Mine Closure 2026 – AB Fourie, G Boggs, J Heyes & M Tibbett (eds)

doi:10.36487/ACG_repo/2615_55

Optimising closure cover design in semi-arid environments through percolation modelling and pilot trials

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Abstract

The design of effective closure cover systems is a critical component of mine closure planning in semi-arid environments, where overall rainfall is limited. However, episodic and seasonally concentrated precipitation events can still influence infiltration processes and long-term water quality. In Turkey, current regulatory guidance prescribes a structured, multi-layer cover system comprising, from bottom to top, a minimum 1 m non-acid-generating (NAG) buffer layer, a low-permeability barrier, a drainage layer and a topsoil cover. While this configuration is intended to minimise water ingress to underlying mine waste, its implementation on large waste stockpiles can present operational, constructability and material-sourcing challenges.

This study presents an early-stage investigation program that forms part of a proactive closure planning approach, focused on the development of pilot-scale trials and a structured framework for assessing cover system performance. This timely approach is intended to enable the systematic collection of site-specific data over an extended period, thereby supporting the development of a technically sound and defensible closure cover design. The program focuses on the development of pilot-scale closure cover trials and a comparative assessment framework supported by percolation modelling.

Four closure cover scenarios have been defined, including the regulatory-prescribed configuration and a range of alternative, simplified designs intended to explore opportunities for comparable infiltration management with reduced construction complexity. Representative materials for the proposed cover layers have been identified for laboratory characterisation, including particle size distribution, soil water retention behaviour and saturated hydraulic conductivity. These data are being used to inform the development of a 2-dimensional percolation modelling framework, designed to support relative comparison between scenarios and guide the design of pilot-scale trials.

The study highlights how data-driven and site-specific approaches can support early decision-making and constructive dialogue within Turkey's evolving mine closure regulatory framework, while remaining aligned with regulatory objectives and long-term environmental protection goals.

Keywords: *cover systems, pilot-scale trials, infiltration control, regulatory framework*

1 Introduction

1.1 Background

Mine closure strategies for waste rock dumps and heap leach facilities commonly rely on engineered landforms and cover systems designed to limit oxygen ingress and reduce net percolation to underlying reactive materials. A range of cover system approaches are applied globally, including store-and-release (evapotranspiration) covers in semi-arid climates and barrier-type or multi-layer covers in more humid

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environments (INAP 2017; ICMM 2019). The selection of an appropriate closure strategy is inherently site-specific and is influenced by climatic conditions, material availability and long-term performance objectives. Experience from field trials and case studies has highlighted the importance of constructability and scalability when applying cover systems to large mine landforms (O'Kane et al. 2006; Queensland Government 2025).

Centerra's Öksüt gold mine is a heap leach operation in central Turkey comprising large waste rock and heap leach facilities that may require long-term management of water quality under semi-arid climatic conditions. While the region experiences relatively low mean annual precipitation, infiltration processes at Öksüt are influenced by episodic and seasonally concentrated rainfall and snowmelt events. These episodic rainfall and snowmelt events can drive disproportionate volumes of percolation through waste landforms, leading to increased loading. Therefore, managing net percolation into underlying waste is a central closure challenge at the site, given its direct role in controlling any potential acid rock drainage (ARD) and metal leaching risks over the post-closure period (INAP 2017).

At Öksüt, these site-specific closure challenges are addressed within a regulatory framework that prescribes a conservative, multi-layer closure cover system for mining waste facilities. This framework is intended to support long-term environmental protection by limiting water ingress to reactive materials. However, these prescriptive designs may be overly complex, and applying the design uniformly across large waste rock and heap leach landforms can introduce practical challenges related to material availability, construction complexity and scale (Punkkinen et al. 2026; O'Kane & Wels 2003; Zappala 2025).

Thus, there is a need for an early-stage, site-specific approach that supports closure decision-making without prematurely committing to a single prescriptive design solution. Rather than treating the regulatory prescribed cover system as the only viable end point, this study adopts it as a conservative reference against which alternative configurations can be assessed. A comparative framework combining percolation modelling and pilot-scale field trials is used to evaluate relative performance, identify key design trade-offs and reduce uncertainty. This approach is intended to support constructive, performance-focused dialogue with regulators while remaining aligned with the underlying objectives of long-term environmental protection.

1.2 Paper overview

The current study evaluates 4 closure cover scenarios, comprising the regulatory prescribed configuration and a set of simplified alternatives that vary in configuration, hydraulic function and construction complexity. Representative materials for these cover systems are used to parameterise a comparative numerical model. Modelling results are then used to inform the selection and design of pilot-scale field trials that are intended to test key assumptions, assess constructability and generate site-specific performance data. The remainder of this paper describes the regulatory and site context, outlines the comparative assessment framework, presents the modelling-based insights used to prioritise scenarios and discusses the role of pilot trials in supporting defensible closure decision-making.

2 Regulatory and site context

2.1 Overview of mine closure cover requirements in Turkey

Mine closure in Turkey is governed by a combination of mining and environmental legislation, with engineered cover systems for mine waste facilities prescribed under the Mining Waste Regulation administered by the Ministry of Environment, Urbanisation and Climate Change (T.C. Çevre ve Şehircilik Bakanlığı 2015). This regulation requires that mine waste facilities be closed using engineered cover systems designed to provide long-term environmental protection, with particular emphasis on limiting water ingress to reactive materials.

