Appendix 12

Landform Design – SAR Waste Rock Emplacement

prepared by

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Tomingley Gold Extension Project

Landform Design

San Antonio and Roswell Waste Rock Emplacement

Erodibility Testing and Modelling

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1 INTRODUCTION

RW Corkery and Co Pty Ltd (RW Corkery), on behalf of on behalf of Tomingley Gold Operations Pty Ltd (the Applicant), a wholly owned subsidiary of Alkane Resources Ltd (Alkane), engaged Landloch to provide technical support to Tomingley Gold Operations (TGO) for design of a waste landform for the Tomingley Gold Extension Project (the Project).

The purpose of this Erodibility Testing and Modelling Program was to provide criteria for adoption in the design and rehabilitation of the San Antonio and Roswell (SAR) waste rock emplacement area (WRE) at the Tomingley Gold Mine (the Mine), approximately 50 km southwest of Dubbo, NSW. It details the laboratory-based erodibility testing on bulk samples of three materials at Landloch's Erosion Testing Facility. Test data were used to derive input parameters for the erosion modelling and to develop the design criteria.

Erosion modelling was undertaken in two phases, using separate models for different purposes. Phase 1 aimed to identify optimal batter options. It evaluated erosion on several 2-dimensional slopes being considered for the WRE with a range of surface conditions.

These findings were provided to RW Corkery and the Applicant, then incorporated in a 3-dimensional model developed for landform design. Phase 2 assessed erosion on this landform post mining by modelling changes over time, at time intervals up to 1,000 years.

1.1 Project Overview

Existing mining activities are undertaken in accordance with development consent MP 09_0155. The approved activities would continue under any new development consent, and MP 09_0155 is to be surrendered following receipt of the new development consent and all required approvals for the project. The approved activities include:

- Extraction of ore and waste rock from four open cut pits, with underground mining beneath three of those open cuts.
- Construction of three out-of-pit waste rock emplacements and one in-pit emplacement.
- Construction and use of various haul roads, a run-of-mine pad and associated stockpiles.
- Construction and use of a processing plant to process up to 1.5 million tonnes per annum.
- Construction and use of two residue storage facilities, being Residue Storage Facility 1 (RSF 1) to Stage 9 or a maximum elevation of 286.5 m AHD, and Residue Storage Facility 2 (RSF 2) to Stage 2 or a maximum elevation of 272 m AHD.

- Construction and use of ancillary infrastructure.

The proposed SAR Operations and additional or modified TGO operations, include the:

- Re-alignment of Newell Highway, Kyalite Road and associated intersections with Back Tomingley West Road and McNivens Lane, and Kyalite Road overpass.
- San Antonio Deposit Open Cut and Underground Mines.
- Construction of two waste rock emplacements, namely the Caloma and SAR Waste Rock Emplacement, and backfilling of the associated open cuts.
- SAR Amenity Bund, Haul Road and Services Road between the SAR Open Cut and the Caloma 2 Open Cut.
- Processing of ore from the SAR deposits using the approved processing plant at a maximum rate of 1.75 Mtpa.
- Increased capacity for Residue Storage Facility 2, from Stage 2 to Stage 9, with a maximum elevation of 286 m AHD.
- Associated surface and underground activities and infrastructure.

In addition, the project would include an extension of the approved mine life, from 31 December 2025 to 31 December 2032.

Figures showing the locality and general arrangement of the Project are provided in Figures A1 and A2, respectively (Appendix A).

1.2 Scope of Work

The scope of work involved:

i. A site inspection to observe existing rehabilitation progress and discuss rehabilitation practices on-site.

ii. Collecting bulk samples of three different materials that could potentially to be used as primary growth media for the rehabilitation of the WRE. These materials were described and detailed in the report *'Draft Tomingley Gold Extension Project Land and Soil Capability Assessment (SSM, 2021)'.*

iii. Erodibility testing of the bulk samples. Triplicate test plots and flumes were prepared and subjected to simulated rain and overland flows.

iv. Characterisation of settling velocity distributions of sediment derived from the rainfall simulation plots.

v. Derivation of parameters for erodibility and sediment data to be used as site specific inputs for erosion modelling.

vi. Erosion modelling on representative slopes and slope conditions for each material.

vii. Development of design criteria for use in the landform design process.

viii. Derivation of landform evolution model input parameters.

ix. Landform evolution simulations of the stability of a three-dimensional landform developed on the basis of landform design criteria.

2 METHODOLOGY

2.1 Bulk Sample Collection

Bulk samples of three materials were collected for detailed erodibility testing. Materials were recovered with an excavator and placed in flexible intermediate bulk containers (bulka bags) by mine personnel. The volume of each bulk sample was approximately 1 m^3. Materials were freighted to Landloch's Erosion Testing Facility in Toowoomba, Queensland for processing.

2.2 Erodibility Testing

Erodibility parameters for the Water Erosion Prediction Project (WEPP) runoff/erosion model (Flanagan and Livingston 1995) were derived from measurements of simulated rain and overland flows.

2.2.1 Rainfall simulation

The design of the rainfall simulator used is described by Loch *et al.* (2001), and applies simulated rain with a kinetic energy equivalent to that of natural rainfall at intensities >40 mm/h. As the simulated rain study is used to derive infiltration and interrill erosion parameters, the actual intensity applied does not affect the parameters obtained, provided it is sufficient to cause runoff, and has appropriate kinetic energy.

Triplicate plots 0.75 m square and 0.2 m deep were packed, compacted, and subjected to multiple wetting/drying cycles to ensure test samples were consistent with soil that had consolidated naturally under rainfall.

The gradient of the plots was set at 20 % and simulated rain was applied for a period sufficient for the samples to reach steady infiltration/runoff rates. Runoff generated by simulated rain was sampled at regular intervals, and sediment concentrations were measured gravimetrically. Samples of the rain-wet surface were taken, when simulated rain stopped, to measure sediment settling velocity distributions using an automated settling column (Loch 2001).

The simulator uses rainwater in all tests to avoid any potential impacts of water quality on infiltration and on the disaggregation of sediment to finer sizes.

2.2.2 Overland flows

Studies of rill erodibility used flumes 2 m long and 0.4 m wide. For all materials, three flumes were run, set at various gradients, ensuring that a wide range of flow tractive force was applied. In all cases, samples were packed, compacted, and subjected to multiple wetting/drying cycles to ensure the test sample was consistent with soil that had consolidated naturally under rainfall. For each flume, a range of flow rates and flow tractive forces was applied and sediment concentrations and flow tractive forces were measured at intervals during each flow rate.

2.2.3 WEPP parameter derivation

Erodibility parameters required for the WEPP model are K_i (interrill erodibility), K_R (rill erodibility), and τ_c (critical shear for rill initiation). These parameters are used to predict changes in erosion processes and rates in response to changes in runoff, slope length, and land management. Also important are the Hydraulic Conductivity parameter (K_e) which is used in the model to predict runoff, and sediment settling velocity distributions which are used to define the transportability of the eroded sediment.

2.3 Erosion Modelling

Two erosion models were used to evaluate the rehabilitated landform design for the SAR WRE:

1. WEPP runoff/erosion model (Flanagan and Livingston 1995); and
2. SIBERIA landform evolution model (Willgoose *et al.* 1989).

The two models have extremely different structures and functions, and are used for different purposes.

2.3.1 WEPP modelling

The WEPP model effectively considers runoff and erosion on 2-dimensional batter slopes. It was developed by the United States Department of Agriculture (USDA) to predict runoff, erosion, and deposition for hillslopes and watersheds. It is a simulation model with a daily input time step, but internal calculations use sub-daily rainfall data (storm data) when predicting runoff and erosion for days on which rainfall occurs.

As a primary planning tool, WEPP has a number of advantages, including the ability to:

- Derive accurate erodibility parameters from laboratory erosion studies;
- Consider site-specific climate (typically using a 100-year synthetic file based on local data);
- Rapidly assess a wide range of slope gradients, profile shapes, slope lengths, materials (soils), and surface vegetation cover;
- Provide erosion and runoff predictions at a range of time scales, from long term averages to daily data, or averages for specified periods or seasons; and
- Provide predictions of erosion rates at 100 points along a slope length, rather than simply averaging erosion over the entire slope length.

2.3.2 SIBERIA modelling

The SIBERIA landform evolution model is a 3-dimensional topographic model that predicts the long-term development of channels and hillslopes in a catchment on the basis of runoff, erosion, and deposition. The location and speed with which rills and gullies develop is controlled by a channelisation function. SIBERIA does not input actual rainfall or material erodibility parameters. Rather, the input parameters that define this channelisation function is related to both runoff and soil erodibility (Willgoose *et al.* 1989) and must be derived for each test material at each project site. SIBERIA solves for two variables:

1. Elevation, from which slope geometries are determined; and
2. An indicator function that determines where channels exist.

Channel growth is governed by an activation threshold that is dependent on discharge and slope gradient. When the activation threshold is exceeded, a channel is predicted to develop. In this way, it is possible for a modelled surface to initially have no gullies, and for channels to develop when the activation threshold is exceeded over time.

The model is equally applicable to any climatic regime as its input parameters are derived by calibration to runoff and erosion data. Input parameters can be derived from output of the WEPP model using methods developed by Landloch in consultation with the developers of SIBERIA.

SIBERIA has been successfully applied to explain aspects of geomorphology of natural landforms (Willgoose 1994) and has been extensively used in the context of mining and subjected to extensive validation. In general, the validation work indicates that provided the model is adequately calibrated, SIBERIA predictions of landform development appear to be reasonable (Hancock *et al.* 2000, Hancock *et al.* 2002, Hancock *et al.* 2003). In addition, Hancock (2004) notes that rates of erosion predicted by SIBERIA for a catchment in the Northern Territory compared favourably with estimates of erosion derived using the Caesium-137 method. As the two methods used completely independent input information, the agreement is particularly significant.

