Field-scale trials of cover system designs

Implications for Leading Practice

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- Failure to effectively manage risks associated with AMD significantly impacts the ability of a minesite to transition to a post-closure scenario.
- A field-scale trial of the preferred cover system design is an important step towards demonstrating whether post-closure outcomes can be achieved.
- Field-scale trials inform the final design of a cover system by providing important information regarding the constructability and performance of the design to achieve its objectives.
- Priority should always be given to source control as the primary method for mitigating AMD generation. In most cases, application of a cover system to the landform's surface will reduce contaminant loading and seepage quantities and delay contaminant loads leaving the site but will not eliminate the potential for AMD generation and seepage.
- While not addressed in our suite of Technical Papers, important interactions between the final landform design, material properties, climate, the applied cover system, vegetation and post-mining land use exist and must be understood.

Background

Mitigation of Acid and Metalliferous Drainage (AMD) at mine sites requires early and ongoing intervention throughout the life of a mine and is supported by a series of management actions. With the assistance of Environmental Geochemistry International (EGi) and other technical experts we have developed three Technical Papers, focused on one such AMD management action: how to approach the task of designing a cover system and undertake a trial of the design at field-scale. The first two papers (Zappala et al. 2025; Dunlop et al. 2025) constitute a two-part review of information pertaining to field-scale trials of cover systems. The final paper (Nicolson et al. 2025) describes how to conduct a field-scale trial focussed specifically on Queensland conditions, but drawing from national and international publications, guidance material and case studies.

Starting at the earliest phases of mine planning, the risks associated with AMD should be determined, and then continually assessed throughout the life of mine. Failure to effectively mitigate AMD generation (or manage existing AMD seepage) is recognised as a barrier to closure and relinquishment, and will establish substantial residual risks and ongoing liabilities such as water treatment or active control of water discharges (INAP 2024). As evidenced by the regular citation in all three of the Technical Papers, the International Network for Acid Prevention (INAP) and Mine Environment Neutral Drainage (MEND) have published several authoritative documents (INAP 2009, 2017, 2020, 2025; MEND 2004) regarding a holistic approach to AMD mitigation and management, and these have informed our assessment.

Sole reliance on cover systems as the only solution to manage AMD issues does not meet leading industry practice and should be avoided. Applying a cover system across the surface of a mine waste landform helps to limit the generation of AMD seepage and its impacts on the receiving environment. However, cover systems rarely reduce seepage to nil, have a design life (i.e. they cannot be expected to work forever) and require ongoing maintenance post closure. For circumstances where sulfidic material has been exposed to oxygen and water, and without immediate actions taken to mitigate generation of AMD; poor quality seepage is inevitable and the application of a cover system at a later stage will only reduce the expression of AMD from the landform, not eliminate it. As identified in Nicolson et al. (2025), INAP (2020) has published six improved construction methods related to source control, some of which can be applied retrospectively to existing mine waste landforms.

Trialling cover system designs

As evidenced in Zappala et al. (2025) and Dunlop et al. (2025), there are many sites where a cover system design has been trialled, or where a constructed cover system has been monitored to determine its performance. Our intent was to inform ourselves on the topic of cover system trials by reviewing the literature, elucidating how sites have previously undertaken trials, identifying reported modes of performance failure, and distilling this information into a practical approach for designing a site-specific cover system and advancing a preferred design to trial at field-scale.

The cost to design, trial, construct and maintain a cover system at scale is significant and requires substantial resourcing. A field-scale trial is an exercise not often repeated by a mine operator and therefore must be well planned and executed to ensure valuable information is obtained to inform the final cover system design. Despite the challenges, field-scale trials remain an important step to test the performance and constructability of a preferred design. Nicolson et al. (2025) seeks to assist this task by advancing a consistent, Queensland-focussed approach for trialling a cover system design. There remain issues not addressed by this body of work such as, the challenges to undertake trials, how to increase shared knowledge and experience regarding cover systems across industry and government, and advancement of management strategies for AMD risks to ensure environmental harm is mitigated.

As part of our investigation, we spoke with other Australian jurisdictions who advised they, and their industry members, face similar issues to those we identified in Queensland. Issues such as limited visibility of trials, poor sharing of learnings and outcomes, difficulty in managing/mitigating AMD risks, the challenging and complex environments within which trials are undertaken, the role of cover systems beyond closure and post-mining land use interactions, the time required to demonstrate a cover system is performing, and challenges in monitoring for these long periods of time were identified.

An approach to develop the most appropriate design and test at field-scale

The approach presented in Nicolson et al. (2025) is designed to ensure the costs and practicalities associated with undertaking trials do not hinder sites from routinely undertaking trials of reasonable duration and size. It is based on the following assumptions:

- Most mines in Queensland at risk of AMD generation are in climatic zones where evaporation exceeds precipitation. Therefore store-and-release covers are the default design discussed and reduction in net percolation (NP) is the key performance measure. We do not suggest other cover systems may not be considered.
- As it cannot be assumed that a trial will experience the necessary weather events to develop seepage, water flux models are used to predict NP rates; and wherever possible, trial monitoring data used to validate and inform model inputs.
- The establishment of vegetation and its influence on cover system performance is not specifically required. This provides a conservative approach where vegetation is not relied on as critical to the function of the cover design.
- The importance of ‘front-loading’ a trial with a detailed understanding of site-specific conditions and baseline information, and then escalation of effort to culminate in a field-scale trial of the preferred design is recognised. This will require that several designs are considered, modelled and preferably tested at bench or mesoscale prior to the selection of the preferred design(s) to trial at field-scale.
- The primary reasons for undertaking a field-scale trial –
    - validating the water flux model used to develop the cover system design

- testing the constructability of a design. As a result, the trial must be built at a scale that uses the same materials, machinery and construction techniques required to construct the cover at full-scale
- verifying whether the proposed cover design is effective in meeting its objective and refine or reject the design.

