

Mine waste cover system trials
– a leading practice approach
for field-scale trials in
Queensland
Technical Paper 3



Prepared by: Environmental Geochemistry International (EGi) on behalf of the Office of the Queensland Mine Rehabilitation Commissioner

© State of Queensland, 2025.

The Queensland Government supports and encourages the dissemination and exchange of its information. This work is licensed under a Creative Commons Attribution 4.0 International License.



Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland as the source of the publication.

For more information on this licence, visit <https://creativecommons.org/licenses/by/4.0/>

Disclaimer

This document has been prepared with all due diligence and care, based on the best available information at the time of publication. The Office of the Queensland Mine Rehabilitation Commissioner holds no responsibility for any errors or omissions within this document. Any decisions made by other parties based on this document are solely the responsibility of those parties. Information contained in this document is from a number of sources and, as such, does not necessarily represent government or departmental policy.

The Queensland Government is committed to providing accessible services to Queenslanders from all culturally and linguistically diverse backgrounds. If you have difficulty in understanding or accessing this document, you can contact us for assistance and we will arrange for this publication to be made available in an alternative format.

Citation

Nicolson L, Dunlop J, Stewart W and Volcich A (2025) *Mine waste cover system trials – a leading practice approach for field-scale trials in Queensland: Technical Paper 3*, Office of the Queensland Mine Rehabilitation Commissioner, Queensland Government, Brisbane.

Acknowledgements

The authors wish to acknowledge Professor David Williams, Professor G. Ward Wilson, Professor Mansour Edraki and Gilles Tremblay for their assistance in developing this paper.

This Technical Paper was funded by a grant from the Financial Provisioning Scheme which supports research into mine rehabilitation.

July 2025

Version history

Version	Date	Description of changes
1.0	12 June 2025	Original publication
1.1	18 July 2025	OQMRC branding, copyright and accessibility information updated

We regularly review our leading practice advice, which can result in updates to our publications. To access superseded versions of our publications, visit the Queensland Government's [library catalogue](#).

Contents

Contents	i
Figures	ii
Tables.....	ii
Executive Summary	1
1 Introduction	2
1.1 Field-scale trials inform overarching AMD management strategies	3
1.2 Store-and-release cover systems	4
2 Leading practice approach to undertake a cover system trial	5
2.1 Scope of the leading practice approach.....	6
2.2 Record management system	6
2.3 Step 1. Determine cover system objectives and design options	6
2.3.1 Identify cover system design objectives	7
2.3.2 Collect baseline information on the site and cover/waste materials	7
2.3.3 Model cover performance to identify cover design(s) suitable to trial at field-scale.....	8
2.3.4 Prepare design and construction specifications for the cover system to be trialled	11
2.4 Step 2. Plan field-scale trial	12
2.4.1 Objectives for the trial.....	12
2.4.2 Determine trial design	12
2.4.3 Location	13
2.4.4 Size.....	13
2.4.5 Duration	14
2.4.6 Design the monitoring system	15
2.5 Step 3. Undertake field-scale trial	17
2.6 Step 4. Refine design based on trial outcomes	18
2.7 Step 5. Report on trial	19
3 Conclusion	21
4 References.....	23
Appendix A.....	25

Figures

Figure 1. Covers and climate types (modified from Holdridge et al. (1971) by INAP (2009))	2
Figure 2. Conceptual illustration of net percolation O'Kane et al. (2002)	5
Figure 3. The 5-step process to undertake a leading practice field-scale trial of a cover system	5
Figure 4. Trial scenario with approximately 15% NP	10
Figure 5. Trial scenario with approximately 1% NP	10

Tables

Table 1. Recommended content for a report on the design and implementation of a mine waste cover trial.....	20
---	----

Executive Summary

The management of acid and metalliferous drainage (AMD) from mine waste has been the subject of international research and management actions given its widespread persistence and deleterious environmental impacts. Cover systems have become a critical element of AMD management. However, in Queensland, the long-term performance of cover systems in abating AMD has not been conclusively demonstrated. The Office of the Queensland Mine Rehabilitation Commissioner (OQMRC) has received anecdotal feedback of cover system failures and varying reports of cover performance from stakeholders. One critical element of cover system performance is the execution of high quality cover trials to design and test their performance and construction.

To develop a focused, practicable methodology to undertake cover trials, OQMRC has undertaken a literature review of trial methodologies (Technical Paper 1), examined case studies on cover trials and cover performance monitoring (Technical Paper 2) and developed a trial methodology for application to the Queensland environment (Technical Paper 3). The trial method recommended in Technical Paper 3 describes how to plan and implement reliable cover trials to support AMD management in Queensland in a pragmatic and cost-effective manner that avoids prescribing excessive requirements. The method applies store-and-release cover design principles and is focused on the primary AMD transport mechanism of net percolation. The work draws on the globally established AMD literature addressing whole-of-mine-life AMD management, including the Global Cover System Design – Technical Guidance Document (INAP 2017) and Global Acid Rock Drainage (GARD) Guide (INAP 2009), and distils those critical elements for undertaking high quality trials tailored to the Queensland operating environment.

Cover design is influenced by a range of factors such as the prevailing climate, materials available to construct the cover and risk of mobilising contaminants and their potential impact on the environment. The cost of constructing a mine waste cover at a large scale in remote locations can be considerable.

A store-and-release style cover is appropriate for most locations in Queensland where evaporation exceeds rainfall. These systems are designed to store infiltrated water within the root zone, allowing the water to be released later by evapotranspiration. By returning infiltrating water to the atmosphere, deep percolation of water is minimised thereby preventing transport of contaminated seepage to the receiving environment.

Evaluation of alternate cover system designs is an important step necessary to develop the final, site-specific cover system design. Trials can demonstrate the performance of different cover designs and configurations and assess the performance of various components of the cover independently and the cover system as a whole. A trial also provides an opportunity to collect field data to calibrate and validate the numerical models used to inform the design of covers. Studies may also be aimed at confirming the criteria for the design of the final landform cover and evaluate the practical constructability of covers.

We consider a field-scale trial to be a series of test cells constructed as would a full-scale cover system. A trial may be undertaken on either existing landforms or in purpose-built cells located on the mine site to control AMD from sulfidic materials stored as tailings, in waste rock dumps or heap leach pads.

Using the leading practice approach, a field-scale trial will follow the steps below:

- Step 1 – Determine cover system objectives and design options (identify cover objectives, collect baseline information, model cover performance and identify a suitable cover design for a field-scale trial, prepare construction specifications).
- Step 2 – Plan the field-scale trial (identify trial objectives, determine the trial design, choose a suitable location, determine trial location and size of test cells, set study duration, and design the monitoring system).
- Step 3 – Undertake the field-scale trial (construct and monitor).
- Step 4 – Refine the design based on trial outcomes.
- Step 5 – Report on the trial.

Broader aspects of cover system design are also addressed within this paper if they are required to ensure a high quality trial. The approach focusses on presenting a strategy to develop a series of cover system design options, identify the most appropriate design and progress that design to a field-scale trial to test its constructability and importantly, performance in reducing net percolation.

1 Introduction

Mining generates substantial volumes of waste rock and tailings. Rehabilitating mine waste, whether held in tailings storage facilities (TSFs), waste rock dumps (WRDs) or heap leach piles (HLPs), remains a critical challenge for the mining industry in Queensland. Where waste rock and tailings contain sulfidic materials and are exposed to air and water, the challenge to rehabilitate these structures is amplified by the potential for Acid and Metalliferous Drainage (AMD) to develop.

The management of AMD from mine waste has been the subject of international research and management actions given its widespread persistence and deleterious environmental impacts. Cover systems have become a critical element of AMD management. However, in Queensland, the long-term performance of cover systems in abating AMD has not been conclusively demonstrated. The Office of the Queensland Mine Rehabilitation Commissioner (OQMRC) has received anecdotal feedback of cover system failures and varying reports of cover performance from stakeholders. One critical element of cover system performance is the execution of high quality cover trials to design and test their performance and construction.

The climate and/or water balance influences the approach to cover control strategies (Figure 1) with the focus on:

- oxidation flux control where precipitation exceeds evaporation
- water flux control where evaporation exceeds precipitation.

Most mine sites in Queensland are in regions where evapotranspiration exceeds rainfall and hence focus on water flux control is most appropriate. In such climatic conditions, it is difficult to maintain saturation in a cover system and prevent oxygen flux and hence AMD generation. As a result, the common types of mine waste covers used in Queensland are 'store-and-release' and 'water-shedding' cover systems (or a combination of the two). The intent of these types of cover systems is to control net percolation (NP). NP is defined as water that migrates into and downward through the material profile to depths not influenced by atmospheric processes (i.e. evapotranspiration) (O'Kane et al. 2015). At a minimum, the design and monitoring of a trial for a store-and-release or water-shedding cover should focus on NP as a key measure of performance.

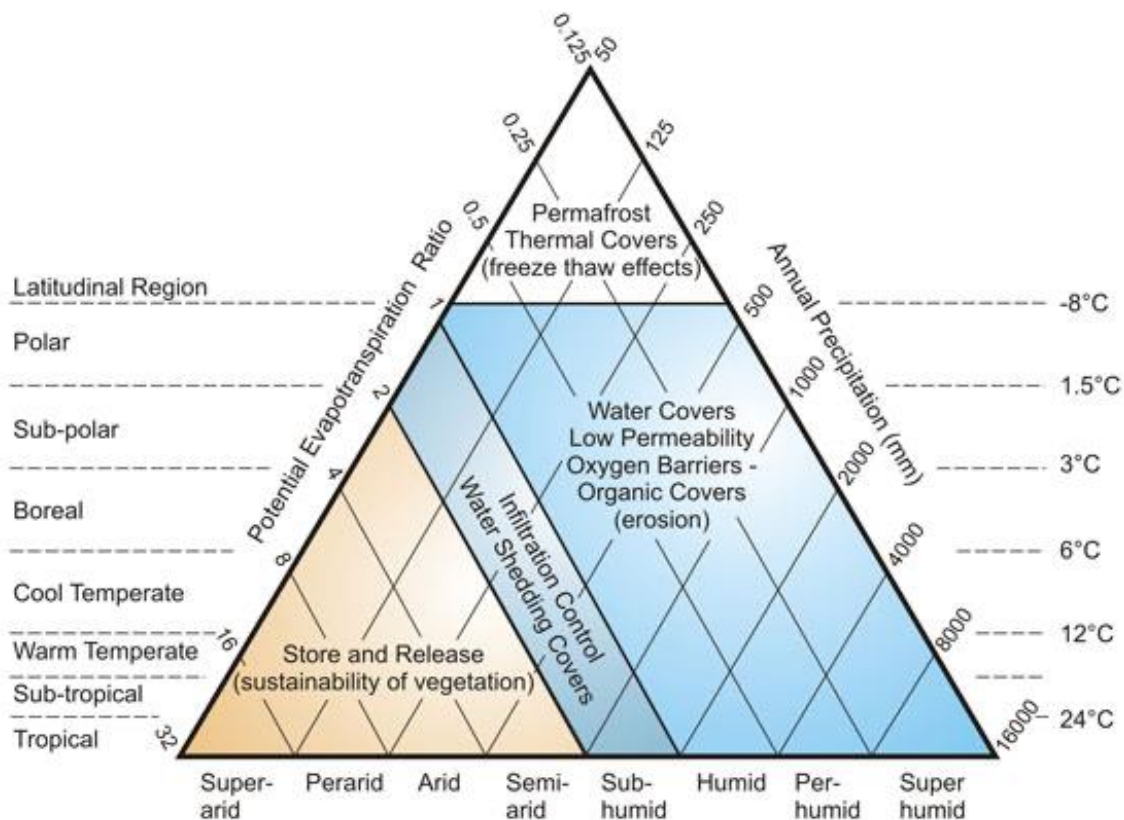


Figure 1. Covers and climate types (modified from Holdridge et al. (1971) by INAP (2009))

In Queensland and globally, there are many examples where the strategy of using a mine waste cover system has failed to adequately reduce or prevent AMD, resulting in ongoing impacts to the environment. The cause of failure can vary but common issues include delayed installation, a lack of proper materials characterisation, the use of an inappropriate cover system design or a failure to properly construct the cover system (Dunlop et al. 2025).

