Cover System Performance Monitoring for Tailings – Are We Doing It Correctly?

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COVER SYSTEM PERFORMANCE MONITORING FOR TAILINGS, ARE WE DOING IT CORRECTLY?

Across the globe it is a common scenario that tailings storage facilities (TSFs) are being decommissioned, however, their subsequent impact on the local environment and landscape can often be overlooked during the mine planning process. In addition, the requirement of a cover system for a facilities closure may not be a priority until latter stages of the mine/mill operation, when potential cover materials may have been utilised elsewhere or worse, buried. Developing a conceptual design and closure plan for a TSF early in a mining venture is fundamental for its success once operations have ceased. If a cover system is a planned component for rehabilitation of a TSF it is vital that its design is appropriate to the facility and any local site constraints, such as climate, cover system material availability, etc. It is also strongly recommended that various cover system options are physically trialled at the site through utilisation of performance monitoring instrumentation. Through this process an informed decision can be made regarding the most appropriate cover system design to meet any regulatory and stakeholder closure objectives and criteria, specific to the site in question. However, in order for the cover system’s performance to be determined through on site trials, it is essential that an appropriate instrumentation design is utilised. Often the case can be that little attention is paid to the data that is being obtained, and its importance may only become apparent after several years of monitoring at an expense to the venture. This should not be the case, and many sites have used an appropriate initial planning stage to understand what is required for the successful closure of a TSF, how it can be achieved and how monitoring data can be utilised to prove, or otherwise, that a cover system design will be a success.

INTRODUCTION

Successful closure of tailings storage facilities (TSFs) is an environmental issue faced globally. During the initial feasibility and design phase importance is often placed on the physical stability of above ground TSFs, whilst closure planning is often considered as ‘basic’ by comparison. However, as the landform is further developed and constructed attention must be paid to regularly revisit the original closure plan and update it as required in order to achieve the best possible situation for both the environment and stakeholders.

TSFs are considered permanent structures and as such represent a legacy to the mining venture. Greater emphasis should be placed on the socio-environmental implications associated with TSF construction and subsequent closure and many scenarios must be considered and questioned from the offset for example: will the facility be considered as sustainable? What are the physical, chemical, ecological and social conditions? How will long-term water quality issues be addressed? (Bjelkevik, 2011). However, information provided to answer these questions should also be used to address the main issue: How will the facility be closed, and will there be any subsequent environmental issues following the landform’s rehabilitation?

Whilst operational a venture commonly undertakes active in situ monitoring at the landform. The number of and type of instruments installed at a facility is developed on a site specific basis, however, commonly they comprise: piezometers, inclinometers, flow gauges and monitoring bores to name but a few. Information obtained from such devices is very important within the day-to-day planning and management of such facility. However, the information also directly feeds into closure planning studies and allows for appropriate...
rehabilitation planning to be undertaken. Data quality issues from \textit{in situ} monitoring equipment may ultimately lead to a misinformed closure design and as such failure to remediate a given facility to the standard required for bond relinquishment.

Developing an initial closure plan is fundamental and should be supported by the progressive development of the facility. TSF closure should provide an inherently stable landform, capable of long-term erosion prevention and suitable to the local surrounds (Department of Primary Industries, 2004). It should require minimal maintenance following rehabilitation and post-closure of the venture, and should also be appropriate to the on-site conditions. The latter of these items is critical to the facility’s overall post-closure success.

At the start of a given project it is fundamental that its design is appropriate to the specific site considered, and likewise this is true for its closure. Rehabilitation undertaken at Mine Site A should not be directly applied to Mine Site B because they have the same owners and who previously ‘worked’ at Mine Site A.

Consideration must be placed on numerous items, including the tailings (particularly deposition method, water content and the rate of consolidation); local climate; hydrology of the site; post-mining land use commitments; availability, quality and quantity of potential cover system materials; and requirements for revegetation.