The regulatory framework adopts a prescriptive approach to cover design, specifying the functional components and minimum requirements to support infiltration management and environmental protection objectives. This approach reflects a conservative regulatory philosophy aimed at minimising infiltration-driven risks to surface water and groundwater over the post-closure period.

The Mining Waste Regulation defines a standard multi-layer closure cover system to be applied to mine waste facilities.

The prescribed configuration comprises, from bottom to top:

- a minimum 1 m-thick non-acid-generating (NAG) buffer layer placed directly over the waste material
- a low-permeability barrier layer, constructed using either clay-based materials or a geosynthetic clay liner (GCL)
- a drainage layer intended to limit water accumulation above the barrier and promote lateral flow
- a topsoil layer designed to support vegetation establishment and provide erosion protection.

The intent of this configuration is to reduce net percolation into the underlying waste by combining low-permeability barriers with storage and drainage functions in the upper layers. By limiting water ingress, the cover system is intended to control potential long-term water quality risks, and to support stable post-closure conditions.

Although prescriptive in structure, the closure cover requirements provide the basis by setting several clear regulatory objectives:

- Infiltration management: reducing the volume of meteoric water entering mine waste facilities to limit leachate generation and contaminant loading.
- Environmental protection: preventing deterioration of surface water and groundwater quality during closure and post-closure phases.
- Long-term stability: supporting erosion resistance and integration of rehabilitated landforms into the surrounding environment.
- Capillary control: limiting the potential for upward movement of moisture and dissolved constituents from underlying materials.

These objectives are consistent with international mine closure principles, where infiltration control is recognised as a primary mechanism for managing long-term geochemical risks at heap leach and waste rock facilities, particularly in semi-arid climates (INAP 2017).

2.2 Practical challenges in implementation on large waste stockpiles

While the regulatory cover configuration is technically sound in principle, practical challenges may arise when covers are implemented on large mine waste landforms. Similar challenges have been widely reported in the application of engineered cover systems at large-scale mine sites, particularly where design assumptions must be translated into field-scale construction (INAP 2017; Queensland Government 2025). The main aspects of these challenges are outlined below.

2.2.1 Material availability

The regulation requires large volumes of suitable NAG material for the buffer layer, as well as low-permeability materials for the barrier layer. At sites with limited availability of fine-grained, geochemically suitable NAG material or natural clay, meeting these requirements can be challenging (INAP 2017). Where quantities of onsite materials are insufficient, reliance on external sourcing may be necessary, introducing additional cost, logistical complexity and uncertainty in long-term supply (O'Kane & Wels 2003).

2.2.2 Constructability

Constructing uniform, multi-layer covers over large, irregular waste landforms is operationally complex (Ayres & O'Kane 2013; INAP 2017). Achieving consistent layer thickness, continuity of low-permeability barriers, and appropriate interface conditions between layers can be difficult, particularly on side slopes. Barrier layers such as compacted clay liners (CCLs) or geosynthetic liners are sensitive to construction quality and may be affected by desiccation, differential settlement or damage during placement of overlying materials. In addition, uneven surface conditions and landform irregularities can influence surface water movement, potentially leading to localised ponding, preferential flow paths and internal erosion processes that may affect cover system performance if not appropriately managed. The assessments highlight gully erosion and the re-establishment of surface drainage networks as the dominant physical risks affecting the landforms (Ayres & O'Kane 2013).

2.2.3 Operational constraints

Closure cover construction must be coordinated with ongoing site operations, materials handling and closure sequencing. Large material movements, extended construction durations and quality control requirements can place pressure on operational resources, particularly during transition from operations to closure (ICMM 2019). These constraints increase the importance of assessing constructability and practicality alongside theoretical performance.

2.2.4 Climatic controls

The challenges associated with closure cover implementation at Öksüt are not unique to Turkey, as many mines operate in arid and semi-arid regions globally and infiltration after closure remains a key consideration even in dry climates (van Zyl & Straskraba 1999). In this context, conservative cover design approaches are often explored as a precautionary response to uncertainty regarding long-term infiltration and water quality performance. In such environments, overall rainfall may be low, but infiltration is often dominated by episodic rainfall and snowmelt events, making net percolation highly sensitive to cover composition and storage capacity rather than average annual rainfall. As a result, there is increasing recognition that early-stage, site-specific assessment of cover performance is needed to ensure that closure designs are both effective and practical.

Within this context, comparative assessment frameworks that evaluate alternative cover configurations against regulatory objectives, rather than against prescriptive layouts alone, can provide a defensible basis for optimisation while maintaining alignment with environmental protection goals.

3 Early-stage investigation program

3.1 Conceptual framework for closure cover assessment

The early-stage investigation program adopts a comparative, data-driven approach to closure cover assessment. The underlying philosophy is to evaluate the relative performance of alternative cover configurations under consistent assumptions, rather than to predict absolute long-term outcomes at this stage of closure planning. Given the uncertainty typical of early design stages, attention is directed towards comparing meaningful performance differences between conceptually distinct cover systems.

At this stage, percolation modelling is applied as a screening and prioritisation tool to examine how differences in cover configuration, layer composition and hydraulic behaviour influence net percolation trends under site-specific climatic conditions. The modelling framework is intentionally simplified and conservative, with emphasis placed on relative performance rather than precise quantification of infiltration rates. The numerical model was developed using literature-based material property ranges representative of the expected cover materials, recognising that site-specific laboratory data were not yet available. Modelling results are used to compare percolation behaviour across alternative cover configurations under a common set of assumptions and to inform the selection and design of pilot-scale trials, which provide the next step for testing key assumptions, assessing constructability and generating site-specific performance data under field conditions.