Trials are commonly used to develop, compare and refine options for mine waste cover designs. To develop a focused, practicable methodology to undertake cover trials, OQMRC has undertaken a literature review of trial methodologies (Technical Paper 1), examined case studies on cover trials and cover performance monitoring (Technical Paper 2) and developed a trial methodology for application to the Queensland environment (this paper, Technical Paper 3). The method recommended in this Technical Paper describes how to plan and implement reliable cover trials to support AMD management in Queensland in a pragmatic and cost-effective manner that avoids prescribing excessive requirements. The method applies store-and release cover design principles and is focused on the primary AMD transport mechanism of net percolation. The work draws on the globally established AMD literature addressing whole-of-mine-life AMD management, including the Global Cover System Design – Technical Guidance Document (INAP 2017) and Global Acid Rock Drainage (GARD) Guide (INAP 2009), and distils those critical elements for undertaking high quality trials tailored to the Queensland operating environment.

Broader aspects of cover system design are also addressed within this paper if they are required to ensure a high quality trial. The approach focusses on presenting a strategy to develop a series of cover system design options, identify the most appropriate design and progress that design to a field-scale trial and test its constructability and importantly, performance in reducing NP.

1.1 Field-scale trials inform overarching AMD management strategies

Where mine waste covers are properly planned, designed and installed early during operations they can help to limit the generation of AMD. Although mine waste cover systems provide a useful way to reduce AMD risks, they should not be considered as a solution on their own. Instead, mine waste covers should be used as part of a broader strategy to manage AMD across the life of a mine where potentially acid forming (PAF) material is identified and handled selectively to reduce the footprint of PAF materials. Leading practice methods to prevent and mitigate AMD throughout the various phases of mine life are discussed in Section 6.6 of the GARD Guide (INAP 2009).

Controlling the source of AMD reduces the quantity of AMD seepage that can be generated. Source control strategies focus on minimising reaction rates, leaching and migration of AMD (INAP 2009). For example, PAF materials must be selectively placed to minimise the 'work' that the cover itself must perform over long periods of time. INAP (2020) outlines six improved construction methods for mine waste stockpiles, aimed at improving the resultant water quality emanating from these structures by implementing key source control methods. In that report, a discussion is also provided as to how some of these improved methods may be retrospectively applied to existing stockpiles.

The Australian Government (2016) states that field-scale trials are necessary to confirm long-term performance of cover designs as predicted by numerical modelling studies. Trials may be required by regulatory authorities or be undertaken independently by mining companies during mining to define cover designs. Trials can demonstrate the performance of different cover designs and configurations and assess the performance of various components of the cover independently and the cover system as a whole. A trial also provides an opportunity to collect field data to calibrate and validate numerical models used to inform the design of covers. Studies may also be aimed at confirming the design criteria for the final landform cover and evaluate the practical constructability of covers.

Mine waste cover trials provide an opportunity to validate the modelling used to design the cover. Trials also provide an opportunity to test the constructability of the cover design. There is no specific number of cover options or variations to include in a trial. However, the Queensland Government 'strongly recommends multiple alternate cover systems are trialled' (DESI 2023a:28). The Cover System Design Tool (INAP 2017) describes two types of field trials – pilot and prototype. Each type runs for a three to five-year period and both are identified as important steps when designing and implementing a cover system. In the design tool, prototype trials are described as being permanent, constructed using commercial scale equipment, intended to optimise the process for full-scale deployment and provide sufficient confidence to progress the design to full cover construction. An example of a prototype trial could be the construction of a cover on one section of a mine waste structure.

In summary, while field-scale trials are the focus of this Technical Paper, it is important to note they are one component of the continuum of practice necessary to develop, implement and monitor a cover system.

1.2 Store-and-release cover systems

The Global Cover System Design – Technical Guidance Document (INAP 2017) describes various types of cover systems and when/where different systems are appropriate for a mine site. Selection of the appropriate system is largely determined based on:

- the climate zone (using a modified Köppen system)
- the necessary geochemical control (i.e. kinetic – oxygen control and/or solubility – net percolation control)
- cover material characteristics/availability.

Based upon the approach presented in Figure 1, a ‘store-and-release’ cover design is commonly used at Queensland sites and accordingly is the focus of the recommendations on how to undertake trials described in this paper. This includes ‘enhanced’ versions where a variety of layers are included in the design to introduce textural discontinuity. Store-and-release designs are typically suitable where evaporation significantly exceeds precipitation (e.g. evaporation equal to 2- or 3-times precipitation).

The amount of water that percolates through a cover system and into the waste material is measured as net percolation (mm/year) or net percolation percent (volume of water from the cover layer(s) into underlying waste materials as a proportion of rainfall) (Figure 2). Store-and-release cover systems are used to limit NP. These systems are designed to store infiltrated water within the root zone, allowing the water to be released later by evapotranspiration. By returning infiltrating water to the atmosphere, deep percolation of water is minimised thereby mitigating transport of contaminated seepage to the receiving environment. In climates where high intensity, short duration rainfall events typically occur and can overwhelm the storage capacity of the cover design, the design is enhanced by adding layers such as capillary breaks and infiltration barriers to assist in preventing breakthrough of percolated water into the underlying waste material and provide a factor of safety for high rainfall events. A capillary break also helps to prevent water wicking to the surface from the buried waste bringing with it salts and other contaminants. A design which is focussed on achieving the required store-and-release capacity can also have water shedding capabilities allowing excess water to be released from the landform during high-intensity rain events as lateral interflow or as surface runoff (INAP 2017).

Cover systems are engineered structures and as such have a design life, which MEND (2012) recommends to be 100 years as a minimum, noting this period is subject to other factors such as regulatory requirements. The design tool presented in INAP (2017) discusses the monitoring assessment period and distinguishes it from the cover system’s design life. The monitoring assessment period commences upon construction of field trials, is focused on monitoring the performance of the cover system and will generally continue after closure.

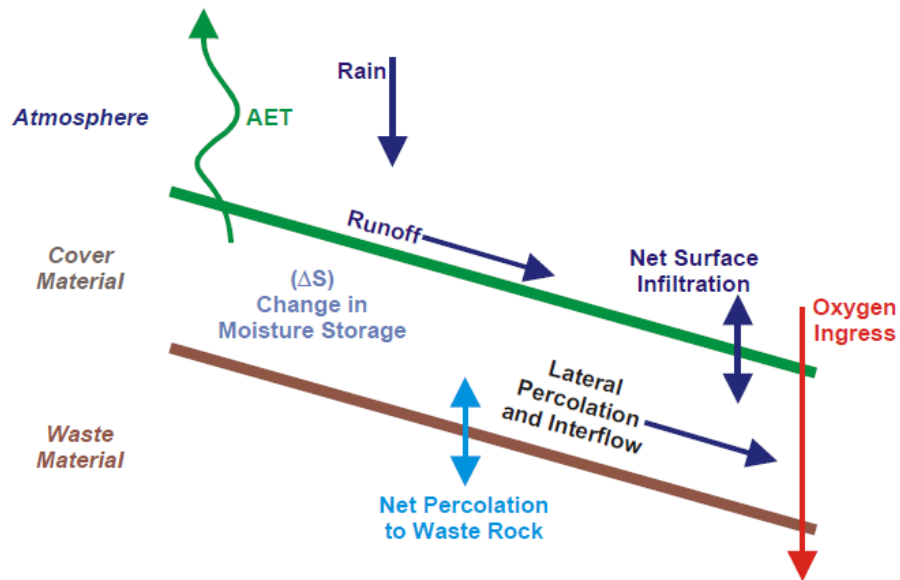


Figure 2. Conceptual illustration of net percolation O’Kane et al. (2002)

2 Leading practice approach to undertake a cover system trial

Evaluation of alternate cover system designs is an important action necessary to develop the final, site-specific cover system design. Prior to the actual commencement of a field-scale trial, there are several early steps critical to underpin the tested design(s). An extended period may be necessary to identify AMD processes at field-scale level. As such, trials may need to be set up many years prior to closure activities (Australian Government 2016).

We propose a 5-step process (Figure 3) as the leading practice approach to undertake a cover system trial at a field-scale. The information gathered in each step of the 5-step approach must clearly demonstrate the rationale for design choices made in subsequent steps. A summary of the leading practice approach is provided as a checklist in Appendix A. The five steps are explained in subsequent sections.

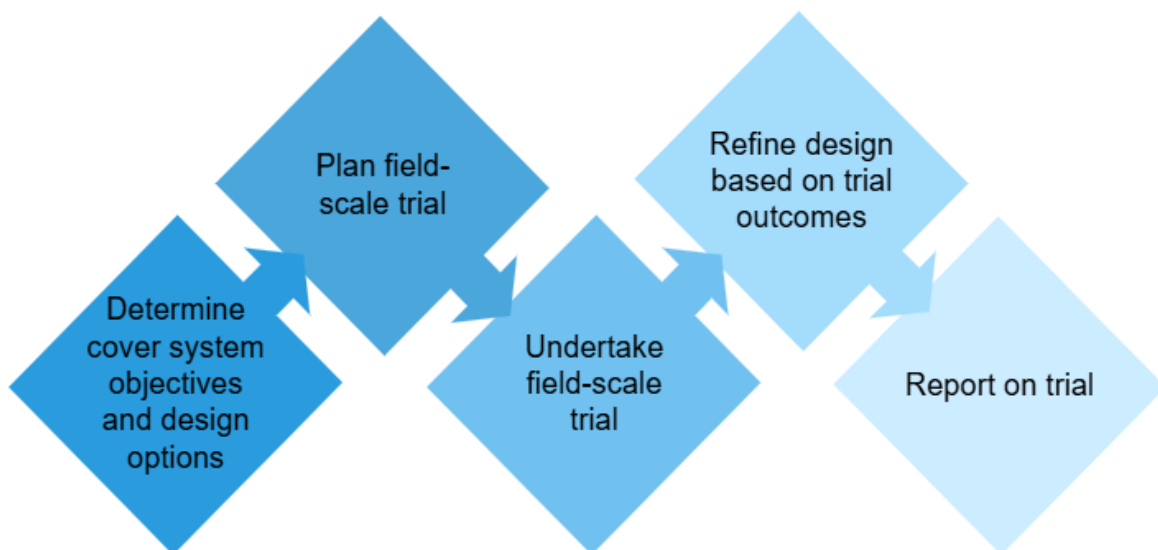


Figure 3. The 5-step process to undertake a leading practice field-scale trial of a cover system

2.1 Scope of the leading practice approach

In the leading practice approach presented in this paper, a field-scale trial is defined as being similar in scale and aspiration to the prototype trial outlined in the Cover System Design Tool (INAP 2017). Here, a field-scale trial is a series of test cells constructed as would a full-scale cover system. A trial may be undertaken on either existing landforms or in purpose-built cells located on the mine site to control AMD from sulfidic material stored as tailings, in WRDs or HLPs.