The SIBERIA model has been widely used for assessment of the development of constructed landforms on a range of mine sites across Australia and overseas (Willgoose 1995, Willgoose and Riley 1993, Boggs *et al.* 2000, Hancock *et al.* 2003, Hancock and Willgoose 2004, Hancock 2004, Mengler *et al.* 2004, Hancock and Turley 2006).

3 SITE SETTING

Relevant site setting details for erodibility testing of materials at the Mine are detailed in this section. The site was inspected by Simon Buchanan from Landloch on 6 May 2021 accompanied by representatives from TGO.

3.1 Climate

The study area is dominated by a sub-humid climate characterised by hot summers and no dry season (NSW National Parks and Wildlife Service, 2003).

Average monthly maximum temperatures in winter tend to range from 16°C to 17°C, and from 31°C to 33°C in summer (BoM, 2020). Summer temperatures can exceed 40°C for short periods.

Average monthly minimum temperatures in winter tend to range from 5°C to 8°C and from 17°C to 19°C in summer (BoM [Climate], 2021). Frosts are frequent through winter (BoM [Frosts], 2021).

Rainfall is relatively uniformly distributed throughout the year, with a median annual rainfall for Peak Hill of 561 mm. However, rainfall can be extremely variable in late spring and early summer when the highest observed falls have exceeded 200 mm in any one month.

Average evaporation exceeds the average rainfall throughout the year (NSW National Parks and Wildlife Service, 2003).

The annual rainfall erosivity (R-factor) for the region is 945 MJ.mm/ha.h.y (Yang, Chapman, Zhu, Tulau, & McInnes-Clarke, 2017). Rainfall erosivity is a measure of the ability of rainfall to cause erosion. Values for monthly R-factors and erosivity ratings are provided in Table 1, and are based on criteria presented in *Soils and Construction – Managing Urban Stormwater* (Landcom, 2004). The rainfall erosivity rating is *low* all year.

Table 1. Monthly rainfall and erosivity R-factor and rating for Tomingley (BoM [Climate], 2021)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	58.5	50.8	51.1	42.0	44.0	43.2	44.5	42.1	38.8	47.9	47.3	51.2
R Factor	86	86	71	74	73	75	71	65	81	80	86	86
Rating	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

3.2 Post Mining Landforms and Land Uses

It is understood that the post mining land uses are yet to be determined. For the purpose of this assessment, they are assumed to be comparable to those detailed for WRE's at TGO in the *Mining Operations Plan (MOP)* (RW Corkery, 2016). Details of relevant features are -

- The final landforms are to be safe, stable, non-polluting, compatible with the surrounding landscape and suitable for the proposed final land use.
- Soils, hydrology, and grassland ecosystem with maintenance needs no greater than those of surrounding, non-mine disturbed land.
- Rehabilitation vegetation is to include either:
  - Grassland to be dominated by shallow rooted grassland species; or
  - Woodland rehabilitation to be consistent with the Inland Grey Box-Poplar Box-White Cypress Pine Community.

3.3 Waste Rock Emplacements

At TGO, excavated waste rock is paddock dumped by truck within prepared emplacement areas before being shaped and profiled by bulldozer.

The existing WRE landforms at TGO are a 'bench' design with lifts at 10 m intervals to a height of 35 to 40 m above the surrounding ground. The gradient of batter slopes is 33 %. Between each lift, a 5 m wide berm with a 5 % backslope and a 0.5 % longitudinal grade is constructed. The benches direct surface runoff into a series of rock chutes that discharge at the toe of the WRE (Photograph 1).

Photograph 1. Looking south-east at TGO's WRE #3. Benches drain laterally into the rock chutes then discharge at the toe of the WRE. This photography was captured after the WRE was hydromulched for revegetation circa December 2019 (Courtesy, the Applicant, May 2021).

3.4 Revegetation

The current practice at TGO is to place approximately 0.2 m of topsoil over waste rock, after it has been shaped to the final contour. The soil materials used to date mainly comprise Red Dermosol Topsoil recovered during mining.

It is understood the Project is considering increasing the depth of topsoil placement to 0.3 m (*pers comm* RW Corkery 2021).

Gypsum is surface applied at a rate of 10 t/ha prior to seeding. Deep ripping and surface tillage is not undertaken. As such, the resulting surface contains negligible microrelief. Seed is hydraulically applied with straw as hydromulch.

At the time of inspection vigorous grass cover was observed on both the crest and batters of the WRE. The area had been seeded approximately 18 months earlier in the summer of 2019/2020 (Photograph 2). Groundcover exceeded 90 % (Photograph 3).

Photograph 2. Vigorous grass and herb cover on the WRE batter at TGO.

Photograph 3. Vegetative groundcover exceeded 90 % at the time of inspection of TGO.

Groundcover species mainly included *Chloris gayana* (Rhodes Grass), *Arctotheca calendula* (Capeweed), *Echium plantagineum* (Paterson's Curse), *Cynodon dactylon*

(*Couch), Avena fatua* (Wild Oats), *Lolium rigidum* (Wimmera Ryegrass*)* and/or *Sonchus oleraceus* (Milk Thistle) (DnA Environmental, 2020).

Rehabilitation progress on a WRE was observed at a nearby minesite (Peak Hill Mine) situated 15 km south of Tomingley Gold Mine. The landform had a similar benched design to the existing WRE's at the Mine, with batters at 33 % gradient and benches separating 10 m lifts (Photograph 4).

Photograph 4. The WRE at Peak Hill Gold Mine has a comparable benched design to the existing WRE's at Tomingley Gold Mine.

Photograph 5. Vigorous grass cover on the batter of the WRE at Peak Hill Gold Mine.

The revegetation was established approximately five years previously. Vegetation at this location was also vigorous, with greater than 90 % ground cover (Photograph 5).

3.5 Waste Rock Characterisation

Characterisation of waste rock regarding its ability to support plant growth is yet to be undertaken. At present it is unknown if the roots of pasture species are mainly limited to the topsoil layer (approximately 0.2m), or if roots extend into the underlying waste materials on the WREs, and are utilising water and nutrient reserves deeper in the profile. Knowledge of the depth of rooting is important as it will influence expectations of the amount of soil water available to plants and the ability of vegetation to withstand periods of drought.

3.6 Existing Erosion

During the inspection, negligible erosion was observed on portions of the WREs that support vigorous vegetive cover. This general absence of erosion was also noted in the 2020 rehabilitation monitoring report (DnA Environmental, 2020) where no rills or gullies were observed in monitoring transects installed on WRE 1, WRE 2, and WRE 3 at TGO.

An exception to this is some isolated instances of accelerated erosion at localised areas adjacent to rock chutes. This erosion is expected to be related to earthwork disturbances (possibly compaction) (Photograph 6). Of relevance to this study is the spacing of rills in these bare areas, which was measured to range from 1 to 2 m. This finding was used as an input in erosion modelling with WEPP.

Photograph 6. Rill erosion observed on the batter of WRE #3. Likely related to disturbances associated with construction of the batter chute.

3.7 Soil Characterisation

Soil data provided in the report *DRAFT Tomingley Gold Extension Project Land and Soil Capability Assessment* (SSM, 2021) was relied upon to assess materials that may be salvaged in the Project for rehabilitation. Three materials have been identified as warranting consideration and detailed suitability assessment. They include:

- Soil 1: *Chromosol and Sodosol Topsoil (CH/SO Topsoil)* – topsoil materials for the Chromosol and Sodosol soil groups;
- Soil 2: *Chromosol Subsoil (CH Subsoil)* – topsoil materials for the Chromosol soil group; and
- Soil 3: *Gilgai Topsoil (VE Topsoil)* – topsoil materials for the Gilgai soil group.

The key physicochemical properties of soils tested are provided in Table 2. Images of soil materials are provided in Appendix B.

Table 2. The key physicochemical properties of soils tested.

Parameter	S1 Chromosol/Sodosol (CH/SO) Topsoil	S2 Chromosol (CH) Subsoil	S3 Gilgai (VE) Topsoil
Colour	Brown	Red or Brown	Brown
Texture	Silty/sandy clay loam	Medium clay	Clay loam
Soil pH	Slightly acidic	Neutral	Slightly acidic
Salinity	Low	Low	Low
Organic matter	Moderate	Low	Moderate
Exchangeable cations	Low	Moderately low	Moderately high
Sodicity	Low	Generally low, sometimes moderate	Low
Organic matter	Moderate	Not tested. Assumed to be low	Moderate
Macro-nutrients	Moderate, except low sulphur		Moderate, except low sulphur
Micro-nutrients	Adequate, expect low zinc		Adequate, expect low zinc
Coarse fragment Content	Low	Low	Low

3.8 SAR WRE Characteristics

Waste materials from SAR Open Cut will be placed into the voids of the Caloma and Caloma 2 Open Cuts until backfilled. The remaining waste will be used to backfill the southern portion of the SAR Open Cut and the SAR WRE.

The SAR WRE design is to be safe, stable, and non-polluting. The intent is to construct a geomorphic design with aesthetics that replicate a natural landform. It is to be without benches, steps or a large, flat plateau surface, and where practicable, not concentrate runoff or require the formation of rock lined engineered drainage chutes or structures.

The estimated volume of the SAR WRE is 41 M m^3 with a height of 70 m and footprint of 160 ha.

4 REPRESENTATIVE SLOPES

A number of representative WRE slopes were prepared for use in erosion modelling (WEPP) to investigate the effects of different gradients, slope lengths, and shapes on erosion.