The results generated through this framework are intended to support 3 primary objectives. First, they provide a structured basis for screening closure cover design concepts and identifying configurations that warrant further consideration. Second, they inform the design of pilot-scale trials by focusing field investigations on the most influential design variables and performance uncertainties. Third, they support constructive and transparent engagement with regulators by demonstrating how alternative cover configurations are evaluated against regulatory objectives using site-specific data and a documented assessment framework.

The conceptual framework is designed to reduce uncertainty progressively through successive stages of investigation, while maintaining alignment with regulatory expectations for environmental protection and long-term closure performance.

3.2 Closure cover scenarios considered

3.2.1 Scenario development and screening approach

The identification of closure cover scenarios followed a structured screening process based on flow chart mapping and decision logic (Figure 1). This process was used to translate closure objectives, particularly infiltration control and long-term water quality protection, into a set of technically credible cover configurations suitable for further assessment.

The screening logic considered the functional role of individual cover layers, the anticipated controls on water and oxygen ingress, and the practicality of implementation using available materials. The regulatory prescribed cover configuration was adopted as a reference case within this framework, against which simplified alternatives were evaluated. Through this process, a broader set of conceptual cover configurations was progressively reduced to a smaller number of scenarios that captured key differences in hydraulic function and construction complexity.

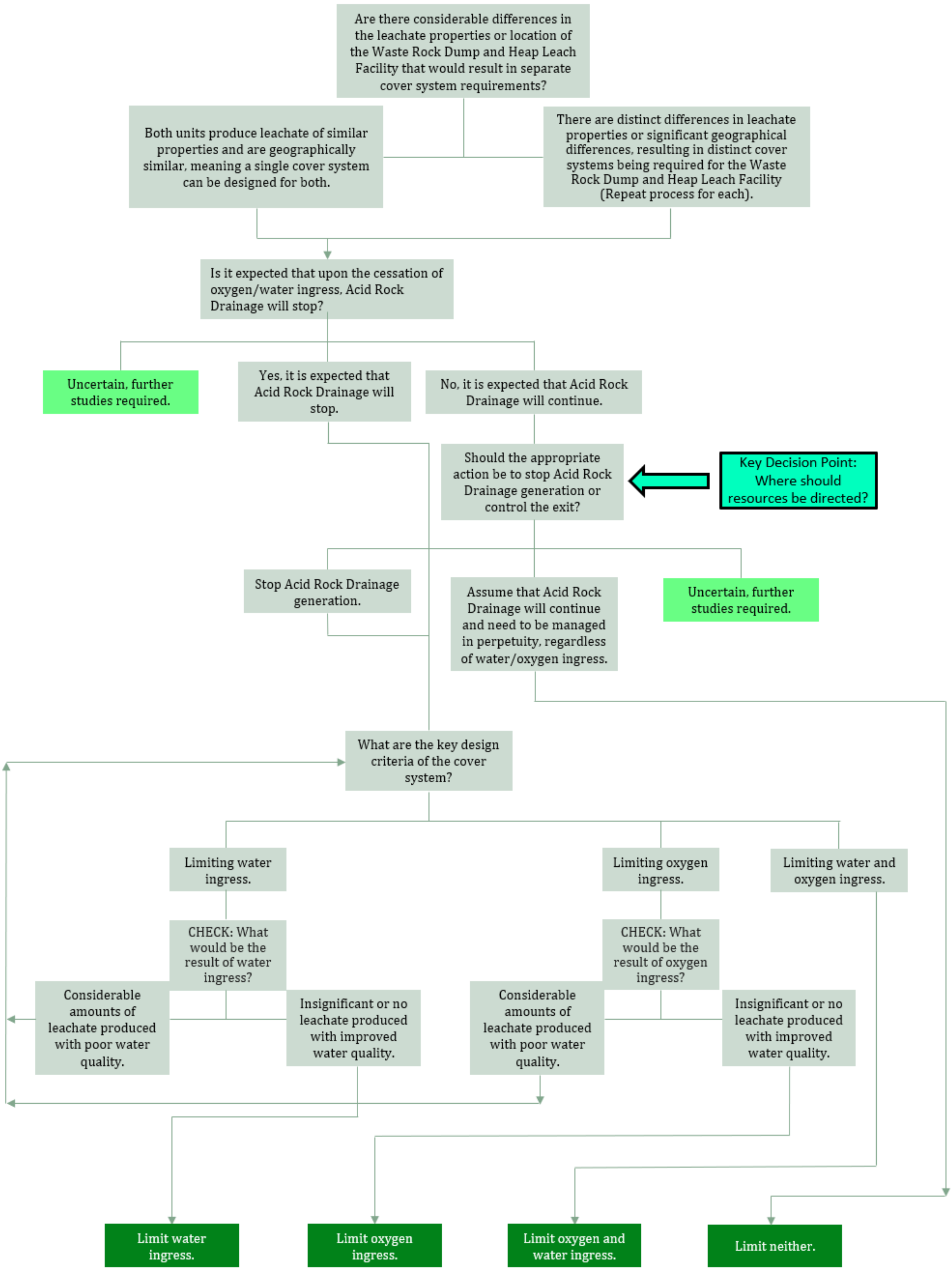

Figure 1 Flow chart mapping and decision logic

Based on the screening framework illustrated in Figure 1, scenario development followed a decision-making process linking site conditions, geochemical behaviour and closure objectives. The initial stage considered whether a single cover system approach could be applied across the waste rock dump and heap leach facility, based on similarities in leachate properties and site conditions. Subsequent steps evaluated the expected progression of ARD, including whether ARD generation could be mitigated through the reduction of oxygen and/or water ingress, or whether long-term management would be required. These decision points informed the key design criteria for the cover system, particularly the relative importance of limiting water ingress, oxygen ingress, or both.