Using NP as the key performance measure in this Technical Paper is not intended to limit trial design, which may consider other variables, such as erosional stability, where necessary. NP influences the quality and volume of seepage generated from a waste structure and its potential impact on the receiving environment. The presence of vegetation and surface roughness across the cover system will affect the in situ water content within the cover, impacting NP rates and ultimately cover system performance (INAP 2017). However, there is evidence that for water-limited conditions such as that experienced in semi-arid and arid climates, the relevance of plants upon evapotranspiration is limited (Arnold et al. 2015). Although vegetation can affect the performance of covers, particularly in the long-term, for example where plant roots can negatively impact a reduced permeability layer, the approach presented here does not focus on measuring the impact of vegetation to meet NP objectives. Often, in water-limited conditions, vegetation may not establish during a trial and under these circumstances its influence on performance would not be properly tested.

The approach presented in this Technical Paper does not include an assessment of the resistance of the landform to erosion, solute transport and impacts upon receiving surface and groundwater environments, geotechnical stability of landforms, whether topsoil material can support vegetative growth, or the composition and characteristics of vegetation necessary to achieve the post-mining land use (PMLU). It is acknowledged that these factors are critical to the successful performance of mine waste structures in addition to the key objective for a cover system (in Queensland) to control NP.

2.2 Record management system

Prior to commencing this leading practice approach, a record management system must be developed and implemented. Good record keeping describing a rigorous scientific process is important for a number of reasons. It will:

- Allow third parties to understand the methodology used to develop the cover system design taken to trial at field-scale.
- Provide evidence of quality assurance and quality control (QA/QC) processes which in turn, allow for the performance of the cover system options to be interpreted with confidence.
- Allow for construction techniques from the field-scale trial to be reviewed and modified to inform full-scale construction methodologies.
- Allow deployment of monitoring data collected during the trial to calibrate models.
- Post completion of the trial, it will provide evidence to support the performance of the recommended cover design option and inform long-term performance monitoring.

Recommendation:

- Develop and implement a record management system for each step of the leading practice approach.

2.3 Step 1. Determine cover system objectives and design options

The first step in the process is to identify and describe the cover design or series of designs to test at field-scale. The process to arrive at a suitable cover design for testing at field-scale requires firstly, defining the objectives for the cover, collecting baseline information about the site and materials available to construct a cover, and undertaking modelling in an iterative way to simulate and predict the performance of covers to check if a proposed design will meet its performance objectives.

2.3.1 Identify cover system design objectives

The objectives of a proposed cover design need to be stated upfront, prior to undertaking trials (DESI 2023a). Objectives for mine waste covers can vary widely. In broad terms, the objective for rehabilitation is to make areas disturbed by mining safe, stable and non-polluting. For a mine waste structure this requires physical and chemical stability. Regulatory settings in Queensland require consideration of protection of the environmental values of surface and groundwaters (Schedule 8 Part 3 of the Environmental Protection Regulation 2019 (Qld)) and that cover systems are designed appropriate to the type of waste generated by the mine and reflect a risk-based approach (DESI 2023b).

Cover system design is ultimately part of the process to design for closure. As such, defining the closure scenario(s) is an important part of determining the design objective for a cover system.

Understanding potential impacts to receptors is a key consideration when determining cover design objectives and closure targets. A site-specific Conceptual Site Model (CSM) should be developed to describe the release, transport and fate of contaminants (INAP 2014). The CSM should be informed by an understanding of the water quality and environmental values of the receiving environment in the catchment.

Reducing net percolation will result in reduced geochemical loading of AMD products leaching from the mine waste landform. There is no universally accepted level of NP within industry or regulatory guidance. The rate of NP adopted as an objective for a waste cover may depend on factors such as the level of protection required, solubility and mobility of contaminants and the likelihood and consequence of impact in the receiving environment. INAP (2017:24) suggest that an objective for waste cover design is to 'reduce NP into the waste to reduce contaminant loading to surrounding water bodies to an acceptable level'. The Cover System Design Tool (INAP 2017) describes how to ascertain a site-specific climate classification and then identify related quality performance criteria for solubility control (i.e. NP) (INAP 2017:app.A).

All these considerations will inform the design objectives for a site-specific cover system.

Recommendations:

- Consider the site-specific closure scenario to determine the design objectives for the cover system.
- Develop a CSM to describe the impact that any seepage may have on the receiving environment and how the cover system design will reduce transport of contaminants.
- Consult INAP (2017) and use the Cover System Design Tool and Appendix A to identify the recommended qualitative performance criteria for NP and use this information to determine your NP objective (cognisant of regulatory requirements).
- Describe the objective in terms of limiting net percolation (e.g. to less than x% of rainfall or x mm/yr) and preventing contaminant migration.
- Commence record keeping in accordance with the previously established record management system.

2.3.2 Collect baseline information on the site and cover/waste materials

Adequate baseline information is needed to inform the selection of cover design(s) to be trialled, the design of subsequent field trials and interpretation of the results obtained. INAP (2017) recommends a review of site conditions. This includes a description of climate, hydrogeology, hydrology, physical conditions at site, recorded observations and legal obligations.

As climate is the key aspect governing the performance of a cover system, site-specific climate data sufficient to understand the dominant climate regime and variability are necessary. Designing landforms such as a waste rock stockpile or a tailings facility and its cover system, requires that seasonal and decadal timescales are considered. Average annual precipitation and potential evaporation data provide a starting point, but net percolation on store-and-release covers is influenced by the variability (timing, volume and intensity) of rainfall. Therefore, an understanding of climate cycles is important to ensure seasonality such as intense, but short wet seasons inform the design (INAP 2017).

Poor performance of cover systems is often associated with a limited understanding of the regional

hydrological setting of a mine waste landform (Australian Government 2016). Slope geometries on the mine waste landform also influence how water moves upon, around and within the landform, in turn influencing the performance of the cover system.

As store-and-release cover systems are focussed on limiting net percolation, the hydraulic/geotechnical characteristics (and availability) of the cover material are critical to ensure the system functions as required (INAP 2017). Defining hydraulic/geotechnical characteristics requires information on material density, specific gravity, particle size distribution, Atterberg limits, optimum compaction rates and hydraulic conductivity, along with an understanding of material variability. Soil water characteristic curve testing can be estimated from other geotechnical test results but ideally should be carried out on key cover materials to better define hydraulic properties of unsaturated materials.

The geochemical properties of both cover and waste materials need to be understood as part of assessing impacts and the level of management effort required. These studies involve a combination of static laboratory tests to understand AMD potential and variability, in conjunction with kinetic leach column tests to define lag times to AMD generation and contaminant leaching rates and also develop AMD source terms¹ as input for hydrogeochemical models to predict downgradient water quality under different cover scenarios. Testing should inform a site-specific understanding of the mineralogy of waste and cover materials. For example, clay mineralogy in cover materials, and the presence of jarosite in waste rocks will influence cover scenarios.

Recommendations:

- Describe the climate, topography (including micro-climate conditions) and the hydrogeological/hydrologic settings at a regional scale, including –
 - seasonal and decadal climate patterns
 - variability (timing, volume and intensity) of rainfall
 - recharge, discharge rates and locations, volumes and rates of water movement and water flow pathways in the hydrogeological and hydrologic settings.
- Describe the geochemical characteristics of covers and waste material, by undertaking the following –
 - static laboratory tests to understand AMD potential and variability
 - kinetic leach column tests to define lag times to AMD generation and contaminant leach rates, and to develop AMD source terms under different cover scenarios for use in hydrogeochemical modelling to predict downgradient impacts.
- Describe the hydraulic/geotechnical characteristics of covers and waste material, by measuring the following –
 - particle size distribution
 - specific gravity
 - dry density
 - moisture content
 - Proctor or modified Proctor
 - Atterberg limits
 - hydraulic conductivity
 - material variability.

2.3.3 Model cover performance to identify cover design(s) suitable to trial at field-scale

Mine waste covers can vary from a simple soil cover through to complex layering of differing materials (e.g. earthen material, geosynthetic-reinforced material, geomembrane liner) that are suited to the

¹ 'Source terms refers to predicted concentrations for waters in contact with various types of geologically-sourced material and surfaces under the expected disposal condition at the Project Site.' (Harper Creek Mining Corporation 2015:7)

climatic conditions (Hersey and Power 2023). There can be many different combinations of layers and variation in the properties of each layer, and this extends to store-and-release designs.

Water flux modelling provides a means to simulate the performance of cover design options in meeting their stated objectives. Modelling can be used in an iterative manner to design, test and validate cover designs and allows a number of alternative cover designs (and variations of designs) to be assessed before proceeding to a trial and ultimately construction of a final cover system. Modelling should test a range of scenarios, including different weather events, to identify the sensitivity of the cover system design to extreme conditions.

Water flux modelling can inform cover design options by estimating:

- water balance to determine ‘average’ net percolation
- upward and downward movement of water and solutes through covers via capillary rise, infiltration and seepage
- soil moisture contents.

A site-specific water flux model and cover system performance assessment should be prepared that describes:

- hydraulic/geotechnical properties of cover layer and bulk fill waste rock, and thicknesses of cover layers
- water input due to precipitation
- water loss due to evaporation
- runoff
- water storage in the cover layers
- net percolation through covers
- aquifer levels (where present)
- transpiration.

Modelling should predict the long-term performance of a cover system under representative climate conditions. Rainfall intensity, duration and frequency of events can influence soil moisture conditions within the cover. The use of long-term average rainfall and evaporation estimates can mask the influence of short-term events that drive soil moisture conditions. Consequently, the climate data used to parameterise models should be representative of seasonal and annual climatic conditions for the site and include higher intensity rainfall events (e.g. $\leq 1\%$ Annual Exceedance Probability (AEP) 24-hour duration event, or an event where rainfall duration extends beyond achievement of saturated conditions in the cover system profile). Various climate datasets for Queensland, suitable for biophysical modelling, research and climate applications are available from the SILO database (<https://www.longpaddock.qld.gov.au/silo>). Models can also be used to predict water loss from the upper layers of a cover from evapotranspiration.

Climate change modelling can be done stochastically through programs such as GoldSim to create daily stochastic time series data of precipitation, temperature, and solar radiation. The Queensland Future Climate Dashboard (<https://www.longpaddock.qld.gov.au/qld-future-climate>) can be used to define the relevant climate scenario(s). It should be used to select climate change data for precipitation and evaporation.

Technical Paper 2 identified case studies where models were used to support the design of covers and trials to assess performance. Example models included VADOSE/W, SEEP/W, SoilCover and Hydrus. The model VADOSE/W can be used to design single or multi layered soil covers over mine waste. It can predict the interaction between the soil profile, vegetation, evaporation and runoff (GEO-SLOPE International 2014). The model SEEP/W can model steady-state conditions or more complex saturated or unsaturated conditions (GEO-SLOPE International Ltd 2012). The SoilCover model is a 1 dimensional model that can be used to predict the exchange of water between the atmosphere and a soil surface (O’Kane et al. 1993). Hydrus is another 1 dimensional model that can be used to simulate the 1-dimensional movement of water and multiple variables in saturated or unsaturated conditions (US Department of Agriculture 2020). Coupled hydrological and geochemical models (e.g. Hydrus HP) can be used. For example, to consider evapoconcentration and accumulation of salts in cover materials, or for prediction of seepage water chemistry under different cover scenarios. These are presented here as examples and no single model is recommended. Instead, the modelling approaches chosen should be fit for purpose and be able to represent the water flux processes.