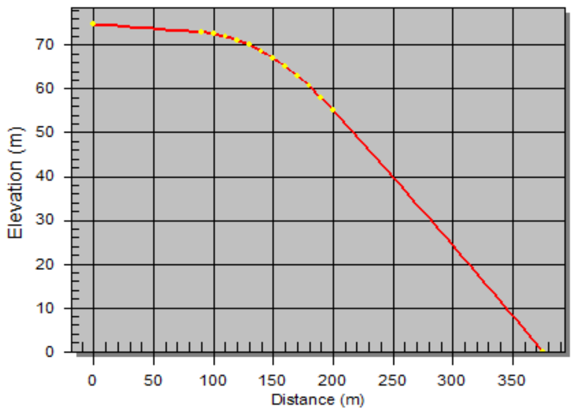
RW Corkery provided a conceptual WRE landform with the following criteria:

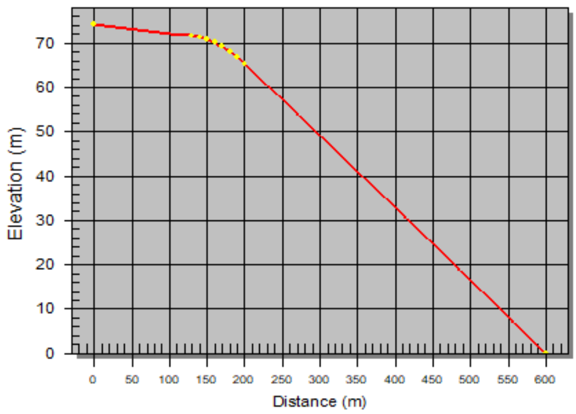
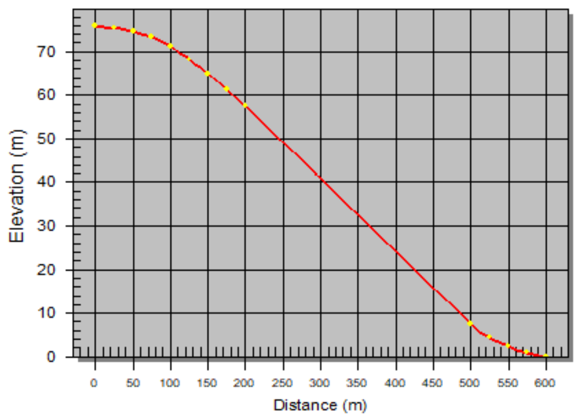
- Height of approximately 75 m relative to the surrounding ground level.
- Crest to be free draining and slightly mounded or undulating.
- Batter gradients between 16.7 % and 33 %.
- Batters to be absent of engineered drainage structures.

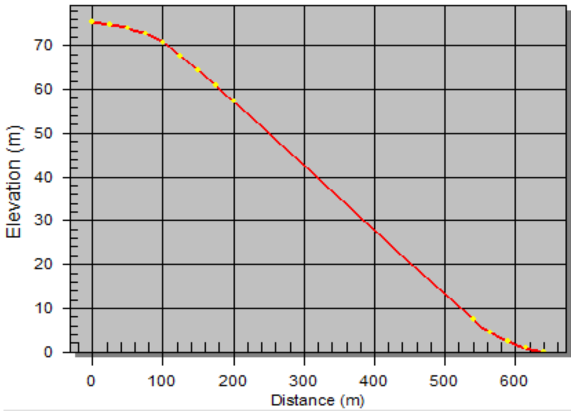
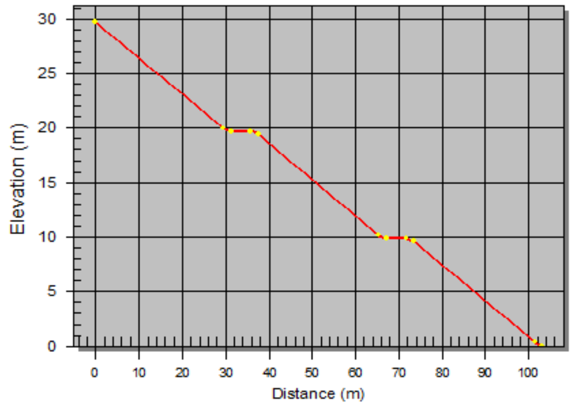
Key details of representative slopes are provided in Table 3.

Table 3. Details of representative slopes used for WEPP model input.

Details	Graphic

<u>RS #1 Convex 33 %</u>
• No benches, berms, or crest bunds.
• Maximum batter gradient 33 %.
• Simulates a convex section at the crest 200 m in length that runs onto the batter.
  o Section 0–100 m at 2 % gradient; and
  o Section 100–200 m increases in gradient incrementally from 2 % to 33 %.
• Linear foot slope that remains at the maximum gradient.
Total horizontal distance from the crest centre is 375 m.
	

<u>RS #2 Convex 16.7 %</u> Similar to representative slope RS #1 Convex 33.3 % except; • Maximum batter gradient is 16.7 %. • Crest gradient increases from 2 % to 16.7 % in Section 100–200 m. Total horizontal distance from the crest centre is 600 m.	
<u>RS #3 S-Shaped 16.7 %</u> Similar to representative slope # 2 Convex 16.7 % except; • Foot slope is concave. Gradient decreases from 16.7 % to 4 % in Section 500–600 m. • Crest gradient increases incrementally from 2 % to 5% in Section 0–100 m. Crest gradient increases incrementally from 5 % to 16.7 % in Section 100–200 m.	

<table>
<tr><th>Details</th><th>Graphic</th></tr>
<tr><td><u>RS #4 S-Shaped 14 %</u>
Similar to representative slope # 3 (S-Shaped 16.7 %) except;
• Maximum batter gradient is 14.7 %.
Total horizontal distance from the crest centre is 640 m.</td><td></td></tr>
<tr><td><u>RS #5 Benched 33 %</u>
• Batter gradient 33 %.
• Benches at 10 m lifts.
• Berms 5 m wide a 0 % gradient.
• Simulated crest bund.
Total horizontal distance from the crest bund is 100 m.</td><td></td></tr>
</table>

5 SOIL LOSS TARGETS

This study used runoff and erosion modelling to identify landform options that would erode at rates low enough to provide long-term stability. Effectively, the landforms are planned to be consistent with tolerable rates of soil loss. Wischmeier and Smith (1978) defined tolerable soil loss for cropland as "*the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely.*"

A value of 11.2 t/ha/y averaged over an area of interest is often cited as a tolerable soil loss rate. However, that value was derived by US soil conservation agencies for deep, fertile cultivated soils, and has little relevance to most rehabilitated minesites. Using similar criteria to those applied for cropping land, a lower soil loss tolerance value of 4.5 t/ha/y was developed by US agencies for erosion of rangeland soils and shallow cultivated soils (Wight and Siddoway 1979).

Lower tolerance values are relevant to rangeland and minesite situations, as not only are the soils shallower and more susceptible to fertility decline, but the lack of regular tillage or disturbance means that any rills or points of scour that form are more likely to extend and develop into gullies over time. These are typically of concern for minesite landforms where there is no bedrock layer at depth that can limit long-term deepening of rill features.

A key priority in setting a tolerable erosion target is the prevention of significant rill or gully development. On that basis, for slopes where long-term erosion risk (for a range of reasons) is considered low, then a mean average erosion rate for the whole slope of 5 t/ha/y and a mean maximum rate at any one point on the slope of 10 t/ha/y has commonly been applied by Landloch. Typically, the *low risk* category includes slopes where:

- The material underlying the topsoil layer is not dispersive and unlikely to be more erodible than the surface layer if exposed.
- Establishment of vigorous and sustainable vegetation is considered to be readily achievable.
- Rainfall in the area and soil fertility/productivity are such that there is a reasonable probability of vegetation stabilising any rills that form during rehabilitation establishment[1].
- The overall landform height is less than 50 m.

The erosion hazard is considered higher on slopes with criteria outside any of the above factors. In such situations a mean maximum erosion rate of 5 t/ha/y at any point on a batter slope[2] is used by Landloch in planning hazardous slopes on minesite landforms, on the basis that - at that value - rilling is largely if not completely absent. A similar approach using a risk assessment to determine target rates for both average and maximum erosion rates on slopes was outlined by Howard and Loch (2019).

In this instance, given that the landform height exceeds 50 m, and the quality of waste rock material is unknown, the target soil loss criterion applied is the mean *maximum* erosion rate *at any one point on the slope* of 5 t/ha/y.

6 ERODIBILITY PARAMETERS

Rainfall simulation and overland flow tests were performed on materials to derive erodibility parameters for use as site specific input data for erosion modelling. Photographs of the test plots are provided in Appendix B.

Erodibility parameters varied for the materials, as would be expected. The key parameters for materials considered in erosion modelling are provided in Table 4 and described below:

- Critical shear – above this value, soil detachment per unit of flow shear stress increases rapidly.
- Interrill erodibility – a measure of the rate of soil detachment by the combination of raindrop impact and shallow overland flows.
- Rill erodibility – a measure of the rate of soil detachment by concentrated rill flow. (It is the increase in soil detachment per unit increase in shear stress of the flow).
- Steady infiltration rate – this directly influences runoff rate. Runoff occurs once the rainfall intensity exceeds infiltration rate.

[1] This would be assessed on the basis of observations of colonisation of bare areas in existing rehabilitation with similar topsoil and subsoil.

[2] Typically, on linear batter profiles, erosion rates increase with slope length as detachment and transport by overland flow increase with increasing flow volumes.

- Surface roughness – relates to the micro-relief of the ground surface and any long-lasting relief (e.g. crests and trough) formed by tillage or ripping.
- Soil analytical data on particle size analysis, cation exchange capacity, exchangeable sodium percentage, and soil aggregate stability to rapid wetting.