Accordingly, 5 scenarios were selected for detailed assessment, capturing increasing levels of complexity from a no cover baseline through to the full regulatory configuration. The scenarios are summarised below and illustrated in Figure 2.

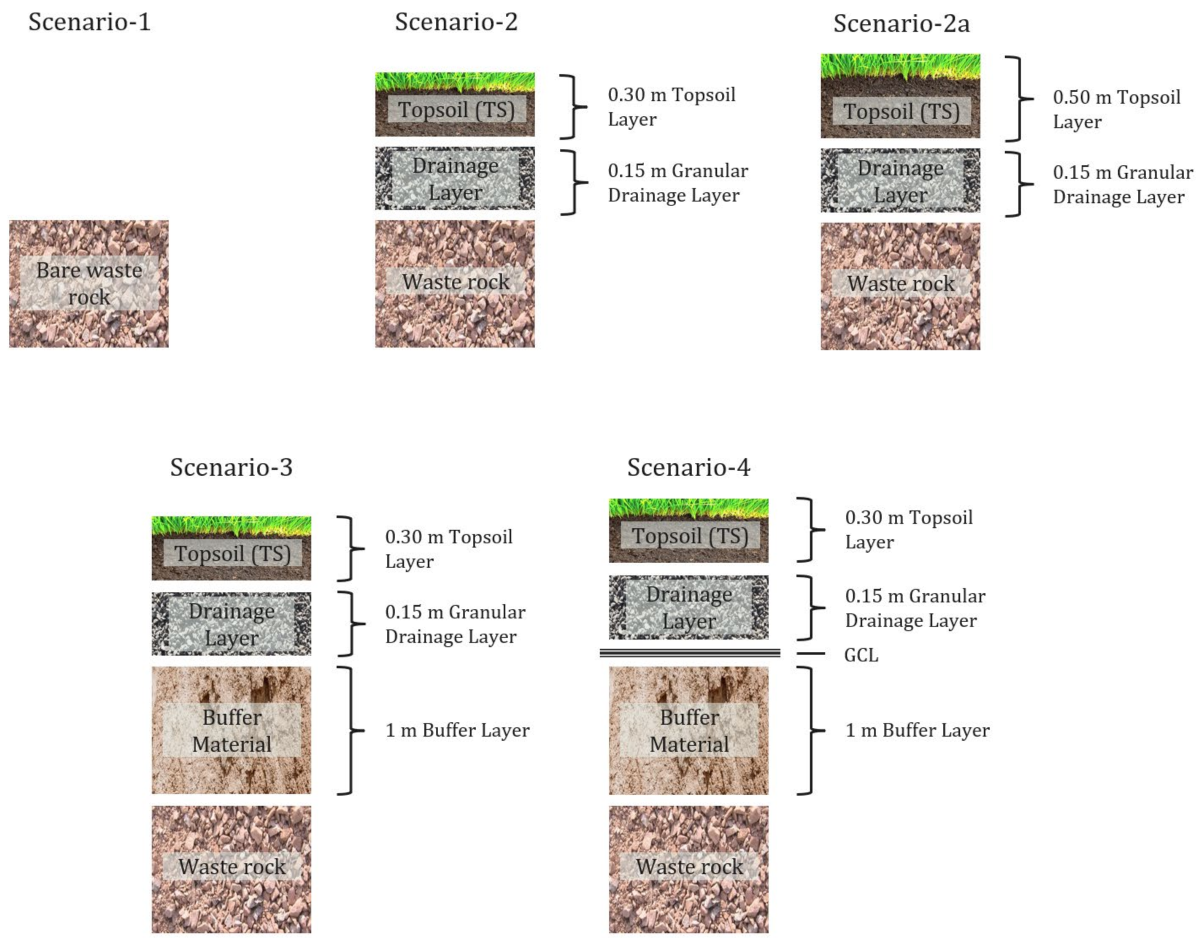

Figure 2 Schematic representation of the closure cover scenarios selected for detailed assessment

3.2.1.1 Scenario 1 – bare waste (control plot)

This scenario represents an uncovered waste surface and serves as a baseline condition. It provides a reference against which the relative effectiveness of engineered cover systems can be assessed. No infiltration control measures are included in this scenario.

3.2.1.2 Scenario 2 – topsoil and drainage layer

This scenario comprises a simplified soil-based cover consisting of a 0.30 m-thick topsoil layer underlain by a 0.15 m-thick granular drainage layer. This configuration relies on near-surface water storage, evaporation and drainage to limit percolation and does not include either a buffer layer or a low-permeability barrier. In contrast to the regulatory concept, this scenario does not include the 1.0 m-thick NAG buffer layer and therefore does not provide significant infiltration attenuation through bulk material storage.

Although this scenario does not meet regulatory closure requirements, it provides a useful lower-bound reference for assessing the effectiveness of minimal cover systems.

3.2.1.3 Scenario 2a – topsoil (increased thickness) and drainage layer

This scenario comprises a simplified soil-based cover consisting of a 0.50 m-thick topsoil layer underlain by a 0.15 m-thick granular drainage layer. This configuration, similar to Scenario 2, relies on near-surface water storage, evaporation and drainage to limit percolation and does not include a buffer layer or a low-permeability barrier.