Figures 4 and 5 provide example flux modelling outputs for two cover systems. The cover system modelled in Figure 4 is a store-and-release system with vegetation present, while Figure 5 represents a store-and-release system with vegetation and an infiltration barrier. Both models use the same

climatic conditions and material properties, and the charts plot the cumulative flux of evapotranspiration, precipitation, runoff, surface infiltration, and seepage over a 5-year period. The climatic conditions over the 5-year period include a dry year and a high rainfall year. For the store-and-release system with vegetation, NP into the waste rock was modelled to be approximately 15% of total rainfall over the period. The NP of the cover system with vegetation and a barrier layer was found to be approximately 1% of total rainfall over the same 5-year period and was the preferred cover option for field trials.

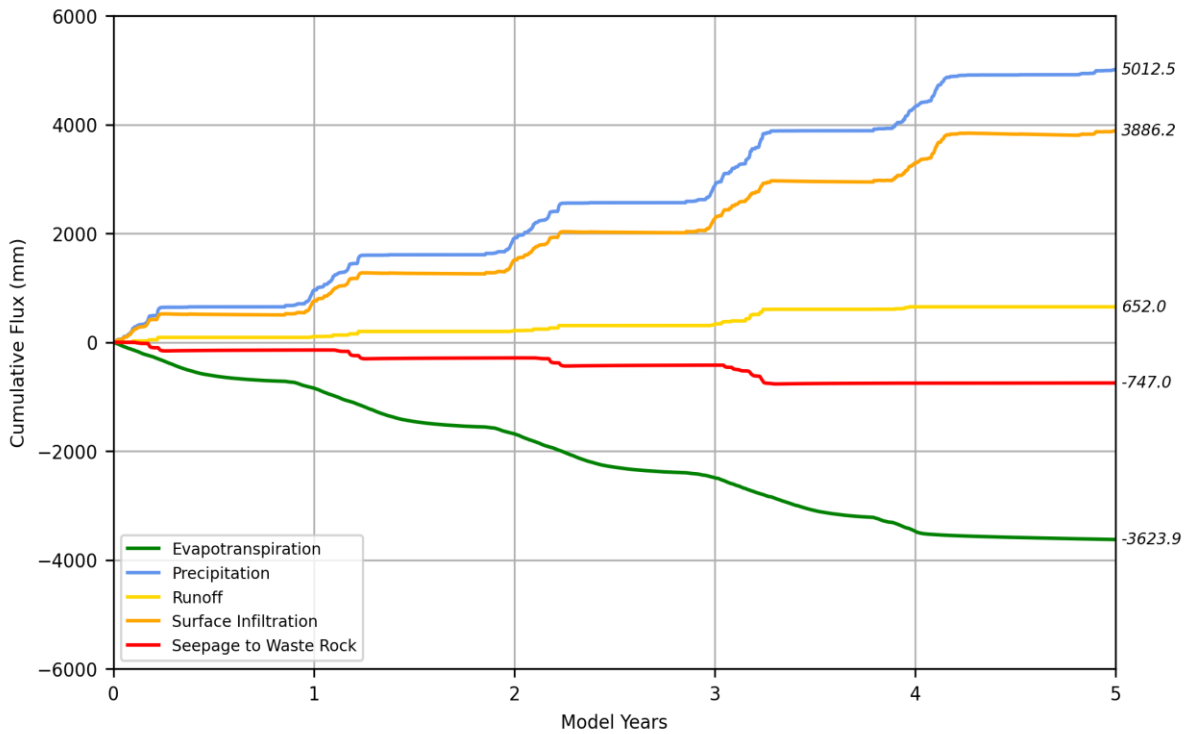


Figure 4. Trial scenario with approximately 15% NP

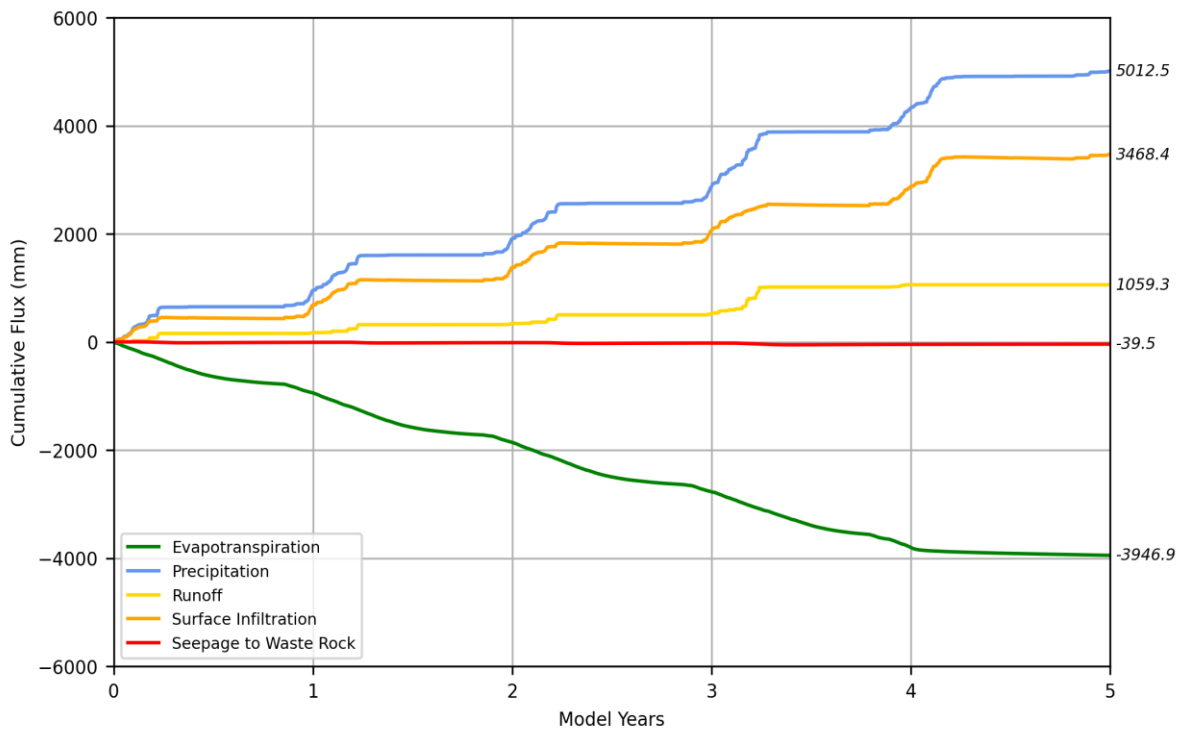


Figure 5. Trial scenario with approximately 1% NP

Large column or mesoscale trials carried out in laboratory conditions are useful to test material properties and check modelling assumptions. They can be used to determine which design should be trialled at field-scale (Zappala et al. 2025). Such trials allow multiple scenarios to be tested in relatively short timeframes. Large column or mesoscale trials provide an opportunity to understand how different elements of the cover will perform over time as they experience wet and dry cycles, both physical (e.g. consolidation), chemical (weathering) and ecohydrological processes (root architecture and water balance) can be simulated, monitored and parameters measured for model inputs.

Although modelling gives an indication of the likely performance, case studies discussed in Technical Paper 2 have shown predicted performance has not always proven accurate. Modelling is a key tool used to develop the cover system design, but modelling predictions require field validation to confirm performance.

Recommendations:

- Undertake large column or mesoscale trials where applicable, to test material properties, inform model inputs and/or check modelling assumptions.
- Carry out a water flux model and cover system performance assessment that models net percolation upwards and downwards through a variety of cover designs to evaluate which designs are expected to meet the design objectives and are feasible to construct.
- Ensure the climate file used in the water flux model is representative of seasonal and annual climatic conditions for the site and includes higher intensity rainfall events ($\leq 1\%$ AEP 24 hr duration or an event where rainfall duration extends beyond achievement of saturated conditions in the cover system profile).
- Use modelling to assess whether the preferred cover design(s) will meet NP performance objectives and are suitable to include in a field-scale trial.
- Propose which cover system design(s) should advance to testing in the field-scale trial and provide a detailed description of the design. Include target design parameter values e.g. permeability, compaction, climatic conditions.
- Describe the rationale for selecting the cover designs and variations of the design(s) to be evaluated.

2.3.4 Prepare design and construction specifications for the cover system to be trialled

The design of the cover system, and the physical and chemical specifications for materials to be used are required prior to construction of both the field-scale trial and any subsequent deployment of the cover design as the final system for closure.

Each cover system layer will typically be linked to a specific geotechnically defined material type, with construction guidelines provided on how to achieve the desired hydraulic properties, and key QA/QC testing required. A schematic diagram of the cover trial options being tested should be provided. The diagram should describe each layer in the cover, the thickness of each layer, the total thickness of the cover and depth to waste. A description of the function of the layers should also be provided.

A detailed construction method should be developed to inform construction techniques (including equipment to be used) for the trial. Details are also required on monitoring equipment to be installed, and methods to isolate test cells from the environment including seepage, flood and erosion protection.

For a design to be feasible, there should be sufficient material available to construct the cover that meets the physical and chemical characteristics required to achieve design objectives. The design needs to be robust enough to allow for unavoidable heterogeneity within an acceptable range and construction specifications must take this into account. If a suitable layer cannot be constructed, alternate engineered barriers such as liners may need to be considered for the final design system to ensure the desired permeability can be achieved. The availability of cover material and distance required to transport this material to site are factors which influence the optimal cover design (INAP 2017). Once the properties and the required volumes of the target cover material(s) have been established, an inventory of the materials needed for construction of the trial and for a full-scale cover system must be undertaken. If the volumes of material are not sufficiently available for full-scale deployment, then there remains little merit in advancing the proposed cover system design to a field-scale trial.

Recommendations:

- Include a schematic diagram of the design showing the cover options being tested, the function of each layer (e.g. topsoil, store-and-release, barrier, capillary break), the total thickness of the cover and depth to waste.
- Provide an inventory of materials on site (or off site if practicable to import) to demonstrate that there is sufficient volume of suitable material available to construct the covers in a trial and demonstrate there would be sufficient material to construct it at full-scale should the trial prove successful.
- Describe specifications for construction of test cells including the physical and chemical specifications for materials to be used, construction methodology and key QA/QC testing to be undertaken. Outline methods for testing/verification of materials to be used and criteria for accepting or rejecting materials based on test results.
- Identify the location (including information regarding the type of geotechnically defined material type) where material for each layer of the cover system design will be sourced.

2.4 Step 2. Plan field-scale trial

The second step in the process is to plan the field-scale trial. Planning (and documenting the plan) is important to ensure the success of the trial and should be finalised prior to commencing the trial. The plan should include the following information.