Table 4. Key input parameters of materials considered in erosion modelling.

Parameter	S1 CH/SO Topsoil	S2 CH Subsoil	S3 VE Topsoil
Clay (%)	13.8	37.6	23.7
Silt (%)	8.8	6.3	8.7
Sand (%)	78.5	56.1	67.6
Cation Exchange Capacity (meq/100g)	5.1	14.2	19.1
Exchangeable sodium percentage (%)	2.1	13	4.7
Steady Infiltration Rate (mm/hr)	14.9	20.3	8
Critical Shear (Pa)	6.1	6.1	8.7
Interrill erodibility ($Kg.s/m^4$)	1,650,953	2,233,538	1,549,905
Rill erodibility (s/m)	0.0030	0.0031	0.0055
Surface Roughness (mm)	30 or 70	30 or 70	30 or 70

7 EROSION SIMULATIONS – BATTER OPTIMISATION - WEPP

Simulations were carried out to:

1. Assess erosion potential of each material at differing levels of cover that included:
   - 0 % (nil cover);
   - 50 % (moderate cover);
   - 70 % (high cover); and
   - 90 % (very high cover).
2. Evaluate the rates of erosion and deposition on representative slopes.
3. Consider the effect of soil roughness on erosion rates. Levels of roughness were 3 cm (low roughness) and 7 cm (high roughness).

All simulations used a 100-year climate file prepared from:

- Daily data from the Peak Hill Post Office, NSW, situated 15 km south of the Mine. It includes daily rainfall records for over 120 years (01/01/1900 to 30/04/2021).
- Sub-daily data for Alectown, NSW, situated 38 km south of the Mine. It includes daily rainfall records for 46 years (1971 to 2017). This data provided detail on the intensity of rainfall events near the Mine.

For each material, measured erodibility parameters and measured equivalent sand size distributions of detached sediment were inputs to the WEPP model.

WEPP settings simulated a well-formed batter with a low degree of micro-relief that does not concentrate flow. A low degree of surface roughness (3 cm relief) was included as the default to be consistent with surface observations of negligible microrelief.

7.1 Comparison of Erodibility of Materials on Bare Surface

The aim of the initial round of modelling was to obtain a broad appreciation of the erodibility of materials on different batter gradients, for the given climatic conditions. Model settings simulated materials in a non-vegetated condition (bare surface) with a rill spacing (across slope) of 2 m, to be consistent with site observations (Photograph 6). Simulation inputs for batters were RS #1$_{\text{Convex 33\%}}$ and RS #2 $_{\text{Convex 16.7\%}}$.

Mean predicted erosion rates are presented in Figure 1. The pattern of erosion shown – with a sharp increase in erosion rate at approximately 100 metres slope length and then reaching a maximum as slope length increases beyond 200 metres length - is typical of a situation where erosion rates become controlled (at longer slopes) by sediment transport capacity of the overland flow.

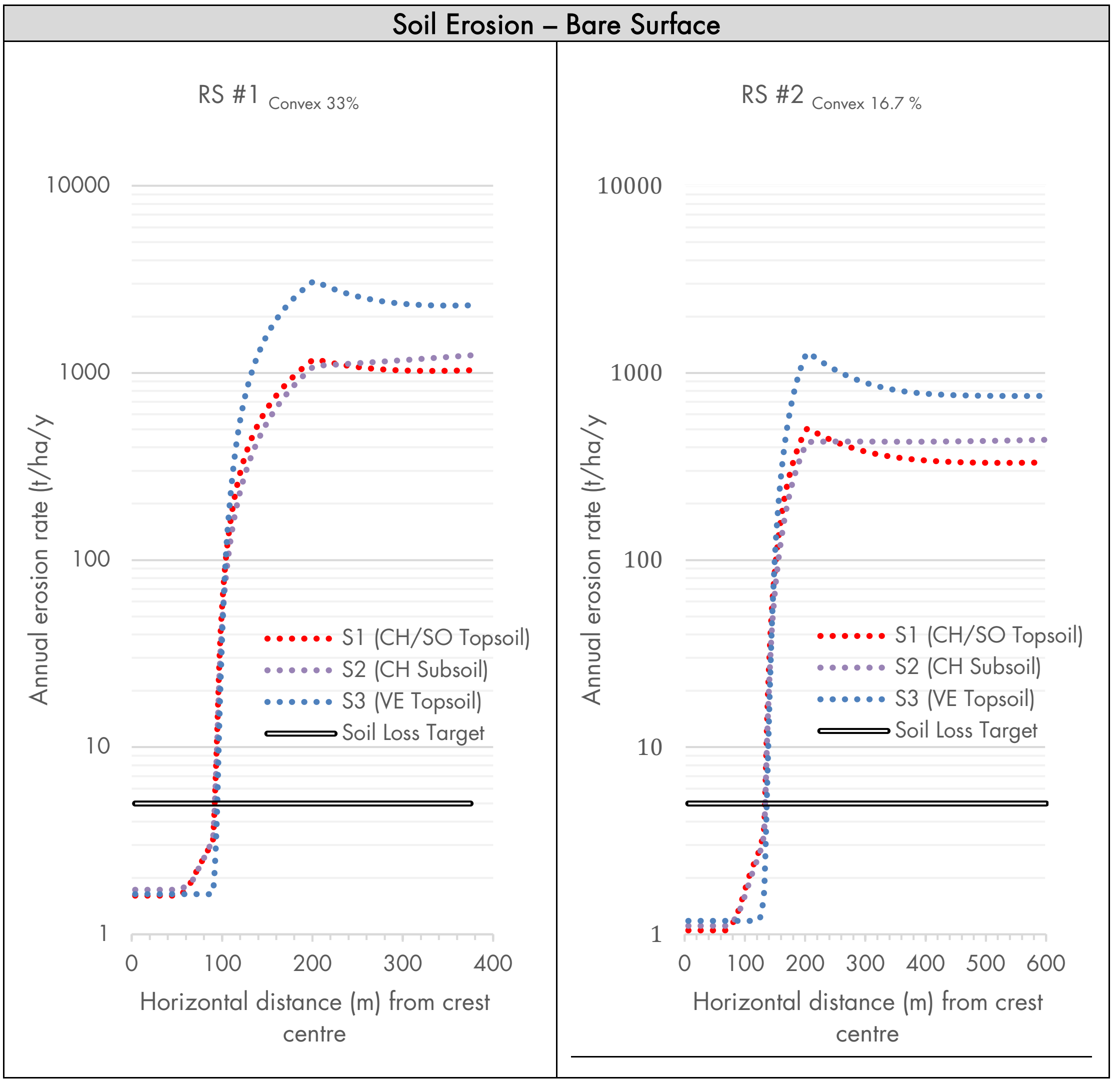


Figure 1. Predicted rates of erosion for bare materials on batter convex slopes of 16.7 % and 33 %.

7.1.1 Materials

Erosion rates for the bare surface condition were substantially higher than the adopted soil loss criterion of 5 t/ha/yr, and consistently greater than 100 t/ha/yr. The CH/SO Topsoil was the least erodible and the VE Topsoil the most. Erodibility of the CH Subsoil was slightly higher than the CH/SO Topsoil.

Comparing predicted erosion rates for the three materials demonstrates how the different material parameters influence erosion (Table 4). The CH/SO Topsoil and CH Subsoil have similar values for *critical shear* and *rill erodibility* but the CH Subsoil has an appreciably higher *inter-rill erodibility,* and would be more prone to raindrop and sheet flow erosion than CH/SO Topsoil. Hence its slightly higher erosion rates.

In contrast, the *rill erodibility* of the VE Topsoil is almost double that of the other materials, indicating that rill detachment rates of this material would be highest of the three tested. As well, sediment transport capacity of this material was clearly highest of the three materials (Figure 2). This is because the swelling clays in Vertosol soils result in detached sediment (aggregates) being swollen, of low density, and highly transportable.

7.1.2 Slope shape

Apart from the differences in magnitude of erosion rates among materials, the erosion characteristics of the materials for the RS #1$_{\text{Convex 33\%}}$ and RS #2$_{\text{Convex 16.7\%}}$ batters shared a number of similarities.

- Erosion rates on Section 0–100 m on the crest (at a gradient of 2%) were consistently low and below 2 t/ha/yr.
- There is a substantial increase in erosion rates along the convex portion of the crests on Section 100–200 m, where gradient increases from 2 % to either 16.7 % or 33 %.
- Peak erosion occurs at the inflection point of the crest and batter around Section 200–250 m.
- Mean erosion rates remain relatively constant along portions of the batter on Sections ≥ 300 m. This occurs at horizontal distances greater than 100 m from the inflection point on the crest/batter.

The predicted erosion rates for the two batters demonstrate how the different slope shape influences erosion (Table 4). On the crest along Section 0–100 m, runoff occurs as shallow sheet flows and results in low rates of erosion. The erosion rates rapidly increase as gradient increases along Section 100–200 m, as runoff volume increases and overland flow begins to converge to form rills that scour the soil surface. Rates of erosion reach a maximum at the inflection point on the slope (and immediately beyond) where maximum gradient occurs.

An important finding is that erosion rates beyond the inflection point remain relatively consistent because they are limited by the transport capacity of the runoff. This is largely governed by the intensity and depth of rainfall, permeability of the soil, gradient of the slope, and the settling velocity distribution of the detached sediment. When erosion is 'transport limited' further increases in slope length have negligible influence on the rate of erosion as the runoff energy has reached its capacity to carry sediment. For all of these scenarios, transport capacity was limited to within approximately 200 m of the crest centre.