In contrast to the regulatory concept, this scenario does not include the 1.0 m-thick NAG buffer layer and therefore does not provide significant infiltration attenuation through bulk material storage. However, the increased topsoil thickness enhances moisture storage capacity relative to Scenario 2, which may contribute to a reduction in net percolation through increased evapotranspiration potential.

Although this scenario does not meet regulatory closure requirements, it provides a useful intermediate reference for assessing the influence of increased soil thickness on the performance of simplified cover systems.

3.2.1.4 Scenario 3 – topsoil, drainage layer and buffer layer

This scenario incorporates a thicker soil profile by introducing a NAG buffer layer beneath the drainage and topsoil. In this configuration, a 0.30 m topsoil layer and a 0.15 m drainage layer overlie a 1.0 m-thick NAG buffer layer. The inclusion of the buffer layer increases storage capacity and delays downward percolation while remaining reliant on soil-based hydraulic controls rather than a dedicated barrier layer. This scenario represents an intermediate level of complexity between simplified covers and the regulatory prescribed design. The inclusion of the 1.0 m-thick NAG buffer layer aligns with the thickness specified in the regulatory cover concept, but without the addition of a low-permeability barrier.

3.2.1.5 Scenario 4 – full regulatory cover configuration

This scenario represents the full regulatory cover configuration and is included as the reference benchmark for comparative assessment. This configuration comprises a 1.0 m-thick NAG buffer layer placed directly over the waste, overlain by a low-permeability barrier represented by a GCL. Above the barrier, a 0.15 m-thick drainage layer and a 0.30 m-thick topsoil layer complete the system. This scenario combines both storage-based and barrier-controlled infiltration reduction mechanisms and represents the highest level of construction complexity among the scenarios considered.

To support relative comparison, geometrical layout, climatic inputs and boundary conditions were treated consistently across all scenarios. At this stage of the investigation, material properties were represented using literature-based ranges considered appropriate for the expected cover materials. The scenarios are therefore intended to be comparable in terms of their conceptual hydraulic function rather than as final design solutions. The intent was not to replace the regulatory design, but to understand the relative contribution of individual layers, particularly buffer thickness and barrier presence, to overall percolation control.

3.3 Material selection and laboratory characterisation

At the time of writing, a comprehensive cover material sampling program has been completed, and samples have been submitted for laboratory analysis; however, the results were not yet available and are therefore not included in the present assessment. Further refinement using laboratory-derived parameters and pilot-scale field data will be undertaken in subsequent stages of the investigation.

Material selection focused on soils and granular materials expected to be used for topsoil, drainage and buffer layers, with emphasis placed on materials that are realistic candidates for large-scale closure implementation rather than idealised or hypothetical options. The laboratory testing program has been designed to characterise key physical and hydraulic properties required to support percolation modelling and subsequent pilot-scale trials. Testing includes particle size distribution analysis to define textural characteristics and support classification of material behaviour, soil water retention testing to describe moisture storage and release under unsaturated conditions, and determination of saturated hydraulic conductivity to define upper-bound permeability.

3.4 Initial preliminary percolation modelling

3.4.1 Approach and model set-up

A preliminary percolation modelling exercise was completed to support early screening of cover concepts and to guide the selection of scenarios for pilot-scale field trials. At this stage, the modelling was intended to provide a directional and comparative indication of likely percolation trends across alternative configurations, rather than absolute predictions of long-term field performance.

The modelling was implemented using HYDRUS-1D (Simunek et al. 1998), simulating vertical water flux through conceptual cover profiles under site-relevant climatic conditions. The conceptual model represents a layered cover system overlying waste, with percolation evaluated at the base of the model domain under free-drainage conditions. The immediate objective at this stage was to quantify the range of net percolation achievable by practical cover configurations and to identify candidate configurations for pilot trials, while noting that geotechnical stability and durability assessments were not part of this early modelling scope.

Climatic inputs were derived from the site meteorological station using monthly precipitation and evaporation data, which were converted to constant daily rates for each month for model application. The upper boundary was defined as an atmospheric boundary condition with surface run-off, and the lower boundary as free drainage. Initial pressure head was set uniformly at −100 cm across the profile. Simulations were run over a 10-year period using annual timesteps.

As stated, at the time the modelling was undertaken, site-specific laboratory-derived hydraulic parameters were not yet available. Cover layer properties were therefore represented using USDA soil property datasets, providing representative hydraulic values for comparative purposes, with the stated intent that site materials would be sampled during pilot trials and the model updated and calibrated as field and laboratory data become available.

Vegetation effects were excluded to provide a conservative estimate of percolation (i.e. no evapotranspiration or root uptake reduction was modelled). In addition, the modelling did not represent lateral drainage because HYDRUS-1D assumes one-dimensional vertical flow; as a result, the drainage layer influence on lateral diversion was not captured and percolation may be overestimated where lateral drainage would occur. Snow accumulation and melt processes were also excluded at this stage, with the intent to address these effects in later updates as more data become available.

3.4.2 Comparative assessment of cover scenarios

The modelling outputs were interpreted using relative metrics suitable for early screening, focusing on comparative percolation trends across scenarios rather than absolute percolation rates. Results were presented as ratios relative to the highest percolation case and as percentage reductions relative to the bare surface baseline.