2.4.1 Objectives for the trial

Results and recommendations developed from the field-scale trial will inform the final cover system design chosen as most appropriate for the site. The objectives of field-scale trials are to:

- Evaluate the preferred design(s) against the cover system design objectives identified in Step 1. For store-and-release cover system designs this will be an evaluation of how successfully the trialled design meets the NP target.
- Verify material property assumptions and the input parameters of the final model/s.
- Provide field data to calibrate models and refine the final cover system design.
- Test construction methods, including type of machinery, response of materials to construction techniques, and the construction process, to optimise the construction process and provide confidence to progress to full cover system construction.

Recommendation:

- Develop a set of clear objectives for the field trial, ensure these are documented in the record management system and used to inform planning for the trial.

2.4.2 Determine trial design

The objective of a cover is to ensure NP is less than or equal to a rate (mm/year) or a proportion of annual percolation through the cover (i.e. x Net Percolation %). That rate or NP% target will be largely based on the water flux modelling work described in Section 2.3.3. It needs to be demonstrated that the field-scale cover trial will adequately test whether the selected cover system will meet that target.

Technical Paper 2 reported examples where controls have been used in mine waste cover trials. These can include a negative control (e.g. where an uncovered cell of mineralised waste material is included). A further example of a control may be the default design required as part of Estimated Rehabilitation Cost calculations (DESI 2023a). A control provides a reference point to measure a response observed in test cell treatments. A control can help to confirm any effect (i.e. a reduction in NP) is due to cover performance and that the variation between cells does not mask the effect of the cover itself.

Technical Paper 2 reported a limited number of case studies where replicate plots were used. The need for replicates is dependent on the variation of the cover system materials and how well these material properties are characterised. Where accurate and reliable baseline information is collected, and model inputs are parameterised, it is assumed that water flux modelling will account for this variation, and that replicates will be unnecessary. In addition, installation of sufficient monitoring equipment in a trial test cell should account for any variation in as-placed materials.

Given field-scale trials are undertaken at a large scale and involve complex planning, design, construction and logistics to establish and monitor, it is impractical to include a large number of cells in the design of mine waste cover trials. The approach taken in this Technical Paper is to rely on the planning and water flux modelling stages of trial design to define and control the sources of variation and to remove uncertainties to as great an extent as practical.

Recommendation:

- Ensure the field-scale trial is designed to adequately test whether the selected cover system will meet an established NP target.

2.4.3 Location

Field-scale trials may be undertaken on existing mine waste structures. Alternatively, the trial may be conducted in purpose-built cells. The choice between these types of location may depend on site-specific limitations. For example, where there is insufficient space on site to establish a dedicated trial, it may be necessary to locate a trial on an existing waste structure. Where this approach is used it will be necessary to consider how test cells are segregated to avoid interaction between cells and to ensure that monitoring equipment can be installed on each test cell independently.

When siting the trial, consideration should be given to ensuring the location will not be impacted by mine operations, can be readily accessed for monitoring activities and is representative of site conditions. The location must be out of flood zones and located away from sensitive receptors such as waterways, aquifers and remnant vegetation. Where necessary, flood and erosion protection may be required.

Recommendation:

- Locate test cells where they can be readily accessed safely by personnel, will not be impacted by mine operations or subject to flood events, ensure they will not impact sensitive receptors, and that appropriate sediment and erosion controls are installed.

2.4.4 Size

Field trials need to be established at a size large enough for test cells to be constructed using the same construction methodology and machinery that will be used to construct cover systems on site. Conducting the trial at such a scale will provide confidence regarding full-scale construction in the future and allow optimisation of the construction process.

As noted above, the size of the trial cell will be largely controlled by the equipment used for construction but will also depend on the nature of the mine waste materials being covered. A tailings material, which is very uniform, may only require a relatively small trial area, whereas very coarse waste rock may require a large area to account for particle size variation. Typically, a minimum of 0.25 ha would be required.

An advantage of field-scale trials is that they are not as prone to the impacts of preferential flow paths as smaller scale trials (Australian Government 2016). The scale should be adequate to avoid edge effects and provide access by personnel maintaining instruments.

The scale used to construct test cells may be constrained by the amount of space available on site and number of test plots needed for the test design. In some cases, it may be necessary to use larger

cells or cells that take a different configuration.

Recommendation:

- Construct test cells at suitable size, at a minimum of 0.25 ha, noting that the shapes and sizes may need to be adjusted to suit equipment being used for placement and the nature of the mine waste materials.

2.4.5 Duration

To determine the trial duration, consideration must be given to the objectives for field-scale trials, as identified in Section 2.4.1:

- To evaluate the ability of the preferred design to reduce NP.
- Verify material property assumptions and the inputs to water flux modelling.
- To provide field data to calibrate models and refine the cover system design.
- To test construction methods and optimise the construction process to confidently progress to full cover construction.

The timeframe recommended by INAP (2017) for field trials is three to five years, the intent being to capture more frequent climate cycles (e.g. El Niño / La Niña cycles) and to allow time for the hydraulic properties of the cover materials to evolve. A study undertaken by Hersey and Power (2023) collected field data over a seven year period in order to develop comprehensive water balances and demonstrate the field performance of various cover systems with a high degree of confidence.

Research shows that the hydraulic properties of cover materials evolve in the initial 3 – 5 years following placement (INAP 2017; Fourie and Tibbett 2007). Large column tests can be undertaken in the laboratory as part of the process to select the cover design tested at field-scale. These studies provide an early indication as to how materials evolve over time and whether the infiltration rates change because of settlement or the influence of precipitation. Weathering processes such as wet-dry cycles, geochemical weathering and biopedturbations change the pore structure of the cover material affecting water storage and flow properties (INAP 2017:B-10). There is a distinction between the wet-dry cycle experienced by a cover and the generation of seepage which results in percolation that can be captured in a lysimeter. Several wetting events may be required to establish the antecedent conditions required for seepage. Regardless of whether seepage occurs, evolution of the cover material continues, and this information can be gathered during the field trial. Schneider et al. (2010:1) also identified that the ‘internal heterogeneity of hydraulic properties had more effect on cover performance than did the initial cover design’, which infers responsibility for cover performance is, in part, related to earlier material property testing and quality assurance of the material used to construct the cover along with the construction techniques used.

Ayres (2021) presents five elements that are of greatest importance for the long-term sustainability of a cover system, of which the ‘proper characterisation of local seasonal and annual climatic conditions’ is one (Ayres 2021:63). It does not take a field-scale trial to identify these climatic conditions. This information can be gathered from other sources such as a site-based automated meteorological station collecting air temperature, wind speed, net radiation, ambient air temperature. Weather stations can be readily operated for extended periods, much longer than that of the field-scale trial. Long-term climate data can also be accessed from SILO (<https://www.longpaddock.qld.gov.au/silo>).

Climate and meteorological conditions, and their impacts on NP rates through the cover system measured during the field trial will provide a further line of evidence to refine and assess water flux modelling of a sustainable cover design. Using a reliable long-term climatic database of 50, but preferably 100 years will ensure the effects of climate variability and antecedent moisture conditions can be properly accounted for when designing the cover system to reduce NP (Ayres and O’Kane 2013).

Artificial rainfall simulation can be used to subject a small area of the cover system to wetting events of a known duration and intensity (Loch 2000). In this way, information regarding infiltration rates into the cover system can be measured and extrapolated for use in water flux modelling by measuring rates of surface runoff and moisture content within the surface of the cover. These data can be used as another line of evidence to validate water flux model inputs and evaluate model predictions regarding cover performance. Any rainfall simulation studies must be undertaken by suitably

experienced technical experts.

It is acknowledged that the influence of climate will have a significant impact on the performance of the cover system. However, we also recognise that not all significant climatic events may be experienced during the trial period, and this is compounded by the significant costs and commitment required to resource field-scale trials. The evaluation of cover system trials reported in Technical Paper 2 clearly identified the failure of studies to capture climatic variation in several instances. This is a difficult aspect to overcome in the field-scale trial design. Considering these constraints, it is recommended that field-scale trials are conducted for 5 years, noting that this is the minimum period expected, and a field-scale trial does not have to be limited to 5 years. In some instances, such as sites where test cells experience a $\leq 1\%$ AEP 24 hr rain event (for which rainfall simulation may be utilised) within the 5-year period, consideration could be given to shortening the duration of the trial, but to no less than 3 years.

Recommendation:

- Undertake the trial for a minimum of 5 years (unless a $\leq 1\%$ AEP 24 hr rain event is experienced earlier with the subsequent trial duration to be a minimum of 3 years).

2.4.6 Design the monitoring system

Monitoring data is needed to verify the performance of a cover against its objectives. Monitoring can be used to:

- provide direct measurements of climate and net percolation
- verify the predicted water balance for the site
- obtain field data to calibrate and validate models that predict cover performance
- develop an understanding for key characteristics and processes that control performance (MEND 2004:1).

The monitoring system should consider variation between samples and ensure the data are sufficient for statistical analyses to be applied. A combination of detailed/primary and secondary instrumentation locations is recommended. Placement of in situ measurement devices should also be located at different points within the profile to capture changes in water flux or other key characteristics of the cover/waste material landform. Careful planning is required to ensure monitoring devices are not damaged by heavy equipment and machinery when the field-scale trial is constructed. Typical methods of measurement for monitoring the performance of a cover system in the field are described in MEND (2004).

Controlling NP is the primary objective of a store-and-release cover. Measurements of NP in a trial cell can be carried out in three main ways:

- direct measurements using a lysimeter placed below the cover system
- indirectly estimated from the water balance
- back calculated from suction or water content sensors installed through the cover system profile.

Of the above, lysimeter installation to directly measure NP and water balance estimates of NP are considered a minimum.

Water balance calculations of NP should be carried out in parallel, since this will provide information on NP in the lag period before any water reports to the lysimeter and provides comparison data. This practice increases confidence at the reporting stage of the trial where cover system performance is evaluated.

Interactions between the cover system (e.g. the use of a reduced permeability layer), soil surface (slope, material characteristics, surface roughness), and vegetation establishment can increase runoff impacting on water balance calculations (INAP 2017). These interactions are investigated as part of water-flux modelling at Step 2.3.3.

In addition to erosion, which can be measured using flumes or sediment traps, other aspects that will affect the performance of the cover trial include occurrence of slumping, and ponding due to

construction issues and/or differential settlement.

Procedures regarding the calibration, installation and maintenance of monitoring instruments must be developed and implemented.

2.4.6.1 Lysimeters

There are a variety of lysimeter types available to directly measure NP. These include weighing lysimeters, zero-tension (gravity-drainage) and tension lysimeters. The most used type is the gravity-drainage lysimeter. The number and locations of lysimeters is dependent on the scale of lysimeters installed. Large lysimeters (e.g. 10 m x 10 m) better account for variability within the overlying cover material and can inform performance based on their construction using full-scale construction equipment. Where smaller scale lysimeters are used, higher variability in NP measurements is anticipated, but there is potential for edge effects. Consequently, an increased number of small scale lysimeters will be necessary to understand variability in cover system materials and performance (INAP 2017).

As with all scientific monitoring equipment, lysimeters must be designed, installed and operated as per specifications to provide accurate and reliable NP measurements (Meiers et al. 2009). Consideration should be given to the type of lysimeter and its design, how the volume of net percolation will be collected (e.g. pumped out, using a piezometer or an automatic drainage system), the location and depth of the instruments. Information regarding the use of lysimeters is provided in INAP (2017) and O’Kane and Barbour (2003).