7.2 Impacts of Surface Vegetative Cover and Batter Shape

The aim of the second series of modelling was to identify the levels of groundcover required to achieve the soil loss target adopted. Scenarios included various cover levels for all three soils on representative slopes RS #1 $_{\text{Convex 33\%}}$ and RS #2 $_{\text{Convex 16.7\%}}$.

The specific impacts of increased surface vegetation cover are:

- Increased infiltration - resulting in lower run-off rates;
- Reduced rill spacing due to greater surface hydraulic roughness - effectively decreasing the degree of cross-slope concentration of overland flows; and
- Surface protection from drop impacts and flow energy.

To simulate varying levels of surface vegetation cover:

- WEPP hydraulic conductivity parameter (K_e) was modified to account for impacts of cover on steady infiltration rates, as shown by rangeland research (Kato *et al.* 2009). Effectively, steady infiltration rate generally increases by 7–10 mm/h for each 10 % increase in surface vegetation cover. As a conservative measure, in this case steady infiltration was increased by 7 mm/h for every 10 % increase in surface vegetation cover.
- Rill spacing (degree of flow concentration across slope) was modified so that flows were less concentrated as surface vegetation cover increased. Adopted rill spacing values were 2 m, 1.5 m, and 1 m for cover levels of 0 %, 50 %, and ≥ 70 %, respectively.
- Cover (C) factors for the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al.* 1997) were derived from reported values for rangeland surface vegetation cover published by the NSW Soil Conservation Service (NSW SCS, 1993) and applied to predicted erosion rates.

Mean predicted erosion rates for representative slopes RS #1 $_{\text{Convex 33\%}}$ and RS #2 $_{\text{Convex 16.7\%}}$. are presented in Figure 2 and Figure 3, respectively.

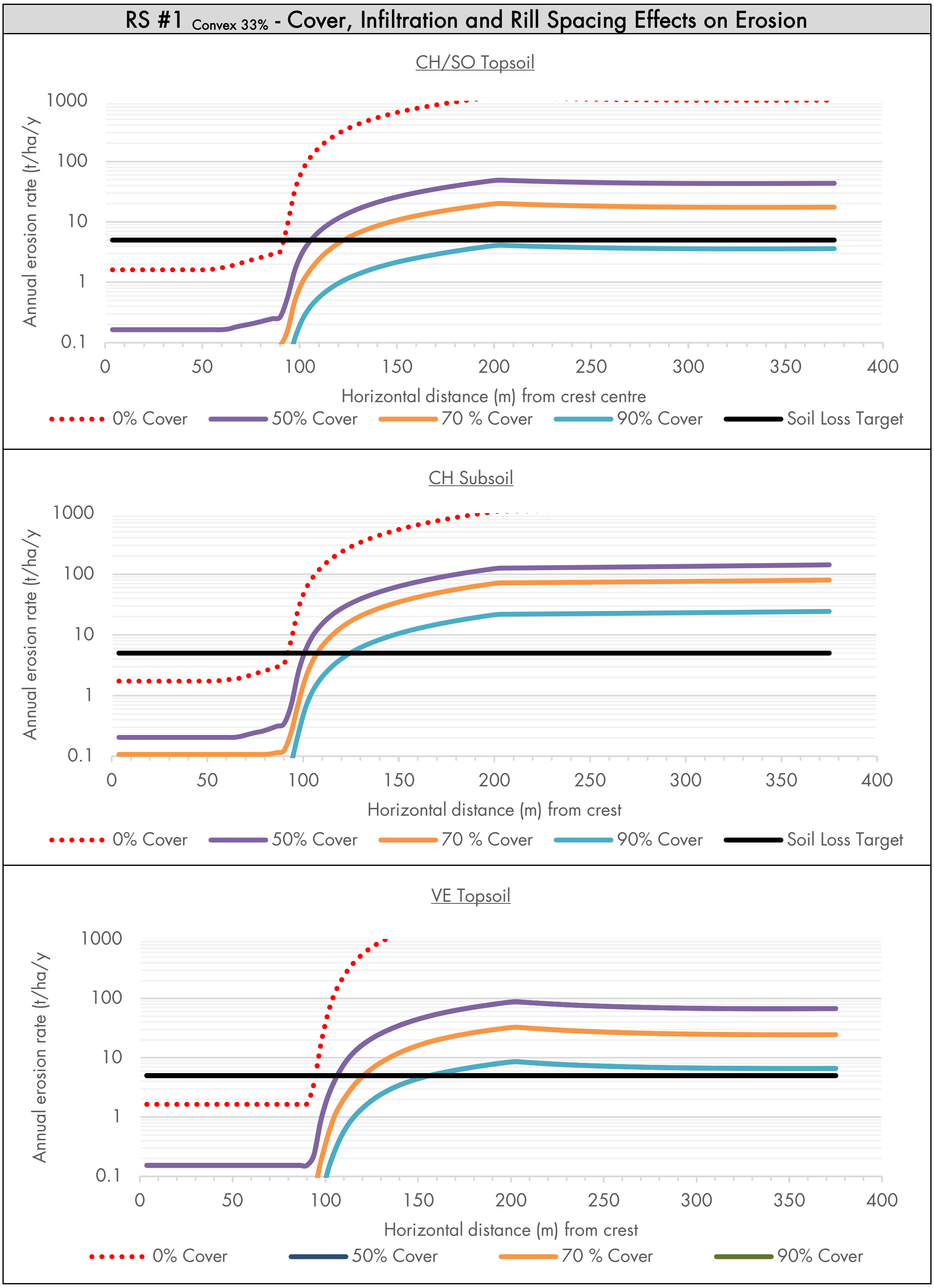


Figure 2. Predicted rates of erosion on convex slopes with a maximum gradient of 33 %. Results for CH/SO Topsoil, CH Subsoil, and VE Topsoil are presented for cover levels of 0 %, 50 %, 70 %, and 90 %.

RS #2 Convex 16.7% - Cover, Infiltration and Rill Spacing Effects on Erosion

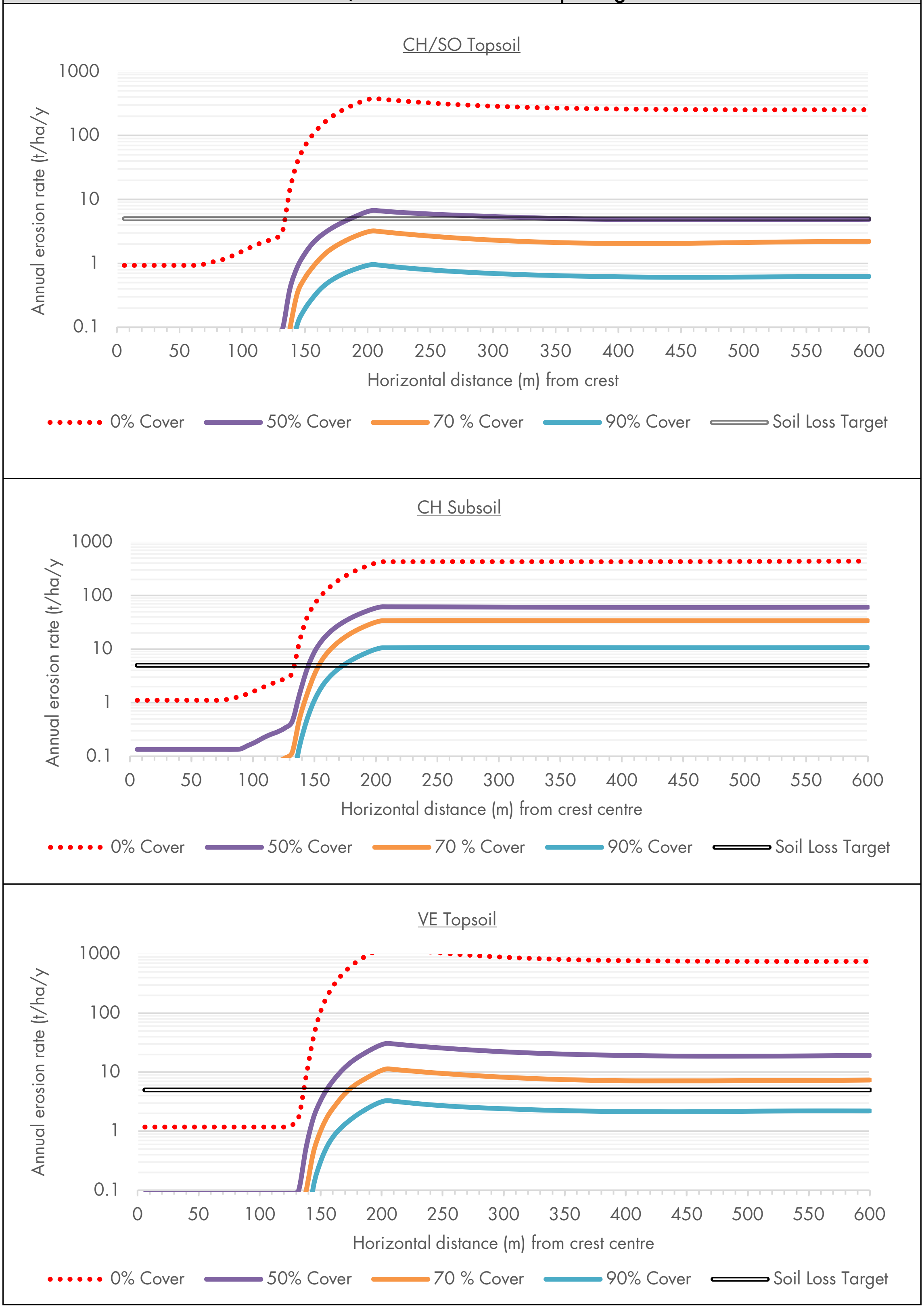


Figure 3. Predicted rates of erosion on convex slopes with a maximum gradient of 16.7%. Results for CH/SO Topsoil, CH Subsoil, and VE Topsoil are presented for cover levels of 0 %, 50 %, 70 %, and 90 %.