It is well acknowledged that the greatest number of options for varying closure designs are available within the early stages of a project. As time progresses and the landform is further developed with construction well underway, the number of options for closure are significantly decreased and in parallel the costs to alter a design according to the most promising closure option are at their highest. As such it is critical to the venture to appropriately plan for closure of a facility prior to significant onsite developments (Mao and Kam, 2011). This should be developed in conjunction with a conceptual design that not only understands the basic requirements of the TSF (volume of tailings to be deposited; control measures to prevent seepage; deposition method etc.) but also how the facility will be rehabilitated, and when. As the landform progresses the conceptual design should be regularly referred to and updated as necessary. For example, a misinterpretation of early geochemical results, or more thorough understanding of waste properties as production is underway, might alter the believed reactivity of the tailings waste and as such the closure options and required rehabilitation. In this example it is fundamental that the conceptual design is revisited and updated in order to allow for any necessary changes to be assessed and implemented as early as possible.

It may be determined that encapsulation of tailings materials is required through construction of an engineered cover system in order to limit atmospheric interactions with reactive materials. The type of cover system, materials to be utilised and their respective thicknesses should be developed based on its suitability to the site and available waste materials. Dependent on the tailings deposition method used at site it may be required that progressive rehabilitation, and cover system construction, is required. This can be beneficial in terms of refining a design following collection of initial data. It allows for a field assessment of the proposed closure design performance and if necessary, provide sufficient time for amendments to the overall design to be made prior to the final closure of the facility. This method also demonstrates to key stakeholders and regulatory bodies that a constructive approach is being made onsite in order to successfully close the facility.
The quality of information obtained through *in situ* monitoring, either within Stage 1 construction or post-mine closure, is dependent on the monitoring methods utilised. If sensors utilised will not provide key information regarding the cover’s performance, or their arrangement within the cover is sub-standard the required knowledge will not be developed and the cover’s performance will be disregarded.

This paper explores the utilisation of an engineered cover system for rehabilitation and closure of a TSF, and instrumentation requirements for use in monitoring the performance of a tailings waste cover system.

**TSF CLOSURE PLANNING**

Early planning for closure of a TSF is paramount to its long-term success post mining. This is with regards to implementation at the facility (for example the physical construction of a cover system) in addition to achieving regulatory and stakeholder approval.

Should closure planning studies determine that a cover system will be required for rehabilitation and closure it must be appropriately designed early within the mine life. This approach may allow the required cover materials to be stockpiled close to the facility for construction use at a later date, or allow for a change to the mining schedule to excavate such materials as needed thereby preventing the requirement of double handling. In parallel, during cover system design studies it is paramount to ensure that the proposed material thicknesses are achievable. For example, the most promising design may have been proposed without consideration of available material volumes, or their use elsewhere within the mine site, thereby developing a design that will not be constructed. Additionally, if material volumes decrease over time through a refined geochemical understanding or use elsewhere within the mine, it is necessary to revisit the cover system design and assess how a variation will affect the previously predicted performance.

**Cover System Design**

Acid and metalliferous drainage (AMD) is a major environmental problem facing the mining industry today. AMD is the result of the combined chemical and biological oxidation of sulfide minerals and the release of associated metals, such as iron, aluminium, manganese, and other heavy metals. Bare surface waste facilities generally have the highest possible net infiltration (net percolation), therefore the potential for seepage rates for a given material and climate may be substantial and environmentally damaging. As such the use of an engineered cover system may be considered to control atmospheric interactions with reactive waste materials. By constructing a ‘dry’ cover system (i.e. one comprised of soil, growth medium or benign waste rock for example), or a ‘wet’ cover the potential for AMD to be generated at a facility can be limited. The cover system then acts to control the ingress of oxygen to the reactive waste or the infiltration of meteoric water. As such, the design of a cover system can be complex and requires site specific knowledge on various factors that have the capacity to alter the potential performance of a cover system.

It is common practice to construct single or multi-layered engineered cover systems to control AMD from reactive waste materials, such as tailings. Typically there are three principal objectives for a cover system over tailings:
1) to function as an oxygen ingress barrier for the underlying waste material by maintaining a high degree of saturation within a layer of the cover system thereby minimising the effective oxygen diffusion coefficient and ultimately controlling the flow of oxygen across the cover system,

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 storage and release layer, and

3) to provide a medium for establishing a sustainable vegetation cover that is consistent with the current and final land use of the area.