2.4.6.2 Water balance calculations

To determine the water balance associated with a cover system, site characterisation data must be collected to measure precipitation, runoff, evapotranspiration and the change in water storage. Matric water potential sensors and water content reflectometers are examples of instruments placed within the cover system to collect data used to estimate change in water storage.

Calculating the change in water storage based on a single location will not be representative of the entire cover system. This is because a single location cannot account for variability in cover material, in situ density or impacts of the topography and vegetation on in situ water content. Consequently, multiple monitoring locations are required.

The location of instruments such as matric water potential or volumetric water content sensors should be at various depths within the cover profile to provide data at the boundaries of each layer comprising the cover system design (Schneider et al. 2010; INAP 2017). These sensors should also be located beside each other to facilitate development of water retention curves and hydraulic conductivity functions (INAP 2017).

Climatic conditions strongly influence the development and performance of a cover system. Evapotranspiration is a mechanism that controls NP and so changes in potential evapotranspiration should be understood by measuring air temperature, wind speed, net radiation, ambient air temperature and available water in the near surface cover material (INAP 2017). Information sufficient to establish evapotranspiration and describe weather conditions during the trial are needed to interpret NP data describing cover system performance. It is recommended that data are obtained via a fully automated meteorological station, located on-site and within proximity of the trial site.

NP can be estimated as the residual once measurements or estimates of the other components associated with a change in water storage of the system are determined. Refer to Hersey and Power (2023) for further explanation of this process. Here, they studied four waste rock stockpiles with various cover designs and used the water balance for each to investigate NP and water dynamics within each cover system.

One disadvantage associated with estimation of NP via a water balance rather than direct measurement is that the magnitude of NP observations is much smaller when compared to the relative range (and associated errors) of measurements for precipitation and/or evapotranspiration. This can mean that estimates of NP from a water balance have a high level of error associated with them.

2.4.6.3 Sampling

Where possible, automated data logging for sensors and other monitoring equipment should be utilised. Data collected at specified time intervals for soil suction and moisture sensors and lysimeter

drainage, combined with data from an on-site weather station allowed Schneider et al. (2010) to evaluate the performance of a number of cover system options in response to the climatic conditions and identify issues associated with a malfunctioning tipping bucket.

Continuous, automated sampling allows accurate average and peak values to be determined from the data, and counter against incorrect interpretation of data due to the hysteresis effect (INAP 2009). Installation of these types of monitoring instruments is not always practical due to hostile field environments, remoteness, changing personnel, challenges with repairs to faulty equipment etc. These issues should be addressed where possible to promote opportunities for automated monitoring equipment to be installed. Sampling frequency will be informed by the trial duration. An operating procedure to ensure sampling equipment is regularly checked, including after significant wet weather events, and maintained should be developed at implemented.

Recommendations:

- Describe the monitoring program, including frequency and methods and instrumentation to be used. Include a list of performance indicators to be monitored (e.g. soil moisture, NP) and procedures for the calibration, installation and maintenance of monitoring instruments.
- Ensure any additional information that is necessary to calibrate the model used to inform cover design options is collected during the monitoring phase.
- Install lysimeters to directly measure NP below the cover system. Identify the appropriate type, size and number of lysimeters necessary to measure rates of NP. Consult INAP (2017) and O’Kane and Barbour (2003) for further guidance on lysimeter design and implementation.
- Spatially locate monitoring instruments to ensure the influence of position and aspect on NP can be identified in collected data.
- Locate sensors at different locations within the profile where changes in permeability (i.e. at the boundary of each layer within the cover system) are anticipated.
- Co-locate matric water potential and volumetric water content sensors.
- Use a combination of primary and secondary instrumentation sites to adequately account for spatial variability in the cover materials.
- Collect evaporation (or potential evaporation), rainfall (mm/hour), net percolation (lysimeters), and temperature data to establish the site water balance and allow an estimation of NP. This will likely require installation of a fully automated meteorological station within close proximity to the trial site that measures air temperature, humidity, air pressure, rainfall, wind direction and speed, solar radiation.
- Visually monitor for the effects of surface erosion, gulying, slumping, ponding and differential settlement in the trial area as these greatly impact the integrity of the trial.
- Identify issues regarding the deployment of automated data logging systems and develop solutions to overcome these challenges.
- Develop and implement a standard operating procedure to routinely check and maintain sampling equipment.

2.5 Step 3. Undertake field-scale trial

The third step in the process is to construct the trial in the field and commence monitoring. Firstly, consideration should be given to when the trial will be constructed and commenced. Construction during the wet season is likely to result in compromised construction techniques and impacts to the integrity of the various components/layers of the cover system.

To ensure a cover system meets its performance expectations, quality control and assurance processes must be diligently followed during construction of the cover system (INAP 2017). This same approach is necessary during construction of test cells to ensure reliable data can be collected during the trial and interpreted with confidence. Information gathered during the construction of test cells at a field-scale can be used to optimise which equipment will be selected for full-scale construction of the nominated cover system design and identify unforeseen construction issues. Checking the physical properties of materials in layers as constructed provides a means to verify construction techniques and materials used are appropriate.

Poor construction techniques can lead to the development of preferential pathways within the cover system. The failure to construct cover systems in accordance with design, driven by poor quality assurance processes is an identified failure mode (Dunlop et al 2025).

Information regarding the geotechnical properties of the trial cover system as constructed should be collected. Testing should be undertaken at depth for each of the different layers forming the cover system design for key parameters, such as density, hydraulic conductivity, particle size distribution and Atterberg Limits.

Ensure that monitoring data collected during the trial are collated and stored. This includes any calibration activities, failure of equipment, repairs and other disrupting events that may impact trial outcomes.

To ensure the trial is maintained in good condition, routine visual inspections should be undertaken and repairs completed in a timely manner.

Recommendations:

- Determine the appropriate time to construct the test cells, eliminating the negative impacts of wet weather on the construction process and integrity of the cover system.
- Develop and implement a QA/QC system to capture and record construction techniques ensuring the test cells meet construction specifications. Include an inspection schedule for the construction phase that describes the tests to be undertaken and items to be inspected (e.g. material placements, layer thickness).
- Undertake key tests to demonstrate consistency with construction specifications, such as density, hydraulic conductivity, particle size distribution and Atterberg Limits at depth for each layer within the cover system design.
- Collate monitoring data collected during the field trial, including calibration processes of equipment and any reported failure of monitoring equipment.
- Undertake routine visual inspections and complete any necessary maintenance or repairs to test cells in a timely manner.
- Identify and record any adaptive management actions necessary to maintain trial integrity, for example repairs to monitoring equipment.
- Store QA/QC documentation in the record management system.

2.6 Step 4. Refine design based on trial outcomes

The fourth step in the process is to collate and analyse the data collected during the trial and then use the interpreted data to inform final cover system design.

The monitoring data should be reviewed against the cover system design objectives identified at Step 1 and a recommendation made regarding the success of the trialed design to achieve the objectives.

An analysis should be completed to show the movement of water through the cover. Present the monitoring results, showing the complete water balance and include rainfall and NP estimates for the period of the trial. Show the NP figures for each cover design option. Identify controlling mechanisms and processes that may influence the NP observations.

Interpret any results from visual monitoring for the effects of surface erosion, gulying, slumping, ponding and differential settlement in the trial area and report if these have impacted on the integrity of the trial. Consider if the presence of observed surface erosional processes influenced rates of surface runoff and if the surface of the cover system is resistant to erosive forces.

Interrogate records kept as part of the implemented QA/QC program to establish whether monitoring data indicate any performance outcomes related to the construction of the cover system. Resultant conclusions should also be used where possible to finalise the design and construction specifications for the final cover prior to full-scale construction across the whole landform. Use the site-specific data collected from the meteorological station and monthly and/or event-based field monitoring data to calibrate and refine earlier model simulations to provide more accurate and reliable output regarding the predicted performance of the design over time. A similar analysis to that presented in Figure 4 and

Figure 5 can be undertaken to interrogate previous model predictions of NP. This iterative approach may also lead to an optimised cover design and waste handling strategies.

Recommendations:

- Present a summary table of locally relevant daily and monthly rainfall (mm), temperature (°C) and estimated evaporation (mm) for the site for the period of the trial.
- For each test cell present a graph of the observed daily cumulative Net Percolation (mm) as a proportion of rainfall for the period of the trial and the target NP for the trial.
- Where comparing between cover designs, provide plots of daily NP for each cell including the control cell.
- For each monitoring indicator present successful data capture rate of data (% of total) that has met QA/QC requirements for the period of the trial.
- Present conclusions as to the erosional stability of the cover design and whether observed surface erosion, gullyng, slumping, ponding and differential settlement in the trial area impacted on the integrity of the trial.
- Present conclusions regarding performance outcomes related to the construction of the cover system. Use these conclusions to finalise the design and construction specification for the final cover at full-scale.
- Use monitoring data to calibrate and refine earlier water flux modelling simulations to improve accuracy and reliability regarding the predicted performance of the cover design over time.

2.7 Step 5. Report on trial

The fifth step is to present information describing the trial using the format described here.

A report is required to describe the process followed to plan and undertake the trial. The report should provide information to describe the trial design, monitoring designs and results and supporting information outlined here as the 'process to undertake a cover system trial'. The report should provide clear recommendations (for example, which is the preferred cover design) or conclusions as to whether the trial hypothesis has been met and quantitative evidence in support of this (e.g. NP design objective in comparison to max NP recorded). Raw data should be provided as an appendix to the report or be available for scrutiny.

Table 1. Recommended content for a report on the design and implementation of a mine waste cover trial

Section	Content
Introduction	Site name, location and map, environmental authority number and mine waste facilities (name, area, volume of waste)
Cover system design objectives	<p>Describe the site-specific closure scenario and resultant design objectives for the cover system design. Include clear statements to describe the objective in terms of limiting net percolation (e.g. to less than x% of rainfall or x mm/yr) and preventing contaminant migration.</p> <p>Present the CSM, developed to describe the impact of seepage on the receiving environment and how the cover system design will reduce transport of contaminants</p>
Site setting	<p>Information on the prevailing climate including annual average rainfall, evaporation, temperature, climate variability and cycles, topography (including micro-climate conditions).</p> <p>Information regarding material properties - describe geochemical and geotechnical characteristics of cover and waste materials</p>
Modelling studies	Outline model predictions for the selected cover designs, including details for the water balance, the upward and downward movement of water through covers via infiltration, evaporation and transpiration, capillary rise, changes in cover water storage and drainage, and estimated net percolation
Cover design specifications	<p>Describe the cover system design that will be trialled.</p> <p>Material Inventory - confirm the material needed to construct the cover is available.</p> <p>Construction methods – detail the methods used to construct the trial and QA/QC Testing</p>
Trial objectives	<p>Define test cells and any controls or replicates.</p> <p>Define the trial location, size and duration.</p> <p>Describe the monitoring system – sampling equipment, indicators, locations, frequency and calibration procedures</p>
Construction	Provide evidence of QA/QC inspections to verify cover met design specifications.
Monitoring	<p>Collate monitoring data collected during the trial, including calibration processes of equipment.</p> <p>Describe any adaptive management actions necessary to maintain trial integrity, for example repairs to monitoring equipment or maintenance of test cells</p>
Performance indicators	Report results against objectives
Conclusions	<p>Recommend whether the trialled cover system design should be taken forward to full-scale construction. Describe any modifications necessary to the trialled cover system design.</p> <p>Demonstrate how the design met performance indicators.</p> <p>Provide a calibrated and/or refined water flux model (post-trial).</p> <p>Present a discussion regarding the constructability of the trialled design.</p> <p>Present any other conclusions arising from monitoring data and observations</p>
Appendices	Raw data, QA/QC records, model output summaries and any other relevant reports or documents are to be provided

Recommendation:

- Use the report template provided in Table 1 to develop the final report.