An overview of scenario selection and the modelling rationale is provided in Table 1. For comparative purposes, 5 scenarios were included in the preliminary percolation modelling to represent a performance spectrum ranging from an uncovered surface to the inclusion of a low-permeability barrier. In addition to the 4 closure cover scenarios defined in Section 3.2, an additional soil-only variant was modelled to assess the sensitivity of percolation behaviour to increased topsoil thickness. This additional case represents a modification of Scenario 2, in which the topsoil thickness was increased from 0.3 to 0.5 m while retaining the same nominal drainage concept.

Table 1 Overview of scenario selection and modelling rationale

Scenario no.	Description	Purpose	Reason for modelling	Remarks
1	Bare waste (no cover)	Establishes the upper bound for net percolation and serves as a baseline for comparison.	Essential reference point; no additional data requirements.	–
2	0.3 m topsoil + 0.15 m drainage layer	Tests the minimum-intervention store-and-release concept combined with lateral drainage.	Low complexity and likely to be the quickest to construct if later selected for piloting.	–
2 a	0.5 m topsoil + 0.15 m drainage layer	Examines the effect of increased soil thickness on net percolation relative to Scenario 2.	Quantifies whether additional thickness delivers meaningful percolation reductions that could justify higher volumes and haulage.	–
3	1.0 m buffer + 0.15 m drainage + 0.3 m topsoil (standard cap; no barrier)	Represents a robust soil-based cap using site-derived materials without a dedicated barrier.	Provides a practical mid-range reference between thin covers and barrier systems.	–
4	Scenario 4 + low-permeability barrier (modelled as 0.5 m CCL, representing CCL or GCL)	Introduces a low-permeability barrier to test the step-change in net percolation achievable relative to soil-only options. This scenario is fully compliant of Turkish regulations.	Although a 0.5 m CCL is unlikely in practice due to lack of local clay, this scenario serves as a performance proxy for a GCL system.	HYDRUS-1D simulations used a 0.5 m CCL due to convergence issues with very thin layers (i.e. GCL). For decision purposes, Scenarios 5 and 6 are assumed to have equivalent hydraulic performance.

3.4.3 Modelling results

The modelling results indicate that Scenario 1 (bare surface) produced the highest percolation rate and was used as the baseline reference. Scenario 2 (0.3 m topsoil with a nominal drainage concept) showed a 45.5% reduction in percolation relative to the bare surface baseline. Scenario 2a (0.5 m topsoil with the same nominal drainage concept) showed a 62.9% reduction, and increasing topsoil thickness from 0.3 to 0.5 m resulted in an additional 17.4% reduction relative to Scenario 2. Scenario 3 (topsoil with a 1 m buffer layer) showed an 81.9% reduction, indicating a marked improvement when storage is increased through addition of a substantial buffer layer. Scenario 4 (Scenario 3 plus a low-permeability barrier represented as a 0.5 m CCL) produced the greatest reduction at 90.3%, indicating the additional benefit of a barrier layer in limiting downward flux. For Scenario 4, a 0.5 m CCL was adopted to represent a low-permeability barrier, serving as a proxy for a GCL because HYDRUS-1D experienced convergence issues with very thin layers.

Based on the modelling outcomes, scenarios were prioritised for pilot-scale trials to test key assumptions, assess constructability and generate site-specific data to support refinement of modelling inputs and interpretation.

The comparative percolation modelling results are illustrated in Figures 3 and 4, which present results as relative ratios to the highest percolation case and as percentage reductions across scenarios, respectively.

