding' type cover systems, or iii) 'capillary break' type cover systems. This approach however has led to a significant misunderstanding in regards to cover system performance expectations. For example, a 'water-shedding' cover system will typically include a barrier layer (low permeability layer) within the cover system and then an overlying growth medium layer. In reality, the growth medium layer is simply another label for a store-and-release cover layer because the functionality of the two is the same (i.e. store surface infiltration within the material, and then evapotranspirate moisture to release it back to the atmosphere). The underlying barrier layer is required to promote 'water-shedding' for conditions when storage is overwhelmed in the growth medium layer (e.g. periods of high rainfall).

This paper puts forth an approach to cover system design that focuses on developing cover systems that meet site-specific requirements and 'work' because a particular cover system has a high probability of meeting the design (or performance) criteria. For example, if it is determined that in order for a particular mine waste storage facility to be closed within the context of meeting site-wide closure objectives, that the average annual net percolation rate for the cover system must be less than 10% of rainfall, then a cover system is 'working' if there is a high probability of meeting this criterion for any given year.

2 Overview of functionality of store-and-release component of cover systems

The suitability of cover systems that rely on the moisture store-and-release concept to control net percolation will depend on site-specific climate conditions, material availability, and the required performance criteria. Figure 1 illustrates a generic store-and-release cover system. Water infiltrates during periods of high precipitation or spring melt in cold regions. The infiltrated water is stored within the cover until atmospheric and biotic demands are able to remove the water through evaporation and transpiration.

The term 'enhanced store-and-release' is used to describe a cover system that utilises the store-and-release concept to meet most of the cover objectives, but includes additional layers (see Figure 1) designed to limit net percolation during relatively short-duration seasonal events in which the storage capacity of a store-and-release layer might be exceeded. This differentiates these covers from barrier-type cover systems in that the permeability of these layers only needs to be lower than the average flux rate during these short-duration seasonal events, rather than functioning as a barrier to water flow throughout the year. If the low permeability barrier used in an enhanced store-and-release cover system is susceptible to processes such as wet/dry cycling, root penetration, etc., then sufficient soil cover must be provided to protect the lower hydraulic conductivity layer from these effects.

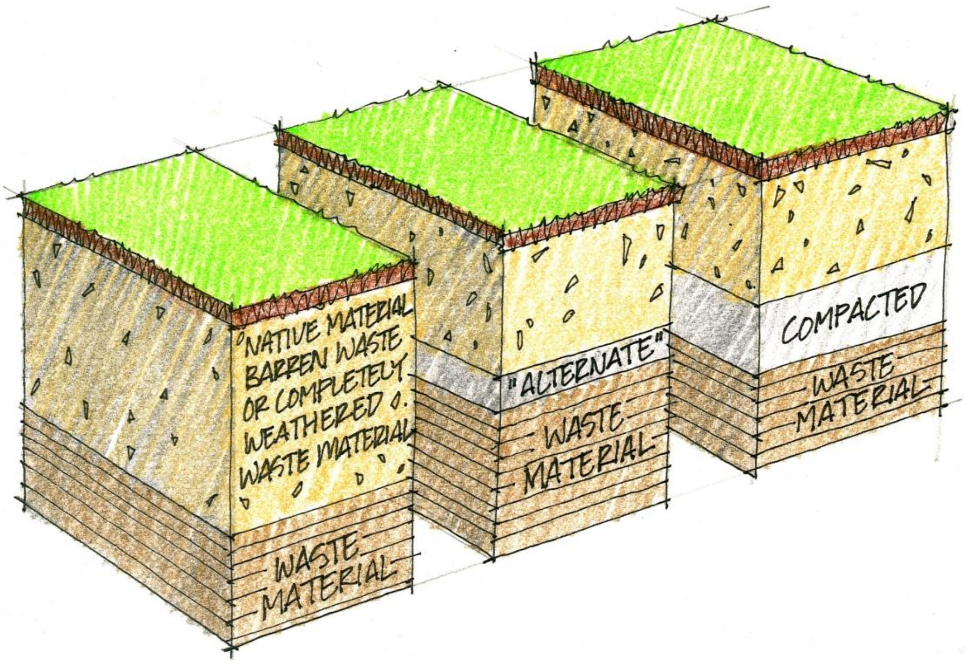

Figure 1 Schematic of cover systems with store-and-release functionality: (left) basic store-and-release cover system; (middle and right) enhanced store-and-release cover systems showing additional lower hydraulic conductivity layers below the storage layer (from MEND, 2012)