Modelling demonstrates large reductions in predicted erosion in response to surface vegetative cover (Figures 2 and 3). Reductions in annual runoff were significant factors in the reduction of predicted erosion. In all simulations, runoff was only produced in years when large rainfall events occurred.

7.2.1 Erosion with 90 % vegetation cover levels

The 90 % cover level represents the site conditions observed at the time of inspection (Photographs 2, 3, and 5). At this level of cover, the soil loss target was achieved in the following soil / representative slope scenarios:

- CH/SO Topsoil on RS #1 $_{\text{Convex 33\%}}$;
- CH/SO Topsoil on RS #2 $_{\text{Convex 16.7\%}}$; and
- VE Topsoil on RS #2 $_{\text{Convex 16.7\%}}$.

7.2.2 Erosion with 50 % and 70 % vegetation cover levels

It is anticipated that cover levels may not always be 90 % or greater. Periods of drought, or areas where woodland establish, may result in reduced groundcover. Hence, to consider such situations, modelling scenarios with 50 % and 70 % cover were performed.

The soil loss target was only achieved with the CH/SO Topsoil on RS #2 $_{\text{Convex 16.7\%}}$. at 70 % cover.

In all other scenarios erosion rates exceeded the soil loss target.

7.3 Targeted Scenarios

A third round of modelling was undertaken to evaluate several targeted scenarios that are considered relevant to the Project. These included:

- RS #3 $_{\text{S-Shaped 16.7 \%}}$ with CH/SO Topsoil with:
  - low surface roughness; and
  - high surface roughness;
- RS #4 $_{\text{S-Shaped 14.7 \%}}$ with CH/SO Topsoil; and
- RS #5 $_{\text{Benched 33\%}}$ with CH/SO Topsoil.

All of the targeted scenarios were modelled only with CH/SO Topsoil because previous modelling events had identified it as the only material with the potential to achieve the tolerable soil loss rate on representative slopes with 70 % groundcover.

7.3.1 Representative slope S-Shaped 16.7 %

An S-Shaped batter with a maximum gradient of 16.7 % that is convex near the crest and concave at the footslope (RS #3 $_{\text{S-Shaped 16.7\%}}$), aims to represent a slope more 'natural in appearance' than representative slope RS #2 $_{\text{Convex 16.7\%}}$. The inclusion of a concave foot slope has an appreciable effect on erosion in two ways.

Firstly, the section of batter at 16.7 % most prone to erosion is reduced in length from 400 to 300 m. This resulted in a small reduction in the mean maximum predicted erosion rates (Table 5).

Table 5. Comparison of mean maximum erosion rates on representative slopes RS #2 Convex 16.7% and RS #3 S-Shaped 16.7% at cover levels of 50 % and 70%.

Cover Level	Mean maximum erosion rates (t/ha/y)	
	RS #2 Convex 16.7%.	RS #3 S-Shaped 16.7%
50 %	4.8–6.7	4.5–5.2
70 %	2.2–3.2	1.9–2.4

Secondly, the presence of the concave footslope results in deposition of eroded materials on the footslope of the batter (Figure 5), rather than beyond the toe of the batter, as occurs in representative slope RS #2 Convex 16.7%.

<u>Surface Roughness</u>

Two scenarios were considered with representative slope RS #3 S-Shaped 16.7%. The first scenario used a surface roughness input of 3 cm, being the same as all previous scenarios discussed. This represents the soil surface as seen in existing rehabilitation on the Mine.

The roughness of the second scenario had a higher value input of 7 cm. This is considered comparable to batters deep ripped along the contour, which might bring an appreciable amount of rock to the surface. It could also apply to a roughened surface formed by shallow ripping, or with a mounding plough, although such roughness in this material would be considered semi-permanent compared to more permanent roughness formed by rock.

Mean predicted erosion and deposition rates for low and high surface roughness, with 50 % and 70 % cover, are presented in Figures 4 and 5.

Increasing surface roughness resulted in substantial reductions in predicted erosion (Figures 4 and 5). The maximum mean erosion rates at:

- 50 % cover reduced from 5 t/ha/yr to 2–3 t/ha/yr; and
- 70 % cover reduced from 2 t/ha/yr to less than 1.5 t/ha/y.

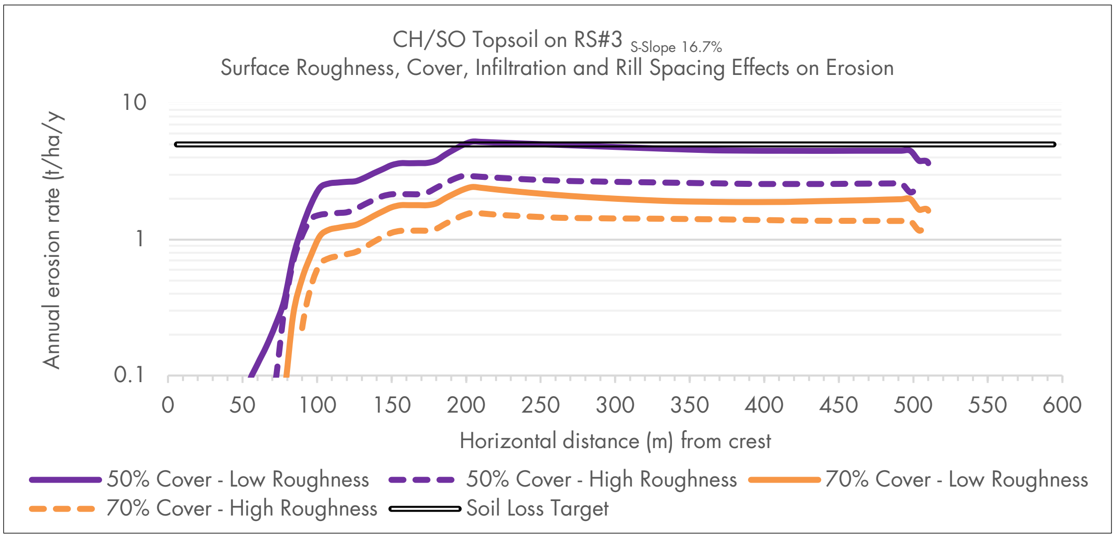


Figure 4. Surface roughness: Predicted rates of erosion on S-slope with a maximum gradient of 16.7 %. Results for CH/SO Topsoil for cover levels of 50 % and 70 %, with low and high surface roughness.

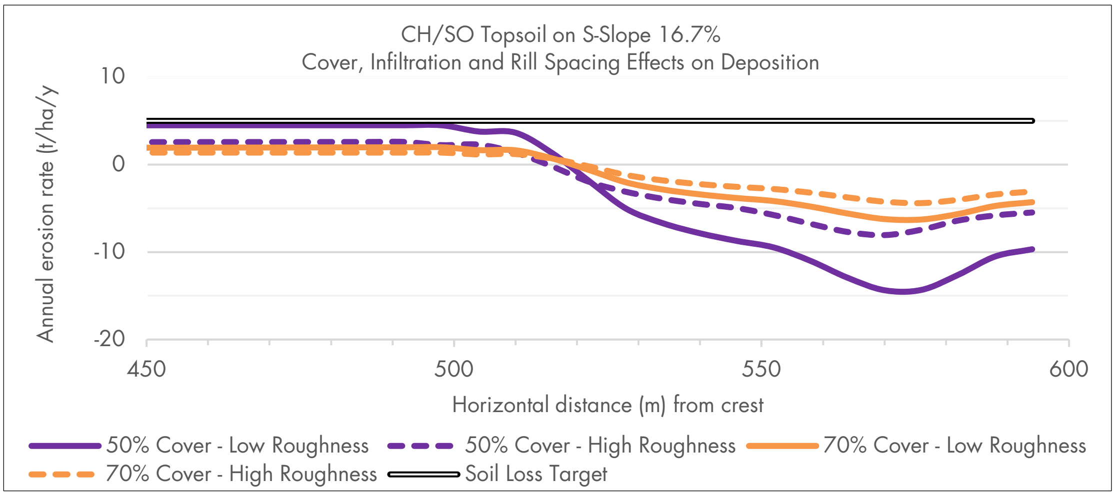


Figure 5. Surface roughness: Predicted rates of deposition at the lower section of S-slope with a maximum gradient of 16.7 %. Results for CH/SO Topsoil for cover levels of 50 % and 70 %, with low and high surface roughness. The figure presents data for the depositional area at the toe of a much longer slope.

7.3.2 Representative slope S-Shaped 14.7 %

An S-Shaped batter with a maximum gradient of 14.7 % (RS #4 $_{\text{S-Shaped 14.7 \%}}$) is similar to representative slope # 3 $_{\text{S-Shaped 16.7 \%}}$, except that it has a shallower gradient and longer slope length and footprint.

Mean predicted erosion and deposition rates for representative slopes RS #3 $_{\text{S-Shaped 16.7\%}}$ and RS #4 $_{\text{S-Shaped 14.7 \%}}$, with 50 % and 70 % cover, are presented in Figures 6 and 7.

Reducing the maximum gradient along the batter from 16.7 to 14.7 % reduced the predicted rates of erosion. The maximum mean erosion rates at 50 % cover reduced from 4–5 t/ha/yr to 2–3 t/ha/yr, and at 70 % cover from 1.9–2.4 t/ha/yr to 1.4–1.6 t/ha/y.