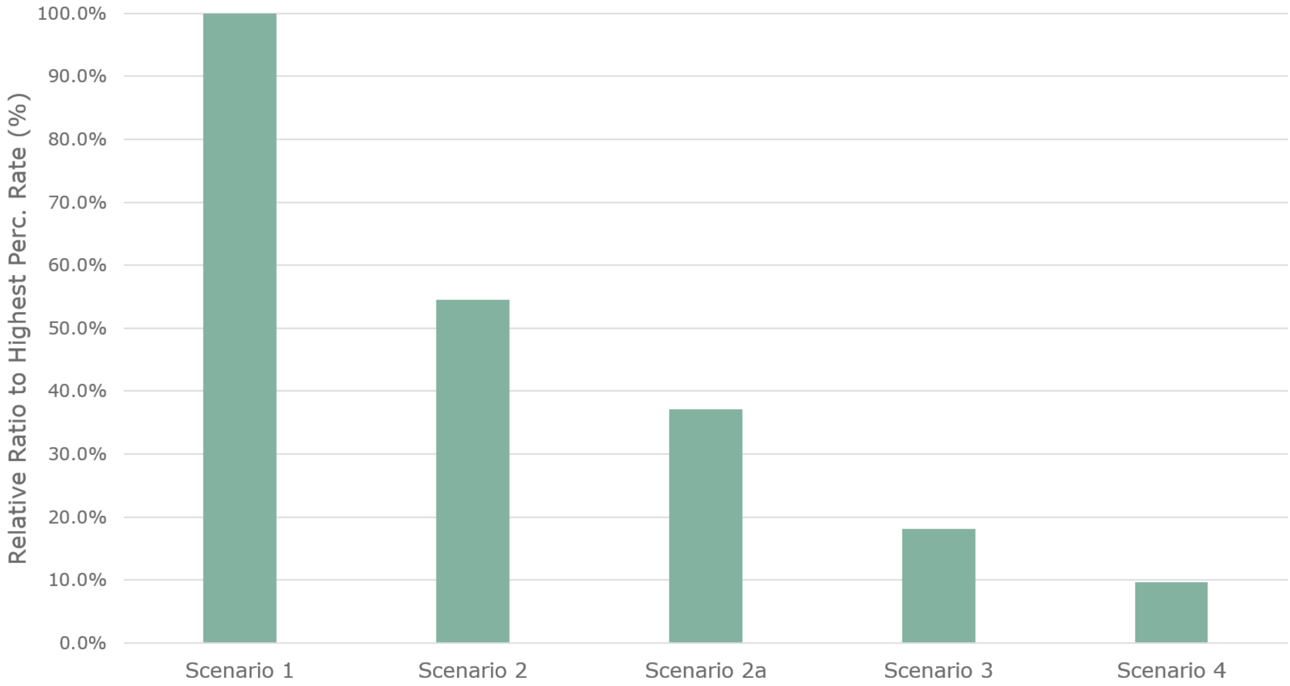

Figure 3 Relative ratio to highest percolation rate

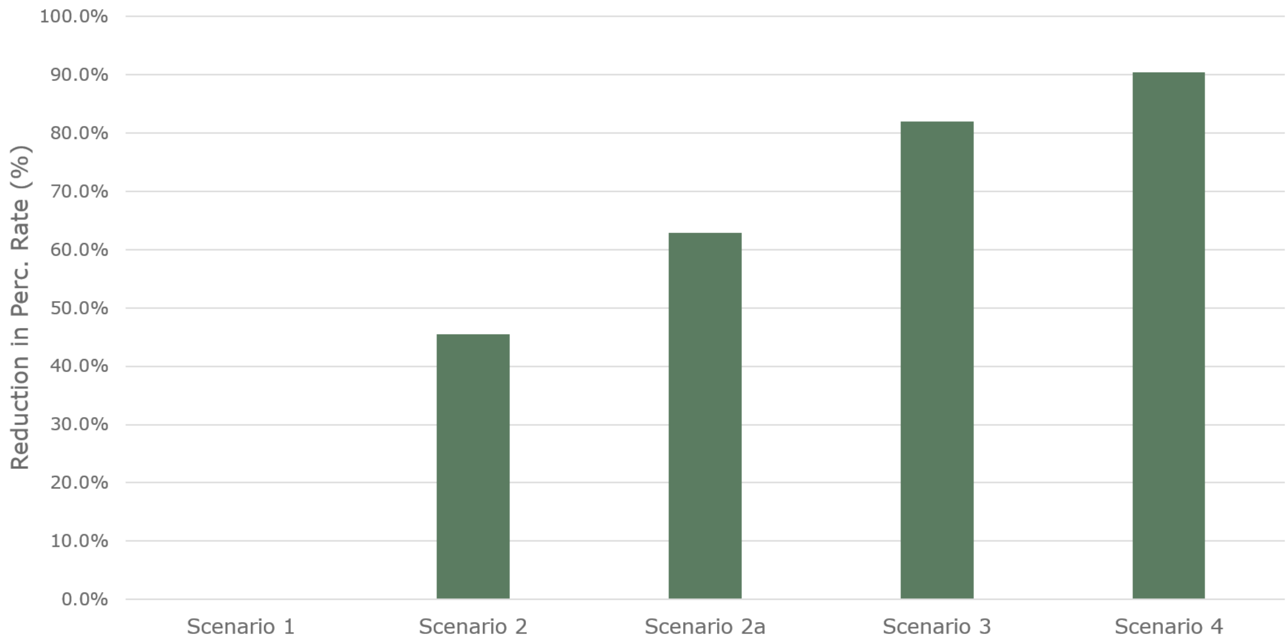

Figure 4 Reduction in percolation rate

4 Pilot-scale closure cover trials

Building on the scenario screening described above and the comparative modelling, the investigation progressed to pilot-scale field evaluation as the next step in the assessment framework. Pilot-scale trials were defined to provide field evidence on the performance and practicality of alternative closure cover configurations under site conditions. The trials are intended to evaluate cover system behaviour in a way that bridges early modelling outputs and full-scale closure implementation, recognising that modelling alone cannot resolve key uncertainties related to construction and field response. Importantly, the trials are positioned as a comparative step to test assumptions and reduce uncertainty rather than to identify a single 'correct' solution at this stage.

The stated closure objectives include minimising net percolation into underlying mine waste, supporting vegetation establishment and generating empirical data to support regulatory engagement where alternatives to the prescribed cover system may be considered. In line with these objectives, the trials were designed to validate hydraulic performance under field conditions, assess constructability using site-sourced materials and site equipment and test monitoring protocols for longer-term closure performance tracking.

A site near the waste rock dump crest was selected to balance representativeness with practical considerations such as access for construction and monitoring, proximity to material stockpiles, security, and minimising interference with active operations. The plots are planned on a level surface to improve comparability and simplify monitoring, with compacted berms included to limit hydraulic interaction between adjacent plots.

The closure cover scenarios described in Section 3.2 were subsequently implemented as pilot-scale field trials in April 2026. The trials were constructed as 4 adjacent plots on a level surface, each corresponding to one of the selected scenarios, to allow direct comparison under field conditions. Individual plots measure approximately 15 × 20 m, with cover thickness varying by scenario in accordance with the conceptual designs outlined previously. Representative cross-sectional drawings of the pilot-scale closure cover trials are shown in Figure 5.