An enhanced store-and-release cover system may include an additional low hydraulic conductivity layer below a non-compacted layer. The purpose of this lower hydraulic conductivity layer is to 'delay' downward percolation. This layer could be weathered surficial waste rock compacted as a result of haul truck traffic on top of a dump lift or compacted locally available silt/clay. Inclusion of this reduced hydraulic conductivity layer at the base of the store-and-release cover system was shown to reduce the average annual net percolation (as a percentage of annual precipitation) by as much as 7% for a 0.5 m cover system and slightly less for thicker store-and-release cover systems (Christensen and O'Kane, 2005). The restricted infiltration layer can lead to increased interflow within the non-compacted layer and increased surface runoff, which increases the risk of surface erosion.

3 Failure of store-and-release functionality and its impact on performance

In the authors' experience, there are a number of reasons why the functionality of a cover system, which primarily utilises the moisture store-and-release concept, fails to meet performance expectations. These are presented in the list below, and then discussed in more detail in subsequent sections.

1. A failure to develop the design criteria for the cover system, such that performance of the cover system can be measured against expectations.
2. A lack of appreciation for incorporating site-specific climate conditions into the design of the store-and-release cover system.
3. A lack of control on materials used for construction of the cover system that meet the design characteristics.
4. A lack of control on proper placement and management of the materials used for construction of the cover system.
5. A failure of vegetation, which had been expected to remove water from the cover system, to establish and/or be sustainable.

In general, the areas within which these cause for a lack of anticipated functionality are associated with design, construction, and performance. Note that this 'lack of anticipated functionality', which can lead to failure of a cover system that utilises, primarily, the moisture store-and-release concept are presented in the context of the cover system failing to meet a design criteria (as discussed further).

4 Setting cover system design criteria

A key component for developing the design of a mine waste cover system is an impacts analysis, which can quantify the relationship between cover performance criteria and environmental impacts; in this context the term 'impacts' are assumed to be adverse to the receiving environment. The specific environmental impacts to be evaluated depend on the objective(s) of the proposed cover system design in conjunction with the site closure plan and other owner, as well as local, state, and federal government commitments. Environmental impacts most commonly evaluated during cover system design include:

- impacts on surface water quality
- impacts on groundwater quality
- impacts on air quality
- impacts on vegetation
- impacts on wildlife.

The goal is to select a closure scenario that will attenuate peak concentrations for contaminants of concern in the receiving environment to levels that can be assimilated without adverse impact over the long term. Once the required criteria have been determined for closure of a given waste storage facility, feasible cover system design alternatives can be developed and carried forward into a soil-plant-atmosphere numerical modelling program. In addition, closure criteria, developed on a site-specific basis, provide the basis for measuring field performance of a cover system and ultimately, determination of whether the cover system is 'working'.

The design of a mine waste cover system and in particular, determination of predicted rates of net percolation over the long term, should involve soil-plant-atmosphere numeric simulations using a long-term climatic database. This database should be comprised of at least 50–100 years of daily records from local and regional meteorological stations. Each year of the long-term climate database should be run continuously for each cover design alternative, thereby taking into account antecedent moisture conditions. This allows curves, as shown in Figure 2, to be developed for each cover alternative, providing mining companies with a means of understanding 'risk' or the 'probability of exceeding' a certain net percolation rate for a given waste storage facility.