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, non-reactive tailings and/or waste rock, geosynthetic materials, and oxygen consuming organic materials. Factors that control the economic and technical feasibility of a cover system for a particular site include, but are certainly not limited to: site climate conditions; vegetation conditions; soil properties and conditions; waste material properties and conditions; soil and waste material evolution; and surface topography. However, it is also important to put the TSF specifics into consideration of the larger site-wide closure plan. For example, studies may indicate that a multi-layer cover system, represents the best option to limit rainfall infiltration and thus net percolation to reactive tailings materials. However, if the overall site-wide closure plan allows for drainage from the TSF to the mining void, and a pit lake at closure, than it may be advisable to construct a thinner, or single layer cover system in order to minimise salt uptake or surface erosion instead, in addition to reducing potential engineering and construction costs. This concept requires the mine planning to be undertaken in unison across the site, and where targeted studies have been undertaken findings should be discussed within the site wide context for appropriate decision making to be undertaken.

Additionally, a cover system design should consider the potential for material variations and conduct sensitivity analysis to evaluate how a change in the proposed cover materials will affect the required performance. For example a variation in material type may have adverse effects on vegetation establishment; net percolation rate to underlying materials; erosion prevention; and prevention of salt uptake, all which could be considered as closure criteria by a mine site.

**COVER SYSTEM PERFORMANCE MONITORING**

Once a cover system design has been decided upon it is common practice to implement a monitoring system to assess its physical performance at the TSF. This concept allows for a design to be amended as necessary as actual field data is recorded. Additionally it demonstrates that consideration is being paid to the most promising closure option/s and how they may perform in real terms, rather than implementing a design based on numerical models and a limited climate database.

The direct measurement of cover system field performance is considered to be state-of-the-art methodology (O’Kane, 2011). As such, care must be made when designing a system and choosing the number and type of sensors for installation. Performance monitoring trials can be costly to a venture. Costs are in terms of physical sensor costs, and calibration if required, but also on site costs with regards to personnel and plant equipment utilised to construct a trial. Further costs are involved following installation to review the data,
interpret its findings and complete any maintenance to equipment as required. Costs can also be considered in terms of time. Performance monitoring often occurs in excess of five years, and the longer the data has been collected for the greater the volume of information available to inform closure planning and refine designs as necessary. However, the timescales considered must be relevant and acceptable to the mine. With instrumenting waste rock storage facilities a cover system field trial may be compromised if the area is required for further material dumping, or exploration. This thereby quickly terminates data collection where processing and mine planning may overrule closure planning and rehabilitation. Fortunately that is rarely the case with TSFs and as such an area designated for rehabilitation is commonly at its final height and waste volume. However, timescale must be considered within the design and implementation phase.

The performance monitoring data collected can only be considered as good as the instrumentation plan designed and implemented. There are many ways in which a believed successful cover system field trial may later be deemed as having failed, as further described within the following sections.

Incorrect Instrumentation Choice

As with the previous example where the cover system needs to be suited to the site wide closure plan, the instrumentation utilised within a performance monitoring installation must have the capacity to demonstrate the success or otherwise of a given design. It is of particular relevance to focus on a potential weakness that has the capacity to impact on successful rehabilitation and TSF closure. For example, where the cover system’s purpose is to limit net percolation the monitoring should be focused on understanding the movement of water within the cover system itself, in addition to within the upper portion of the tailings waste. As such instrumentation should be appropriate to collecting data relating to moisture and/or matric suction measurements. Monitoring analysis would then look at moisture fluxes across the cover system:tailings interface to understand the localised water balance. This data is further improved with the installation of a meteorological station within close proximity to compare rainfall events with cover system performance and potential for moisture storage.