Good modelling practice is critical to the approach. This includes identifying the objectives of the modelling exercise, justifying the selection of model type and calibration method, extensive model testing (including field validation, sensitivity analysis and peer review of the model) and description of the model's limitations and assumptions (State of Queensland 2018).

We recognise that during trial conditions, any vegetative groundcover that develops will protect the surface from erosive processes and any rate of vegetation growth contribute to the performance of the cover system. However, when considering the evapotranspiration (ET) component of the water balance on a cover system, the contribution by vegetation (i.e. via transpiration) has been demonstrated as negligible in water-limited climates where vegetation cover is low, and plants are shallow-rooted (Arnold et al. 2015; Gwenzi et al. 2014; Garcia et al. 2008). A further consideration is that a specific rate of vegetative cover is not guaranteed in either trial or final landform conditions and testing a system without the contribution of vegetation to ET presents a necessarily conservative approach. Therefore, to facilitate a practical, cost-effective and relatively short-duration field-scale trial, the role of vegetation upon the performance of the store-and-release cover system in these types of climatic conditions is not tested by our approach.

The definition of AMD applied here includes neutral and saline drainage as well as acid drainage. While the literature and case-study reviews presented in Zappala et al. (2025) and Dunlop et al. (2025) are largely focussed on acid drainage from metalliferous mines, Queensland coal wastes (e.g. spoil, rejects and tailings) can be prone to generating saline drainage. The approach presented in Nicolson et al. (2025) can be applied across all types of commodities and drainage. In some circumstances, the cover system design objectives and site-specific information developed early in the approach may determine that a different type of cover system design is required and an alternate performance measure to NP identified. Regardless, the principles outlined in each step of the leading practice approach will apply.

Failure modes identified from case studies

Of particular interest are the cover system failure modes identified in several case studies (Dunlop et al. 2025). Reflecting on the commonly reported modes of failure, we can see the importance of foundational principles such as:

- rigorous and ongoing materials characterisation
- a systematic approach to the development and selection of the most appropriate cover system design
- adherence to quality assurance and quality control procedures to ensure materials are fit for purpose and construction achieves the required specifications.

Failure to construct a cover system in accordance with the design was identified as a common issue during autopsy style investigations, initiated sometime after the cover system had been constructed and lagging indicators such as poor vegetative growth or AMD seepage emanating from the landform were observed. The various failure modes and foundational principles identified from case studies are important learnings which inform leading practices for cover system design and implementation.

Concluding remarks

An appraisal of the performance of a final landform must be holistic and consequently, is multi-faceted. This requires consideration to the way a landform is constructed, how materials are selectively handled and placed, geotechnical and erosional stability, climatic influences, the impact of vegetation on surface stability and cover system performance, potential impacts (such as exacerbated erosion) resulting from the post-mining land use on the cover system, hydrogeochemical generation of AMD and solute movement within the landform (salts, metals and metalloids), ongoing seepage collection and treatment, and consolidation of the landform and cover system, to name a few. A site-specific understanding of these interactions is essential but was outside the scope of our project.

There are no widely accepted criteria for NP or other performance measures (e.g. rates of oxygen ingress) for cover system designs. The only reference we detected (and consequently recommended in Nicolson et al. 2025) was in the Cover System Design Tool which describes how to ascertain a site-specific climate classification, and then identify related quality performance criteria for solubility control (INAP 2017: Appendix A). We are aware of reported inconsistency in performance objectives used to design systems across various mine sites in Queensland (DETSI, personal communications, 23 January 2025). Such a situation serves to highlight the importance of undertaking site-specific risk assessments to understand potential impacts from AMD on receiving environments. A risk-based approach, starting with a conceptual site model and iteratively applied as more detail regarding waste material and site-specific conditions becomes available, provides the opportunity to determine the degree to which AMD products need to be managed to prevent impacts, which in turn influences cover design. It also brings into focus the role of clearly stated objectives for the cover system in guiding the development and construction of the final cover system design.

Ensuring a cover system is fit for purpose and achieves its objectives requires time and commitment from the miner. Nicolson et al. (2025) outlines a process which can be followed for the early stages of cover system development, including testing of the design via a field-scale trial. This must happen prior to full-scale construction and the subsequent monitoring and management actions necessary to achieve closure approvals. The trial methodology presented is designed to demonstrate the performance of a cover system but does not guarantee a ‘successful’ cover system that meets a particular regulatory standard.

Considering the challenges associated with undertaking a field-scale trial, commitment and vision from all stakeholders is critical to success. However, a rigorous and consistent approach to develop and trial cover system designs, combined with active and persistent AMD management strategies across the whole of mine life, will improve the resilience and performance of final cover systems and mine waste landforms.

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