The authors' suggest that for general context, cover systems that achieve: i) 'very low' net percolation rates are those that have a high probability for the net percolation rate for any given year to be between 1–5% of the rainfall; ii) 'low' net percolation rates are those that have a high probability for the net percolation rate for any given year to be between 5–15%; and iii) 'moderate' net percolation rates are those that have a high probability for the net percolation rate for any given year to be between 10–40%.

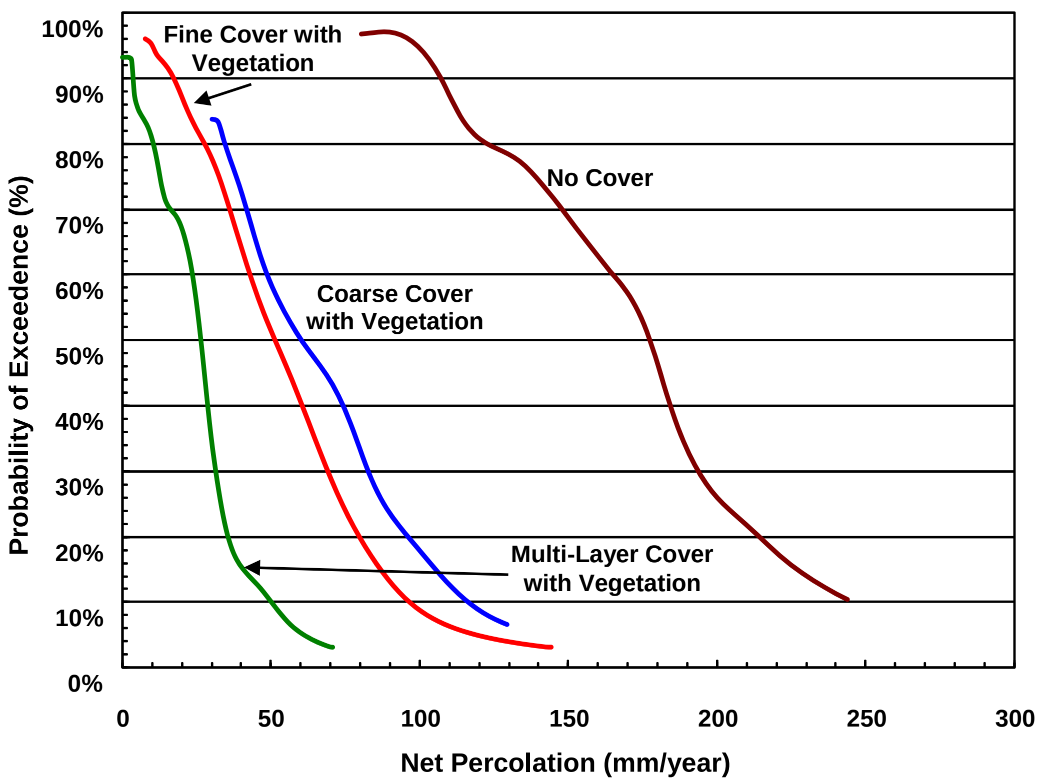

Figure 2 Example illustration of net percolation probability of exceedence curves generated from the results of continuous 100 year climate simulations for a 'no cover' scenario, and three different cover system scenarios

5 Site specific climate conditions

Caution must be used when designing cover systems that rely on the moisture store-and-release concept based on annual average climatic data (MEND, 2012). Figure 3 is taken from the Global Acid Rock Drainage (GARD) Guide (INAP, 2009), and provides general guidance when comparing the potential evaporation ratio to the annual precipitation (rainfall) in order to determine, as a 'first pass', the appropriate type of cover system for a site. However, sites that experience highly variable climatic conditions (e.g. high-intensity precipitation over short periods of time) may have low average precipitation and high potential evapotranspiration; yet, due to the timing of precipitation, the storage capacity of the cover system may be overwhelmed during periods of low potential evapotranspiration. For example, in many cold regions it would not be unusual for the net infiltration from snowmelt to exceed the storage capacity of the cover material such that net percolation will occur (MEND, 2004). Similarly, there are many sites in which precipitation exceeds potential evapotranspiration on an annual basis, but during the growing seasons these sites have moisture deficits due to potential evapotranspiration exceeding precipitation and soil water storage. Cover systems must be designed and monitored to evaluate the design against a longer term, site-specific climatic record (e.g. tens of years) rather than an average 'design' year, and to monitor performance over the longer term (i.e. within individual years, net percolation may exceed design specifications, but the long-term average value may be acceptable) (O'Kane and Barbour, 2006; MEND, 2004).