Poor Installation Methodology

Monitoring equipment is commonly fragile and costly to a project. As such it is paramount that the correct and appropriate installation procedures are followed. Unlike installation within waste rock, which commonly comprises coarse particles with boulders and cobbles present, tailings waste is typically uniform in terms of its particle size distribution. As such installation within tailings material itself may not lead to sensor damage. However, care should be taken within sensor installation within the overlying cover system, in particular with regards to further building the cover profile if the trial is considered on the large scale, utilising run-of-mine plant equipment and construction methods. In addition care should be made to ensure that instrumentation is accurately monitoring the medium they are intended to, rather than a seating or bedding unit they are installed within or on. Where sensors are installed deep within a profile it may only be apparent that there is an issue following installation at a point where excavation and maintenance or replacement is not an option.
Infrequent Data Collection

Following appropriate sensor and instrumentation selection another important aspect of cover system performance monitoring is determining the frequency of data collection. This further emphasises that a successful monitoring plan and design will have clearly defined what the monitoring data will be used for and ultimately how it can potentially effect TSF closure and rehabilitation.

It may be necessary complete data collection from a full sensor profile within a cover system and tailings waste profile at multiple times during a day. Alternatively some equipment may only need to record when a certain event is achieved. Failure to record a critical event or occurrence within the cover system has the potential to prevent the trials success.

Appropriateness to Project Outcomes

As previously described, commonly the use of a cover system is to control atmospheric interactions with reactive tailings waste. As such, this form of cover system should be instrumented to assess oxygen diffusion rates or pore gas concentrations directly. Methods to monitor the infiltration of water were previously discussed.

Following prolonged monitoring an understanding should be developed as to how successful the designed cover system is controlling the atmospheric interactions. With a cover system designed to limit water ingress a further understanding of the moisture storage capacity of the cover system itself can be developed, information which can then feed into vegetation studies.

Data Verification

Whilst it is accepted that performance monitoring can be costly, the success of a project requires that sufficient data is collected and thus any data patterns verified. Often projects might contain one or two detailed monitoring profiles (comprising a high sensor frequency with depth) with a supplementary profiles of reduced sensor frequency or omitting certain sensor types. The secondary profiles allow for an indication of spatial variation to be developed whilst still collecting key performance monitoring data values.

Locations of the primary and secondary stations should be designed as such to reflect any variable conditions that may be present at the facility. For example, required differences in vegetation communities, grain size differences within cover system materials or meso-topographic conditions.

Data Capture Length

It might not be viable for a project to allow long-term performance monitoring at a given site. However, the longer data is collected for the greater the confidence that can be placed on understanding the cover systems’ long-term performance. For example, if data collection is limited to three years, and these coincide with three below average rainfall years, the project must rely on numerical and conceptual models to understand the cover systems’ performance when the potential storage capacity is overwhelmed. This is of particular importance within cover systems utilising the moisture ‘store-and-release’ concept. Additionally, vegetation establishment may play an important role in cover system behaviour and performance. However,
it should be considered that vegetation community development may take a number of years and as such the initial monitoring is not necessarily representative of long-term conditions (Howard et al., 2011). Where a TSF is being progressively rehabilitated data collected after the first three to five years may lead to an alteration within the proposed design for the remainder of the facility. Thus allowing a dynamic closure approach.

MINE SITE EXAMPLES

Conducting a literature review on performance monitoring field trials for cover systems installed at TSFs produces a minimal number of publically accessible data, when compared to cover systems installed at waste rock storage facilities. However, a limited number of sites have been previously compared in technical proceedings (for example Robertson and Swane, 2008). Data presented within this section has been collected from unpublished sites and is discussed in literal terms for context to this paper.

Case Study #1: Poly metallic mine, Australia

A poly metallic mine in Australia constructed two cover system field trials at its TSF to develop an understanding of how different cover materials responded to long-term moisture cycling. Both cover profile configurations had been initially numerically modelled to provide an assessment of predicted performance over a range of climate events. The first profile comprised a growth medium, underlain by a low permeability unit and finally benign waste rock over reactive tailings waste. The second profile comprised the same materials but each with an overall thinner profile, and also omitted the low permeability unit (Figure 1). Both trials comprised two primary sensor nests, comprising a thorough coverage of sub-surface hydrological monitoring (including soil moisture content, matric suction and temperature). A third (secondary) profile was installed at both trials, but only monitored soil moisture content changes. Additional instrumentation commissioned comprised runoff monitoring instruments and a fully automated meteorological station.