3 Conclusion

In Queensland’s climatic conditions, evaporation typically exceeds precipitation and cover control strategies are focussed on controlling water flux through the mine waste landform. Consequently, store-and-release cover system designs are recommended. NP is the key measure of performance for a store-and-release design.

Trials are used to develop, compare and refine options for mine waste cover designs. Trials require significant resourcing and are often undertaken in remote and logistically challenging locations. This Technical Paper describes a leading practice approach on how to trial a proposed cover system design at field-scale. A field-scale trial is defined here as a series of test cells constructed as would a full-scale cover system, with a minimum area of 0.25 ha.

A 5-step process is proposed:

- Step 1 – Determine cover system objectives and design options (identify cover objectives, collect baseline information, model cover performance and identify a suitable cover design for a field-scale trial, prepare construction specifications).
- Step 2 – Plan the field-scale trial (identify trial objectives, determine the trial design, choose a suitable location, determine trial location and size of test cells, set study duration, and design the monitoring system).
- Step 3 – Undertake the field-scale trial (construct and monitor).
- Step 4 – Refine the design based on trial outcomes.
- Step 5 – Report on the trial.

The site-specific closure scenario should be considered to determine the design objectives for the cover system design. The design objectives for the cover system should then be stated upfront and include a quantitative performance measure related to limiting net percolation. Baseline studies and information gathering activities are key to inform which cover system design(s) will advance for testing at field-scale. Information gathered at this stage should describe the geochemical and geotechnical characteristics of both the mine waste and cover system materials, the climate, topography and hydrogeological settings. A site-specific water flux model and cover system performance assessment should be prepared. Modelling should predict the long-term performance of the cover system under representative climate conditions. Large laboratory column tests and smaller field tests can be undertaken to test material properties and check modelling assumptions. Prior to construction of the field-scale trial, design specifications for each layer in the cover system must be prepared and a materials inventory undertaken to locate and quantify the volumes of materials required to construct the cover system.

Planning the field-scale trial requires a set of clear objectives for the trial to be developed and used to inform decisions regarding trial design, location and size of the test cells, trial duration and monitoring. As controlling NP is the primary objective of a store-and-release cover system, lysimeters must be installed to directly measure NP and water balance estimates of NP established. A fully automated meteorological station in close proximity is required to develop potential evapotranspiration rates and identify site-specific weather conditions and patterns.

Undertaking the field-scale trial involves constructing the test cells and monitoring performance of the cover system for a defined period. Diligence is required to ensure the cover system is constructed according to the design, as failure to follow design specifications has previously been identified as one reason why cover systems fail to meet their performance objectives. A QA/QC system must be developed and implemented during the construction phase of the trial. Monitoring data collected during the trial must be stored, including any calibration activities, failure of equipment, repairs and other disrupting events.

Once the trial has been completed, monitoring data will be collated and interpreted to inform the final cover system design. The water balance must be determined and presented along with an analysis to show how water moved through the cover system during the trial (i.e. reporting on NP). Monitoring

data must also be used to calibrate and refine earlier water flux modelling simulations to improve accuracy and reliability regarding the predicted performance of the cover system over time.

The fifth and final step of the approach is to present information describing the trial and its outcomes. A template outline of the structure and content of the report has been presented. Raw data should be provided as an appendix to the report or be available for scrutiny.

The field-scale trial must be supported by a record management system to ensure each step in the leading practice approach is documented and records maintained for future use.

The leading practice approach presented here describes how robust field-scale trials may be undertaken in a manner particular to Queensland conditions. The intent is for trials to be cost-effective, and the approach avoids prescribing excessive or impractical requirements. Field-scale trials are an important part of the broader process necessary to develop and implement strategies to control AMD and potential impacts on the receiving environment.

4 References

- Arnold S, Schneider A, Doley D and Baumgartl T (2015) 'The limited impact of vegetation on the water balance of mine waste cover systems in semi-arid Australia', *Ecohydrology*, 8(3):355–367, doi:10.1002/eco.1485.
- Australian Government (2016) *Leading practice sustainable development program for the mining industry: Preventing acid and metalliferous drainage*, Australian Government, <https://www.industry.gov.au/publications/leading-practice-handbooks-sustainable-mining/preventing-acid-and-metalliferous-drainage>, accessed 20 March 2025.
- Ayres B (2021) 'Cover systems and landforms for rehabilitation of mine waste storage facilities: Practical insights', *CIM Journal*, 12(2):60–70, doi:10.1080/19236026.2021.1919010.
- Ayres B and O'Kane M (2013) 'Mine waste cover systems: An international perspective and applications for mine closure in New Zealand', *Mine Waste Cover Systems: An International Perspective and Applications for Mine Closure in New Zealand*¹⁰, <https://okaneconsultants.com/wp-content/uploads/2023/09/Ayres-and-OKane-2013-Mine-Waste-Cover-Systems-NZ.pdf>.
- DESI (Department of Environment, Science and Innovation) (2023a) *Estimated rehabilitation cost under the Environmental Protection Act 1994*, DESI, Queensland Government, https://www.des.qld.gov.au/policies?a=272936:policy_registry/rs-gl-erc-ep-act.pdf.
- (2023b) *Guideline: Progressive rehabilitation and closure plans (PRC plans)*, DESI, Queensland Government, https://www.des.qld.gov.au/policies?a=272936:policy_registry/rs-gl-prc-plan.pdf.
- Dunlop J, Nicolson L, and Purtill J. 2025. Mine waste cover system trials – a comparative review of case studies: Technical Paper 2. Brisbane: Queensland Mine Rehabilitation Commissioner, Queensland Government.
- Fourie A and Tibbett M (2007) 'Post-mining landforms — Engineering a biological system', in *Mine Closure 2007: Proc. Int. Seminar on Mine Closure, Mine Closure 2007*, Aust. Ctr. for Geomech., Santiago, Chile.
- GEO-SLOPE International (2014) *Vadose zone modeling with VADOSE/W*, <https://downloads.geoslope.com/geostudioresources/books/8/15/vadose%20modeling.pdf>, accessed 17 September 2024.
- GEO-SLOPE International Ltd (2012) *Seepage modeling with SEEP/W*, <https://downloads.geoslope.com/geostudioresources/books/8/0/2/seep%20modeling.pdf>, accessed 17 September 2024.
- Harper Creek Mining Corporation (2015) *Application for an Environmental Assessment Certification/Environmental Impact Statement 6. Geochemistry*, Impact Assessment Agency of Canada, <https://iaac-aeic.gc.ca/050/documents/p61898/101038E.pdf>, accessed 11 April 2025.
- Hersey D and Power C (2023) 'Assessing water dynamics and net percolation rates within engineered cover systems for mine waste rock piles: A long-term field monitoring study', *Journal of Hydrology*, 627:130471, doi:10.1016/j.jhydrol.2023.130471.
- Holdridge L, Grenke W, Hatheway W, Liang T and Tosi J JA (1971) *Forest environments in tropical life zones: a pilot study*, Oxford, New York, Pergamon Press.
- INAP (International Network for Acid Prevention) (2009) *The global acid rock drainage guide (GARD Guide)*, INAP, doi:10.1007/s10230-009-0078-4.
- (2017) *Global cover system design*, <https://www.inap.com.au/wp-content/uploads/global-cover-system-design.pdf>.
- (2020) *Rock placement strategies to enhance operational and closure performance of mine rock stockpiles phase 1 work program – Review, assessment & summary*, <https://www.inap.com.au/wp-content/uploads/2020-Jan-INAP-Improving-Stockpile-Construction-Phase-1-Final-Report.pdf>.
- Loch RJ (2000) 'Using rainfall simulation to guide planning and management of rehabilitated areas: Part I. Experimental methods and results from a study at the Northparkes Mine, Australia', *Land Degradation & Development*, 11(3):221–240, doi:10.1002/1099-145X(200005/06)11:3<221::AID-LDR381>3.0.CO;2-2.
- Meiers GP, O'Kane M and Barbour SL (2009) 'Measuring net percolation rates for waste storage

facility cover systems', *Canadian Geotechnical Society*,
<https://members.cgs.ca/documents/conference2009/GeoHalifax09/pdfs/125.pdf>.

MEND (Mine Environment Neutral Drainage) (2004) *Design, construction and performance monitoring of cover systems for waste rock and tailings*, Edited by O'Kane Consultants Inc. Natural Resources Canada, <https://mend-nedem.org/category/prevention-and-control/>.

— (2012) *MEND 1.61.5c cold regions cover system design technical guidance document*,
<https://mend-nedem.org/wp-content/uploads/2013/01/1.61.5c.pdf>.

O'Kane M, Ayres B, Christensen D and Meiers G (2002) *CANMET – CETEM manual on cover system design for reactive mine waste*, https://www.researchgate.net/publication/229040104_CANMET-CETEM_Manual_on_Cover_System_Design_for_Reactive_Mine_Waste/link/546f42ff0cf24af340c07de5/download?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19.

O'Kane M and Barbour SL (2003) 'Predicting field performance of lysimeters used to evaluate cover systems for mine waste', in *Sixth International Conference on Acid Rock Drainage (ICARD)*,
<https://doi.org/10.7939/r3-hp2x-8t91>.

O'Kane M, Birkham T, Goodbrand A, Barbour SL, Carey S, Baker T and Klein R (2015) 'Near-surface water balances of waste rock dumps', in *10th International Conference on Acid Rock Drainage and International Mine Water Association Annual Conference*, Santiago, Chile,
<https://dx.doi.org/10.14288/1.0042678>.

O'Kane M, Wilson GW and Barbour SL (1993) 'SoilCover, a new computer model to aid in the design of soil cover systems for acid generating waste rock and tailings', in *Proceedings of the 17th Annual British Columbia Mine Reclamation Symposium*, Port Hardy, BC,
<https://open.library.ubc.ca/soa/cIRcle/collections/59367/items/1.0042221>.

Schneider A, Baumgartl T, Doley D and Mulligan D (2010) 'Evaluation of the heterogeneity of constructed landforms for rehabilitation using lysimeters', *Vadose Zone Journal*, 9(4):898–909,
doi:10.2136/vzj2009.0172.

US Department of Agriculture (2020) *HYDRUS-1D Model*, *US Salinity Laboratory*,
<https://www.ars.usda.gov/pacific-west-area/riverside-ca/agricultural-water-efficiency-and-salinity-research-unit/docs/model/hydrus-1d-model/>, accessed 17 September 2024.

Zappala L, Clay M, Nicolson L, Dunlop J and Purtill J. 2025. Mine waste cover system trials – a literature review: Technical Paper 1. Brisbane: Office of the Queensland Mine Rehabilitation Commissioner, Queensland Government.