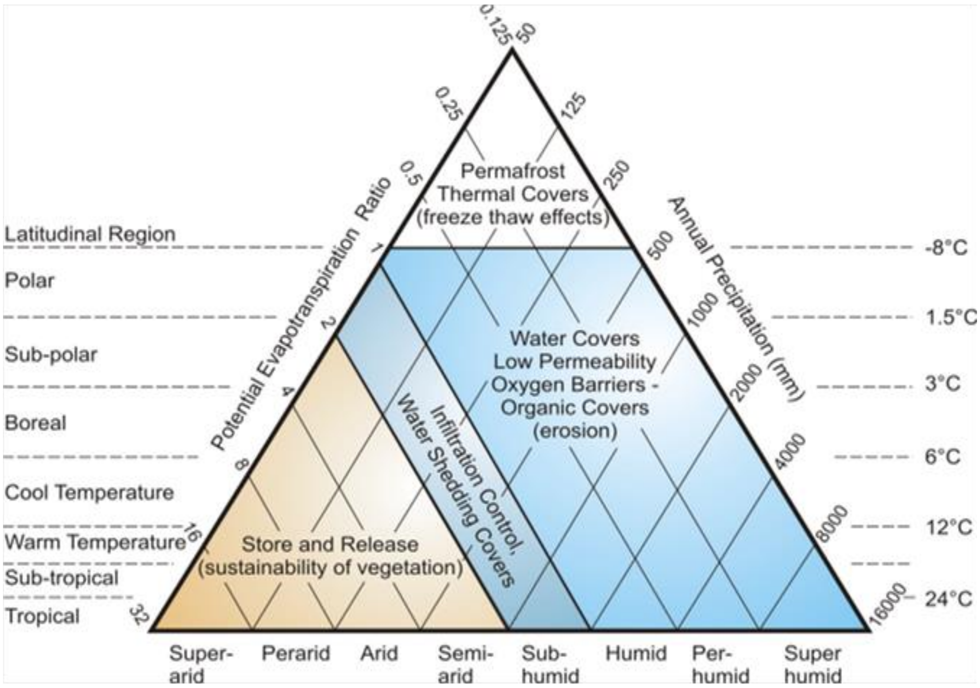

Figure 3 Cover systems and climate types (INAP, 2009)

The most common misuse of such an approach, as shown in Figure 3, is for arid to semi-arid climatic regions where the ratio of potential evaporation to rainfall may be as much as 3:1 or even 4:1, when considering average annual climate conditions. In these cases, the expectation is often that the net percolation rate will be very low. However, it is common, if not typical, that for much of the year the ratio might be much higher than 3:1, but for the 'rainy' or 'wet' season, the ratio can be 2:1, or even 1:1 or lower. Hence, net percolation during these latter periods of the year, while only as little as two or three weeks, can dominate the annual net percolation rate determination and result in rates that are much higher than expected.

6 Cover system construction materials

It is common to utilise run-of-mine (ROM) non-acid forming and non-metal leaching material when constructing cover systems that utilise the moisture store-and-release concept to manage mine waste for closure. As a result of this there is a desire to directly place the ROM material used for the cover system as part of mining operations, with over haulage costs kept to a minimum. Ideally, this results in the cost of closure to be an incremental increase in the overall project costs, as opposed to being substantially higher if cover system construction was left to the end of operations. However, it is not yet fully appreciated by the mining industry that placement of the ROM materials, which do not meet the textural envelope for the ROM material used as part of design, has a substantial adverse impact on performance.