Data has been collected for nearly 10-years, and fortunately has experienced a range of climate events including well-below average and well-above average rainfall years, in addition to several where rainfall was experienced outside of the typical seasonal pattern to be expected for the site’s location. As such, a wealth of knowledge exists regarding the cover system’s response to climate variations, in addition to the cover system evolution overtime following natural vegetation development, animal disturbance and surface erosion. In parallel with other studies, the data collected has allowed the mine to make informed decisions regarding closure planning and rehabilitation at its TSF, and subsequently revise the previous closure concept.

Since the monitoring equipment was commissioned the overall combined average data capture rate has been in excess of 90%. The high value is attributed to regular routine maintenance and data acquisition and review to investigate the presence of any anomalies within the recorded values.

Figure 2 illustrates the cumulative change in the volume of water measured at all three profiles for both cover systems monitored during a certain period within the trials’ history. As depicted, the data gives a clear indication of cyclic seasonal variation within each respective cover system profile. Additionally, the cover system’s response to large events can be easily seen allowing for a developed understanding of what
volume of rainfall, or series of events, are required for storage capacity to be overwhelmed and net percolation occur. At this project site the water content data collected was used to back-calculate the analytical water balance using other water balance components measured at the field trials. The procedure used is further described within Meiers et al, 2012. The respective water balances were used to provide an accurate estimate of net percolation values on a yearly basis, thereby adding a further understanding of each respective cover system’s performance.

The actual performance of cover systems using site specific field data can be further used to evaluate predicted long-term performance through field calibration methods, for example as undertaken at mine sites

**Case Study #2: Poly metallic mine, Australia**

It has been proposed that as part of initial closure planning of a TSF at a poly metallic mine site in Australia a cover system field trial will be established within a portion of the facility as the TSF landform is progressively closed. This method will allow for a field assessment of the proposed cover design performance and if necessary, provide sufficient time for amendments to the overall design to be made prior to the final closure of the facility.

Following completion of tailings placement a cover system will be constructed as per a design previously prepared. A large scale field trial is then to be constructed in order to directly measure the performance of the cover system and gain field information on the hydrologic performance of preferred cover design through installation of automated monitoring systems. Performance of the cover system field trial will be monitored for a minimum of three years before proceeding to cover system construction over the remaining TSF footprint. Field data obtained will also be used to calibrate the original numerical model developed in the design phase in order to improve the confidence in the predicted long-term average net percolation rate for the TSF cover system. Where necessary data obtained can be used to refine the cover system design.

The field trial will also allow for assessments of: consolidation and settlement of tailings; draindown rates; erosion; vegetation establishment and behaviour, catchment characteristics and seepage quality in addition to monitoring specific cover system evolution with time. Data can be used to demonstrate cover system performance to stakeholder and regulatory bodies, in addition to providing confidence within the proposed design prior to full implementation at site.

**CONCLUSIONS**

Where a cover system is to be constructed at a TSF for rehabilitation and closure it may be considered advisable to install performance monitoring equipment. With this approach over time a real understanding can be developed with regards to: 1) how the cover system is performing; 2) how the cover materials are evolving with time and physical, chemical and/or biological changes to the profile; 3) how the design may need to be refined to achieve the most promising closure outcome for a site. It is acknowledged that performance monitoring equipment and ongoing monitoring and data interpretation can be costly, and as such highlights why care and consideration must be taken when designing the trial and physical equipment installation.
REFERENCES


FIGURE CAPTIONS
FIG 1 – Illustration of two cover system profiles constructed and monitored at Case Study #1

FIG 2 – Cumulative change in water storage at two cover systems monitored at Case Study #1
FIGURES

FIG 1 - Illustration of two cover system profiles constructed and monitored at Case Study #1.

FIG 2 - Cumulative change in water storage at two cover systems monitored at Case Study #1.