Appendix A

Table A - Checklist for cover system field-scale trial setup, construction and monitoring

Step from leading practice approach	Item	Description	Actions
Prior to commencing leading practice approach	Record management system	<p>A record management system is necessary to document:</p> <ul style="list-style-type: none"> • Development of the cover system design option taken to field-scale trial • Cover system specifications and construction methodology • QA/QC processes • Monitoring program and collected data 	Develop and implement a record management system for each step of the leading practice approach
1. Determine cover system design objectives and options	Cover system design objectives	Consider the site-specific closure scenario to determine the design objectives for the cover system design	<ul style="list-style-type: none"> • Consult INAP (2017) and use the Cover System Design Tool and Appendix A to identify the recommended qualitative performance criteria for NP and use this information to inform your NP objective (cognisant of regulatory requirements). • Develop a CSM to describe the impact that any seepage may have on the receiving environment and how the cover system design will reduce transport of contaminants to an acceptable level. Ensure the CSM is informed by an understanding of the water quality and environmental values of the catchment receiving environment. • Describe the objective in terms of limiting Net Percolation (e.g. to less than x% of rainfall or x mm/hr) and preventing contaminant migration
	Collect baseline information on the site and cover materials	Undertake studies to adequately inform the selection the cover system design(s) to be trialled, the design of the field-scale trial and interpretation of results	<ul style="list-style-type: none"> • Describe the climate, topography (including micro-climate conditions) and the hydrogeological/hydrologic settings at a regional scale, including – <ul style="list-style-type: none"> ○ seasonal and decadal climate patterns

Step from leading practice approach	Item	Description	Actions
			<ul style="list-style-type: none"> ○ variability (timing, volume and intensity) of rainfall ○ recharge, discharge rates and locations, volumes and rates of water movement and water flow pathways in the hydrogeological and hydrologic settings. • Describe the geochemical characteristics of covers and waste material (including an understanding of the materials' mineralogy), by undertaking the following – <ul style="list-style-type: none"> ○ static AMD laboratory tests to understand AMD potential and variability ○ kinetic leach column tests to define lag times to AMD generation and contaminant leach rates. • Describe the hydraulic/geotechnical characteristics of covers and waste material, by measuring the following – <ul style="list-style-type: none"> ○ particle size distribution ○ specific gravity ○ dry density ○ moisture content ○ modified Proctor ○ Atterberg Limits ○ hydraulic conductivity ○ material variability
	<p>Model cover performance to identify cover design(s) suitable to trial at field-scale</p>	<p>Develop and iteratively use a water flux model to design, test and validate the cover system design. Using the model assess a number of alternative cover designs (and variations of designs) before proceeding to a field-scale trial.</p> <p>Large column trials carried out in laboratory conditions, or small in situ field tests may be useful to test material properties and check modelling assumptions</p>	<ul style="list-style-type: none"> • Where applicable, undertake large column or mesoscale trials to test material properties, inform model inputs and/or check modelling assumptions. • Carry out a water flux model and cover system performance assessment that models net percolation upwards and downwards through a variety of cover designs to evaluate which designs are expected to meet the design objectives and are feasible to construct.

Step from leading practice approach	Item	Description	Actions
			<ul style="list-style-type: none"> • Ensure the climate file used in the water flux model is representative of seasonal and annual climatic conditions for the site and includes higher intensity rainfall events (\leq 1% AEP 24hr duration or an event where rainfall duration extends beyond achievement of saturated conditions in the cover system profile). • Use modelling to assess whether the preferred cover design(s) will meet NP performance objectives and are suitable to include in a field-scale trial. • Propose which cover system design(s) should advance to testing in the field-scale trial and provide a detailed description of the design. Include target design parameter values e.g. permeability, compaction, climatic conditions. • Describe the rationale for selecting the cover design(s) and variations of the design(s) to be evaluated
	<p>Prepare design and construction specifications to be trialled</p>	<p>Material properties - specifications for materials used in the cover system (e.g. waste, clay). Methods for testing/verification of materials before construction. Criteria for accepting or rejecting materials based on test results.</p> <p>Material inventory - inventory to demonstrate sufficient quantities of materials (meeting specified material properties) are available to construct the cover system.</p> <p>Construction methods - description of construction techniques and equipment to be used</p>	<ul style="list-style-type: none"> • Include a schematic diagram of the design of each cover being tested showing the cover options being tested, the function of each layer (e.g. topsoil, store-and-release, barrier, capillary break), the total thickness of the cover and depth to waste. • Provide an inventory of materials on site (or off site if practicable to import) to demonstrate that there is sufficient volume of suitable material available to construct the covers in a trial and demonstrate that there would be sufficient material to construct it at full-scale should the trial prove successful. • Describe specifications for construction of test cells including the physical and chemical specifications for materials to be used, construction guidelines and key QA/QC testing to be undertaken. Outline methods for testing/verification of materials to be used and criteria for accepting or rejecting materials based on test results. • Identify the specific location (including information regarding the type of geotechnically defined material type) of material for each layer of the cover system design

Step from leading practice approach	Item	Description	Actions
2. Plan field trial	Objectives for the trial	<p>The objectives of field-scale trials are to:</p> <ul style="list-style-type: none"> i. evaluate the preferred design(s) against the cover system design objectives identified in Step 1. For store-and-release cover system designs this will be an evaluation of how successfully the trialled design reduces NP. ii. verify material property assumptions and the input parameters of the final model/s. iii. provide field data to calibrate models and refine the final cover system design. iv. test construction methods, including type of machinery, response of materials to construction techniques, and the construction process, to optimise the construction process and provide confidence to progress to full cover system construction 	Develop a set of clear objectives for the field trial, ensure these are documented in the record management system and used to inform planning for the trial
	Determine trial design	Determine how the field-scale trial will adequately test whether NP objectives are achieved by the cover system design	Ensure the field-scale trial is designed to adequately test whether the selected cover system will meet an established NP target
	Location	Field-scale trials may be undertaken on existing mine waste structures or in purpose-built cells	Locate test cells where they can be readily accessed safely by personnel, will not be impacted by mine operations or subject to flood events, and ensure they will not impact sensitive receptors, and that appropriate sediment and erosion controls are installed
	Size	Field trials need to be established at a size large enough for test cells to be constructed using the same construction methodology and machinery that will be used to construct cover systems on site	Construct test cells at suitable size, typically at a minimum of 0.25 ha, noting that the shapes and sizes may need to be adjusted to suit equipment being used for placement and the nature of the mine waste materials

Step from leading practice approach	Item	Description	Actions
	Duration	<p>The duration is informed by the objectives identified for the field-scale trial –</p> <ul style="list-style-type: none"> i) To evaluate the ability of the preferred design to reduce NP. ii) Verify material property assumptions and the inputs to water flux modelling. iii) To provide field data to calibrate models and refine the cover system design. iv) To test construction methods and optimise the construction process to confidently progress to full cover construction 	<p>Undertake the trial for a minimum of 5 years (unless a $\leq 1\%$AEP 24 hr rain event is experienced earlier with the subsequent trial duration to be a minimum of 3 years)</p>
	Design the monitoring system	<p>Controlling NP is the primary objective of a store-and-release cover. Lysimeter installation to directly measure NP and water balance estimated of NP are critical components of the monitoring system.</p> <p>Consider the type, number and location of monitoring sensors.</p> <p>Ensure equipment is designed, installed and operated as per specifications to provide accurate and reliable measurements.</p> <p>Monitor for other aspects that may disrupt the trial or impact upon the integrity of the trial.</p> <p>Where possible, use automated data logging for sensors and other monitoring equipment.</p>	<ul style="list-style-type: none"> • Describe the monitoring program, including frequency and methods and instrumentation to be used. Include a list of performance indicators to be monitored (e.g. soil moisture, NP) and procedures for the calibration, installation and maintenance of monitoring instruments. • Ensure any additional information that is necessary to calibrate the model used to inform cover design options is collected during the monitoring phase. • Install lysimeters to directly measure NP below the cover system. • Identify the appropriate type, size and number of lysimeters necessary to measure rates of NP. Consult INAP (2017) and (O’Kane and Barbour 2003) for further guidance on lysimeter design and implementation. • Spatially locate monitoring instruments to ensure the influence of position and aspect on NP can be identified in collected data. • Locate sensors at different locations within the profile where changes in permeability (i.e. at the boundary of each layer within the cover system) are anticipated. • Co-locate matric water potential and volumetric water content

Step from leading practice approach	Item	Description	Actions
		<p>Sampling frequency will be informed by the trial duration.</p> <p>A standard operating procedure is necessary to ensure routine checks and maintenance of sampling equipment</p>	<p>sensors.</p> <ul style="list-style-type: none"> • Use a combination of primary and secondary instrumentation sites to adequately account for spatial variability in the cover materials. • Collect evaporation (or potential evaporation), rainfall (mm/hour), net percolation (lysimeters), and temperature data to establish the site water balance and allow an estimation of net percolation. This will likely require installation of a fully automated meteorological station within close proximity to the trial site that measures air temperature, humidity, air pressure, rainfall, wind direction and speed, solar radiation. • Visually monitor for the effects of surface erosion, gullying, slumping, ponding and differential settlement in the trial area as these greatly impact the integrity of the trial. • Identify issues regarding the deployment of automated data logging systems and develop solutions to overcome these challenges. • Develop and implement a standard operating procedure to routinely check and maintain sampling equipment
3. Undertake field trial		Construct the test cells and commence monitoring	<ul style="list-style-type: none"> • Determine the appropriate time to construct the test cells, eliminating the negative impacts of wet weather on the construction process and integrity of the cover system. • Develop and implement a QA/QC system to capture and record construction techniques ensuring the test cells meet construction specifications. Include an inspection schedule for the construction phase that describes the tests to be undertaken and items to be inspected (e.g. material placements, layer thickness) • Undertake key tests to demonstrate consistency with construction specifications, such as density, hydraulic conductivity, particle size distribution and Atterberg Limits at depth for each layer within the cover system design. • Collate monitoring data collected during the field trial, including calibration processes of equipment and reported failure of

Step from leading practice approach	Item	Description	Actions
			<p>monitoring equipment.</p> <ul style="list-style-type: none"> • Identify and record any adaptive management actions necessary to maintain trial integrity, for example repairs to monitoring equipment. • Undertake routine visual inspections and complete any necessary maintenance or repairs to test cells in a timely manner. • Store QA/QC documentation in the record management system
4. Interpret data and use		Collate and interpret the data collected during the trial and then use the interpreted data to inform final cover system design	<ul style="list-style-type: none"> • Present a summary table of locally relevant daily and monthly rainfall (mm), temperature (°C) and estimated evaporation (mm) for the site for the period of the trial. • For each test cell present a graph of the observed daily cumulative Net Percolation (mm) as a proportion of rainfall for the period of the trial and the target NP for the trial. • Where comparing between cover designs, provide plots of daily NP for each cell including the control cell. • For each monitoring indicator present successful data capture rate of data (% of total) that has met QA/QC requirements for the period of the trial. • Present conclusions as to the erosional stability of the cover design and whether observed surface erosion, gullyng, slumping, ponding and differential settlement in the trial area impacted on the integrity of the trial. • Present conclusions regarding performance outcomes related to the construction of the cover system. Use these conclusions to finalise the design and construction specification for the final cover at full-scale. • Use monitoring data to calibrate and refine earlier water flux modelling simulations to improve accuracy and reliability regarding the predicted performance of the cover design over time

Step from leading practice approach	Item	Description	Actions
5. Report on trial outcomes		Develop a final report to describe the process followed to plan and undertake the trial, and present recommendations and conclusions developed after data interpretation	Use the report template provided in Table 1 to develop the final report