The most common issue is placement of ROM that is too course textured such that moisture retention within this cover layer is insufficient; in terms of providing a medium for surface infiltration to be stored near surface, and subsequently evapotranspirate. The result is a failure of the cover system to store the required volume of moisture for any given rainfall event, and this infiltration then leads to higher net percolation (NP) rates. In many instances, the coarser textured material results in 'macro-pore' flow during higher intensity rainfall events, which leads to rapid infiltration to the base of the cover system, and ultimately higher than expected net percolation rates.

Schneider et al. (2011) provides a recent example of this issue that adversely impacts on performance. In this study, the site identified the appropriate ROM material to be used for large-scale cover system field trials, and stockpiled these materials for construction of the trials. However, this stockpile was buried as part of operations, and the field trials were constructed using much coarser textured material.

More often than not, gradation limit specifications for a cover system's moisture store-and-release layer are not developed. In many cases, this practice has led to poor performance of a cover system that relies heavily on the moisture store-and-release concept to control net percolation rates. Ideally, a moisture store-and-release layer should consist of a well-graded material ranging from silt/clay size particles up to cobble/boulder size particles. The required textural gradation is site-specific; however, in the authors' experience a 'first pass' estimate when using ROM material for this layer, is that a well-graded material with at least 40% passing 4.75 mm (the #4 sieve size) should be utilised. Many ROM materials possess a sufficient percentage of fines and coarse-size particles, but lack the intermediate-size particles (this gradation is referred to as gap-graded). Hence, the authors' recommend that the 4.75 mm size fraction should be used for initially evaluating the suitability of the texture of the material, as opposed to using a typical soil science approach, which classifies 'fines' as being less than 2 mm. Gap-graded materials have a greater propensity for segregation compared to well-graded materials, particularly when they are placed using large haul trucks. In short, site-specific gradation limit specifications should be developed for cover system moisture store-and-release layers in the same manner as is undertaken when compacted low permeability layers are constructed. It is the authors' opinion that in order to ensure a cover system's design and/or predicted performance can be achieved in the field, the mining industry should undertake a higher level of quality control than is currently practiced, when using ROM material for constructing cover systems.

7 Segregation of run-of-mine cover material

As discussed initially in the previous section, ROM material tends to be well-graded to gap-graded. In addition, even if this material meets the required textural gradation, placement of this material can result in segregation. The segregated zones of coarser textured material can result in macro-pore flow, and as described above will lead to preferential flow during higher intensity and longer duration rainfall events, and ultimately higher than expected net percolation rates. The key issue is that rapid and deep infiltration occurs via the coarser textured segregated material, and the only manner in which this water can 'report' back to the atmosphere via evaporation and/or transpiration is via the finer textured material. This is typically a slower and more dampened response, and if a subsequent lower intensity rainfall event occurs, unsaturated piston flow can 'push' the original water deeper in to the profile; again, ultimately resulting in higher than expected net percolation rates.

The adverse affect of ROM material segregation within a moisture store-and-release cover layer was observed at BHP Billiton Iron Ore's (BHPBIO's) Mt. Whaleback operation, located in the Pilbara region of Western Australia approximately 1,200 km N-NE of Perth, by INAP (2003). The Pilbara region is semi-arid with potential evaporation greatly exceeding rainfall on a yearly basis. The 100 year average rainfall at Mt. Whaleback is 310 mm per year. Average potential evaporation is approximately 3,000 mm per year.