As expected, reducing the gradient also resulted in an increase in (horizontal) length of the batter from 600 to 640 m from the crest centre.

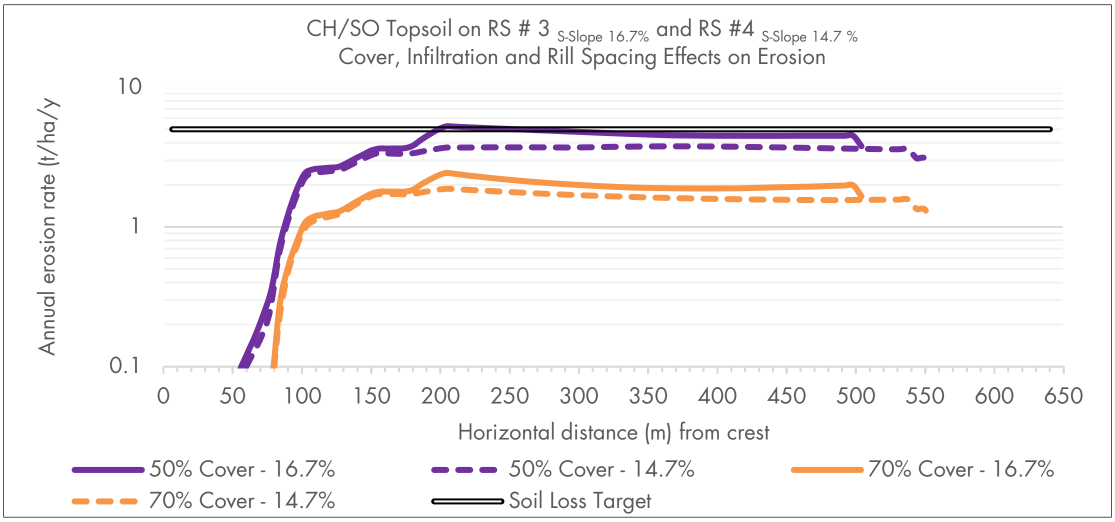


Figure 6. Slope gradient: Predicted rates of erosion on S-slope with a maximum gradient of 16.7 %. Results for CH/SO Topsoil for cover levels of 50 % and 70 %.

7.3.3 Representative slope benched 33.3 %

A benched batter with a maximum gradient of 33.3 % (RS #5 $_{\text{Benched 33 \%}}$) is similar to existing WRE batters at the Mine, except in regard to the catchment area that contributes to each lift of the batters.

The benches on existing WRE batters slope have a gentle back slope, and drain to chutes. As such, the catchment for each bench is currently the 10 m high section of batter immediately above it.

In contrast the benches modelled are flat. On the representative slope RS #3 $_{\text{Benched 33 \%}}$, the catchment area increases with length, so the catchment for the lowest batter lift also receives run-on from the two 10 m high sections of batter immediately above. This batter represents a post-mining landscape where the freeboard and drainage structures are no longer maintained, and silt has accumulated, so that much of the runoff cascades from upper batter sections onto the lower sections.

Mean predicted erosion rates for representative slopes RS #5 $_{\text{Benched 33 \%}}$, with 50 %, 70 %. and 90 % cover, are presented in Figure 8.

As with previous scenarios, modelling demonstrates large reductions in predicted erosion, in response to surface vegetative cover.

Erosion rates over the horizontal distance of 0–33 m from the crest bund reflect erosion when the catchment is limited to the 10 m lift above the bench. Under these conditions tolerable soil loss is achieved when cover approaches 60 %.

This modelling result, over the horizontal distance of 0–33 m, correlates with site observations of negligible erosion on existing rehabilitated batters (Photographs 1–3, and 5). At the time of inspection, cover was greater than 90 % and the drainage network was less than two years old and in a serviceable condition.

These low erosion rates over the horizontal distance of 0–33 m could also be expected on lower batters <u>when the drainage system is well maintained</u>, i.e. the catchment is limited to the 10 m lift above the bench.

In situations when the drainage system is poorly maintained, then the modelled rates of erosion at horizontal distances of 33–66 m and 66–100 m apply. They show a steady rise due to increases in catchment area as the runoff cascades over the benches, and this leads to increased erosion. Under this scenario, vegetation cover needs to approach 80 % to maintain tolerable soil loss.

However, it should be noted that where benches overtop, flow concentration is generally greatly increased, and such flow conditions commonly form significant gullies.

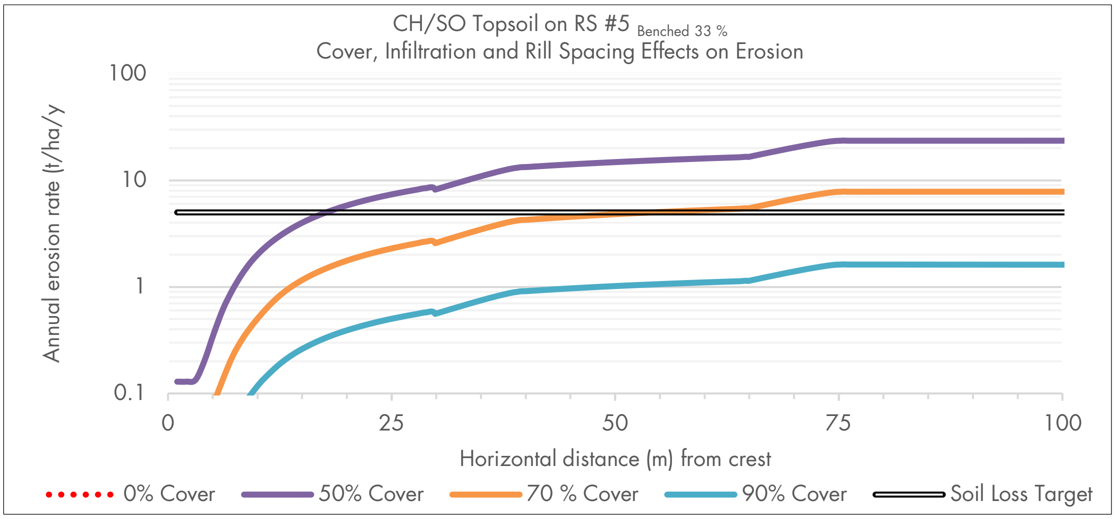


Figure 7. Predicted rates of erosion on benched slope of 33.3%. Results for CH/SO Topsoil are presented for cover levels of 50 %, 70 %, and 90 %.

7.4 Summary of WEPP Modelling

Modelling erosion of 2-dimensional slopes with WEPP considered five different representative slopes, three soil types, four levels of surface cover, and two soil surface roughness conditions. The key findings are:

a) Bare (unvegetated) slopes are highly prone to erosion until permanent vegetation is established, except on the crest of the WRE where gradient is less than 2 %.

b) All of the soils are sufficiently resistant to erosion for use in rehabilitation on the crest of the WRE, provided the gradient is no greater than 6 %.

c) The CH/SO Topsoil is the only material sufficiently resistant to erosion for use in the rehabilitation of batter slopes at gradients 6 % to 16.7 %, <u>provided at least 60 % cover is achieved.</u>

d) Reducing the maximum gradient of slopes from 16.7 % (1H:6V) to 14.7 % (1H:7V) reduces erosion rates. Similar gains were achieved by increasing surface roughness.

e) Increasing surface roughness with rock has the potential to reduce the minimum vegetative cover level requirement to 50 %.

8 EROSION SIMULATIONS – LANDFORM EVOLUTION - SIBERIA

8.1 Model Settings

Alkane designed the SAR WRE landform based on the findings from Section 7 for representative slope RS #2 $_{\text{Convex 16.7 \%}}$ with batters largely at a gradient of 16.7 % (1V:6H) and convex in shape. Representations of the landform are presented in Figures 8 and 9.

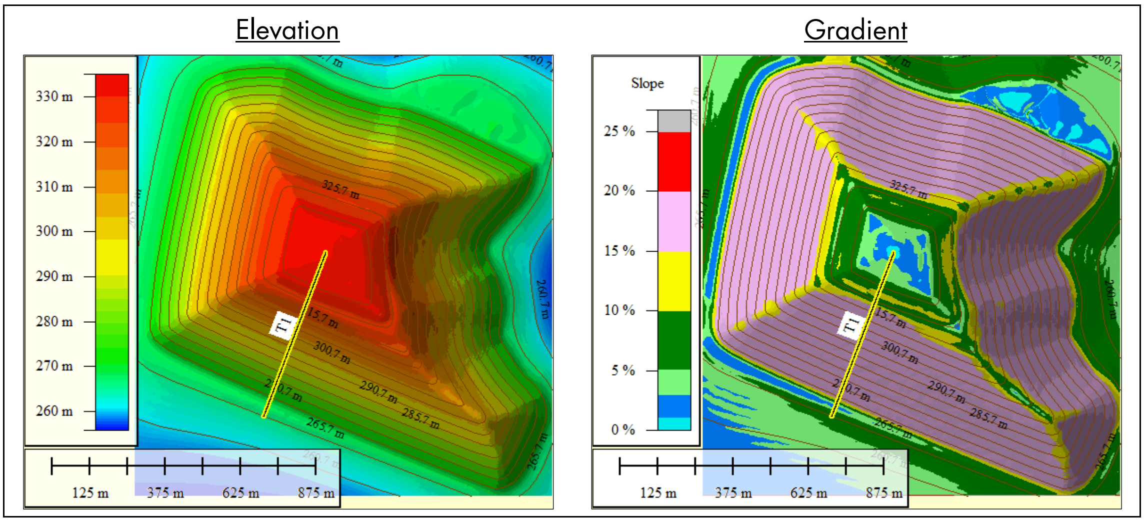


Figure 8. Topography of the SAR WRE landform.