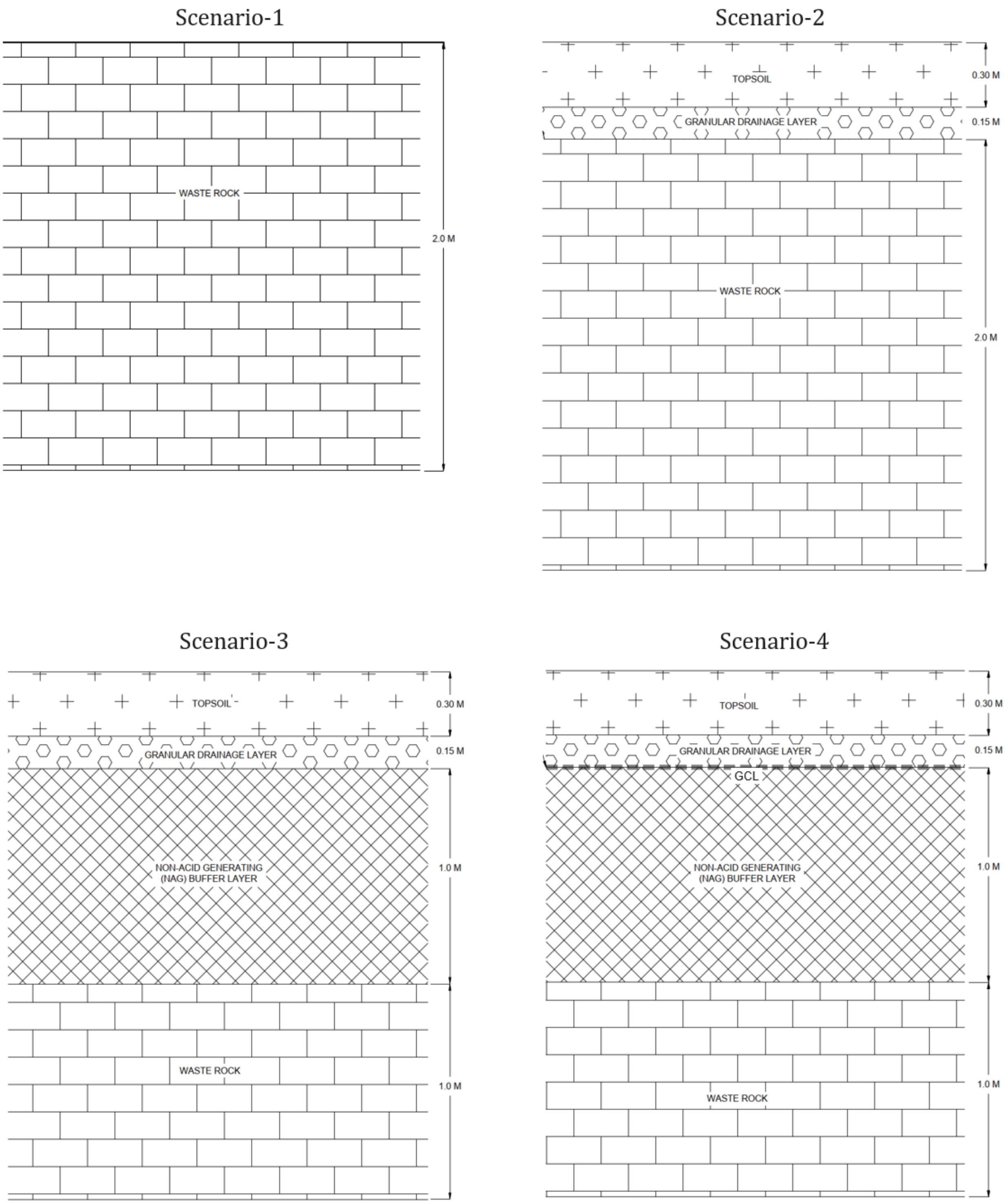

Figure 5 Representative cross-sectional drawings of the pilot-scale cover trials

5 Conclusion and implications for closure practice

This study demonstrates the value of a structured, early-stage assessment framework for closure cover design that integrates comparative modelling with pilot-scale field trials. The preliminary percolation modelling results highlight the importance of layering configuration in controlling net percolation and show that meaningful performance differences can be identified even at an early stage using relative, data-driven comparison. The work illustrates how modelling-informed pilot trials can be used to focus subsequent investigations on the most influential design variables, rather than treating closure cover selection as a single prescriptive end point. This approach supports informed optimisation while remaining aligned with regulatory objectives for infiltration management and environmental protection. Limitations associated with simplified modelling and laboratory assumptions are acknowledged, emphasising the role of field-based validation in improving confidence in long-term closure outcomes.

The pilot-scale trials were constructed in April 2026. At the time of writing, monitoring data were not yet available. The next phase of work will focus on systematic data collection from the trials, including measurements of soil matric potential and soil water content to characterise moisture storage, movement, and percolation behaviour within each cover configuration. An atmospheric monitoring station has also been installed at the trial area, allowing collection of site-specific climatic data to support interpretation of cover performance under actual field conditions. It is intended that monitoring will continue for a minimum of 2 years to capture seasonal variability, with data collection extended through to final closure where practicable. The monitoring program is intended to improve understanding of field performance of alternative cover systems in a semi-arid setting and to inform refinement of closure cover designs without compromising environmental protection. In parallel, the approach provides a transparent technical basis to support constructive regulatory engagement as closure frameworks develop.

Acknowledgement

The authors would like to acknowledge Centerra Gold and the Öksüt Environmental Team for their constructive engagement, active support and continued collaboration throughout the course of the study.

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