BHPBIO constructed cover system field trials at Mt. Whaleback in 1997 using ROM material. In December 1999 a rainfall event over 36 hours of in excess of 280 mm was recorded. Water content and suction sensors were installed at a number of different depths ranging from near surface to greater than 4 m (see O'Kane et al., 1998). Sensors at a depth of 10 cm responded almost immediately following the rate of the rainfall event in December 1999. The sensors at a depth of 100 cm responded some 24–36 hours later, consistent with matrix dominated flow and an advancing wetting front. However, at one monitoring profile the sensors at a depth of approximately 200 cm responded in less than six hours to the rainfall event. The hypothesis, as reported by INAP (2003) and further modelled, was that a zone of segregation of coarser textured material within the profile at the monitoring location became a location for macro-pore flow resulting in rapid wetting conditions deep within the profile. The evidence of macro-pore flow during and following this rainfall event was not observed prior to the rainfall event, nor subsequent to it (Meiers et al., 2010; O'Kane, 2011).

8 Development of a sustainable vegetation cover

Another key component to successful performance of a cover system that relies heavily on the moisture store-and-release concept is establishment and maintenance of an appropriate vegetation cover. In some cases, rapid establishment of vegetation following cover material placement is important to limit erosion of and sediment transport from the cover materials, particularly where receiving environments are intolerant of sediment delivery. In addition, some unweathered borrow materials will undergo drying and/or cementation following placement, which is another reason for seeding or planting immediately following cover construction. Generally, a diverse vegetation community that mimics or replicates the existing native communities in the surrounding area will provide the best long-term cover performance (MEND, 2012).

The objectives for the cover system and vegetation required for meeting objectives must be developed in concert such that there is an understanding of how different plant functional groups respond physiologically to interacting biotic and abiotic factors on cover systems. A set of guidelines for plant-model parameters are required, and the designer must determine the most appropriate approach to incorporating them into the numerical model being used to predict/compare performance of different cover system alternatives for the site. In general, one should differentiate vegetation performance on the basis of the different biogeoclimatic regions and determine the methodology to appropriately determine growth medium thickness required for a particular site.

Currently, predictions of vegetative cover system performance for reactive mine waste typically requires users (designers and/or modellers) to specify rooting depths, rooting patterns, and empirical relationships that control transpiration rates. Within models, these parameters tend to remain constant throughout numerical simulations and are not representative of their dynamic nature. Rather, parameters such as rooting characteristics, leaf area index (LAI), and evapotranspiration (ET) respond to site-specific biotic and abiotic interactions that affect overall cover system performance on a site-specific basis (Lamoureux et al., 2012). It is the authors' opinions that improvements on the ability of the mining industry to properly model these biotic and abiotic interactions will result in a substantial increase in the ability to appropriately predict cover system performance.

9 Summary comments

This paper puts forth a systematic approach to cover system design, with specific focus on utilising the moisture store-and-release concept for primary control/management of net percolation rates. The key concept arising from this paper is that determination of whether the cover system 'works' or not is whether it meets the design criteria, which in the case of a cover system that utilises the moisture store-and-release concept, is typically a certain net percolation rate. This also provides the basis for measuring performance of the cover system. Hence, if the cover system was designed to achieve a high probability of achieving a net percolation rate less than 10% for any given year, and through appropriate monitoring (i.e. 'direct' cover system monitoring), this is demonstrated, then the cover system should be seen as 'working'.

In general, it is the authors' experience that a failure of the moisture store-and-release functionality of a cover system to meet expectations is a result of: i) a lack of appreciation for incorporating site-specific climate conditions into the design; ii) a lack of control on materials used for construction of the cover system that meet the design characteristics; iii) a lack of control on proper placement and management of the materials used for construction of the cover system; and iv) a failure of vegetation, which had been expected to remove water from the cover system, to establish and/or be sustainable.

Often, cover systems that utilise the moisture store-and-release concept to control net percolation rates to achieve, with an expected high probability, the design criteria use ROM material. In order to properly integrate the use of this material it must be utilised in the context of mine closure planning, which is a process that involves determining site closure objectives, such as planned final land use, and implementing the processes and steps required to meet those objectives. The closure objectives should be integrated into the mine plan to a much greater extent, more efficiently, and more cost-effectively when closure planning is developed as part of feasibility studies for the potential mine, but at the very least prior to closure (or abandonment) of the mine. This integration should include considerations of segregation of waste streams, stockpiling topsoil and non-reactive overburden, and progressive reclamation. The authors are aware of several instances where ROM material, suitable for a moisture store-and-release cover system layer, has been buried in surface stockpiles due to mine plans not adequately considering closure plans. In short, the mine plan needs to be linked with the closure plan so that economically viable sources of cover material generated from mine operations can be set aside for closure of reactive waste storage areas. In short, there is a need to think of there being 'one plan', as opposed to a myriad of different plans, which often have competing objectives; whether perceived or real.

References

Christensen, D. and O'Kane, M. (2005) The use of "enhanced" moisture store-and-release cover systems over reactive mine waste in cold and warm semi-arid climates, in Proceedings 2005 National Meeting of American Society of Mining and Reclamation, June 19–23, Breckenridge, CO., USA, pp. 224–235.

INAP (2003) The International Network for Acid Prevention. Evaluation of the long-term performance of dry cover systems, final report, Prepared by O'Kane Consultants Inc., Report No. 684-02, March.

INAP (2009) The International Network for Acid Prevention. Global Acid Rock Drainage Guide (GARD Guide), viewed 11 July 2012, http://www.gardguide.com/

Lamoureux, S., Straker, S., Barbour, S.L. and O'Kane, M. (2012) Enhancing the Understanding for the Influence of Vegetation on Cover System Performance in a Canadian Mining Context, in Proceedings 9th International Conference on Acid Rock Drainage (ICARD), W.A. Price, C. Hogan and G. Tremblay (eds), 20–26 May 2012, Ottawa, ON, Canada.

Meiers, G., Huys, B., Heyes, J., Sommerville, K., Christensen, D. and O'Kane, M. (2010) Management of Overburden Storage Areas at the Mt. Whaleback Mine – A Review of 12 Years of Cover System Performance Monitoring and Application to Closure, in Proceedings Fifth International Conference on Mine Closure (Mine Closure 2010), A.B. Fourie, M. Tibbett and J. Wiertz (eds), 23–26 November 2010, Viña del Mar, Chile, Australian Centre for Geomechanics, Perth, pp. 487–500.

MEND (2004) Mine Environment Neutral Drainage. Design, construction and performance monitoring of cover systems for waste rock and tailings, Canadian Mine Environment Neutral Drainage Program, Project 2.21.4, July.

MEND (2012) Mine Environment Neutral Drainage. Cold regions cover system design technical guidance document, Canadian Mine Environment Neutral Drainage Program, Project 1.61.5c, in progress.

O'Kane, M. (2011) State-of-the-Art Performance Monitoring of Cover Systems – Moving from Point Scale to Macro Scale Approaches, in Proceedings 7th Australian Workshop on Acid and Metalliferous Drainage, L.C. Bell and B. Braddock (eds), 22 June 2011, Darwin, NT, Australia.

O'Kane, M. and Barbour, S.L. (2006) Choosing representative climate years for predicting long-term performance of mine waste cover systems, in Proceedings 7th International Conference on Acid Rock Drainage (ICARD), R.I. Barnhisel (ed), 26–30 March 2006, St. Louis, MO, USA.

O'Kane, M. and Wels, C. (2003) Mine waste cover system design – linking predicted performance to groundwater and surface water impacts, in Proceedings 6th International Conference on Acid Rock Drainage (ICARD), T. Farrell and G. Taylor (eds), 14–17 July, Cairns, Qld, Australia.

O'Kane, M., Porterfield, D., Endersby, M. and Haug, M. (1998) The design and implementation of the field test plots at BHP Iron Ore, Mt Whaleback – A cover system for an arid climate, Pre-print 98–70, Presented at the SME Annual Meeting, Orlando, Florida, March 1998.

Schneider, A., Baumgartl, T., Mulligan, D. and Doley, D. (2011) Store and Release Cover Systems: Experiences from Eastern Australia, Workshop on Understanding Cover Limitations: Risks and Opportunities, March 10–11, 2011, Brisbane, Australia.