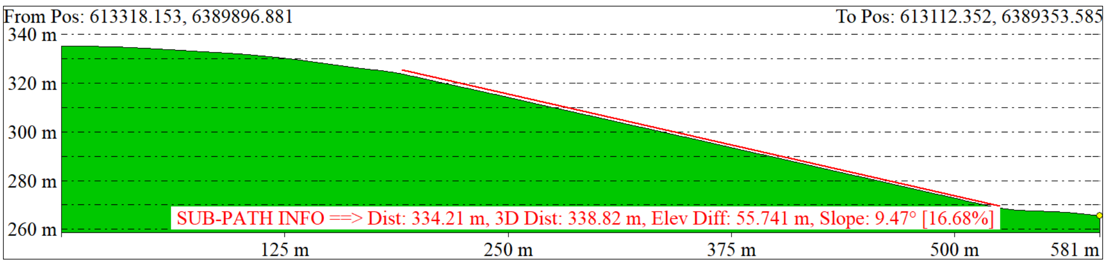


Figure 9. Typical cross section (T1) of the SAR WRE. Batters are convex with a maximum gradient of 16.7 % (1V:6H).

SIBERIA modelling was undertaken with two vegetation cover scenarios (50 % and 70 %) for the CH/SO Topsoil. The other soil materials were excluded, on the basis of the results of Phase 1 erosion modelling that concluded the materials are too erodible for use on the batters, at the cover levels expected for post mining land use.

The intent of this modelling exercise is to consider erosion of the WRE surfaces only, including the interface between the constructed batters and the natural landscape.

The following SIBERIA outputs were produced:

- Visual outputs showing the evolved DEM and erosion/deposition locations at years 10, 50, 100, 500 and 1000, with vegetation cover levels of 50 % and 70 %; and
- Predicted erosion on the batters for each simulation period:
    - Average erosion (t/ha/y);
    - Cumulative erosion (mm); and
    - Maximum (largest ~5 % excluding outliers) depth of gullies (minimum depth of 0.3 m used to define a gully).

The outputs from the SIBERIA model runs were processed to produce a series of visualisations for each model run. For each model run, visualisations of the erosion and deposition on the modelled surface are given, with scaling to show erosion/deposition ±0.3 m in green, deposition >0.3 m in blue, and erosion >0.3 m in red.

8.2 SIBERIA Results

Graphical outputs of erosion for all time intervals are provided in Appendix C, with summary details presented in Table 5.

These data show that erosion is low when the surface of the WRE has 70 % vegetative cover, for all simulated years. Predicted erosion rates are 2.4–2.8 t/ha/y and fall below the soil loss target of 5t/ha/y. Higher erosion is predicted for the lower vegetative cover condition of 50 % with rates of 5.2–5.5 t/ha/y, and marginally exceed the soil loss target.

Table 6. Long term erosion predictions of the WRE batters at time intervals from 10 to 1000 years, with vegetation cover levels of 50 % and 70 %.

Simulation Year	Average Erosion Rate (t/ha/y)		Cumulative Erosion Depth (mm)		Maximum Gully Depth (m)	
	50 %	70 %	50 %	70 %	50 %	70 %
10	5.2	2.4	17	8	<0.3	<0.3
50	5.3	2.5	35	16	<0.3	<0.3
100	5.3	2.5	53	25	<0.3	<0.3
500	5.5	2.7	71	34	0.5	0.4
1000	5.6	2.8	90	43	0.9	0.7

Modelling shows that rills (<0.3 m deep) are expected to develop into gullies (>0.3 m deep) within 500 years. The areas of the WRE most prone to gully erosion is the convex portion at the crest-batter transition zone as gradient increases from 5 % to 16.7 % over a distance of 100 m, with a corresponding elevation change 10 m (Figure 10 and Figure 11). This portion of the batter most prone to erosion ranges in length from 60 m to 100 m.

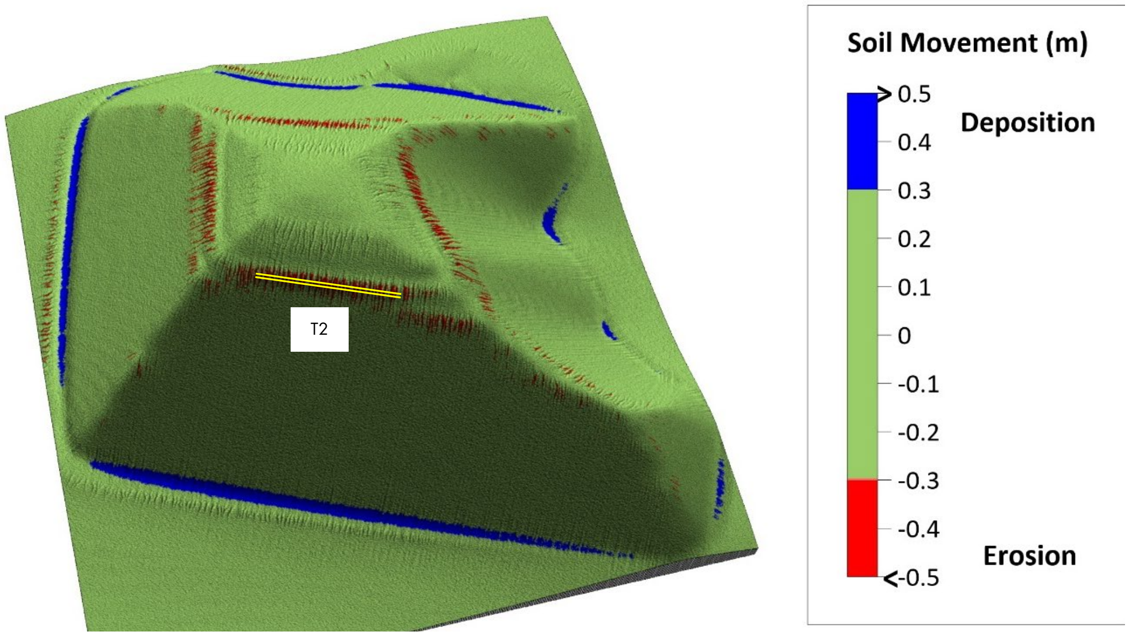


Figure 10. Scenario 500 years with 70 % Cover:- The portion of the landform most prone to erosion is where the crest transitions to the batter.

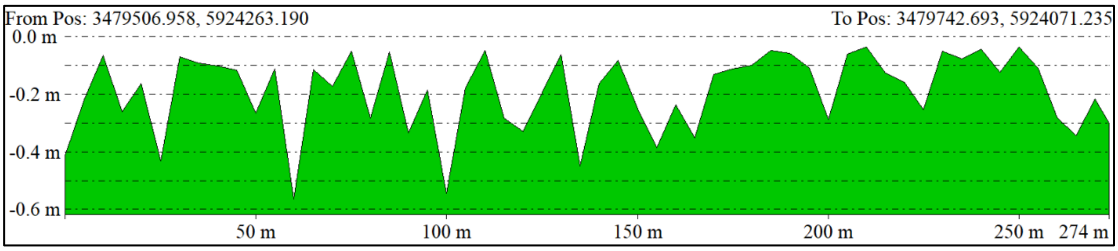


Figure 11. Scenario 500 years with 70 % Cover:- Typical cross section (T2) of the crest-batter transition zone of the landform that is most prone to erosion.

8.3 Summary of SIBERIA Modelling

Landform evolution modelling of a 3–dimensional surface of the SAR WRE considered one soil type, two levels of surface vegetative cover, and six time periods. The key findings are:

a) The long-term average erosion rate will be within the soil loss target of 5 t/ha/y provided at least 60 % vegetative cover is achieved on the batters.

b) In some areas, gullies will begin to erode through the capping layer (assumed thickness 0.3 m) within 500 years. This is mainly on the convex portions of the landform where the crest transitions to batters and gradient increases from 5 % to 16.7 %. Mitigation options are:

   i. Reinforcing these areas with a soil/rock matrix to reduce the erosion potential in these areas; and

   ii. Ensuring that the waste materials in the root zone are suitable for plant growth and absent of soil hazards. For planning purposes, a root zone depth of 0.8–1.0 m is nominated. This will need to be revised based on results from additional studies.

9 SOIL-ROCK COVER

The convex sections of the SAR WEA, where the crest transitions to the batter, are prone to gully development within 500 years and require reinforcing with a less erodible material. Such sections are suitable for the placement of a soil-rock cover to function as a growth medium and support plant growth, as well as provide a surface that is more resistant to erosion.

The use of rock to stabilise batter slopes is not uncommon on minesites, though it is frequently limited by the availability of suitable rock. When used correctly, soil-rock covers should consist of an interlocking coarse matrix of rock that has the spaces between rock filled with soil. The rock provides a high degree of resistance to erosion, and the soil provides the nutrients and water storage to support plant growth.

Rock-soil covers will, at best:

- Support vigorous grass/tree vegetation;
- Generate some surface runoff, but generate lower rates of seepage compared to rock only covers.
    - This reduces the rate of downslope seepage, and consequently,
    - Reduces the potential for tunnel erosion at the cap/clay interface; and
- Be resistant to erosion:
    - In the initial establishment stages, and at times when vegetation is reduced or removed (drought, fire); and
    - By lessening ground disturbance from stock and wildlife.

Binary Packing Theory (Bodman & Constantin, 1965) can be applied to rock-soil mixtures. When mixing coarse (rock) and fine (soil) particles, the resulting binary mixture (Figure 12) commonly reaches maximum packing (minimum void ratio /maximum bulk density) when the volume of coarse particles (Vsc in the graph) is approximately 70 % and the volume of fines (Vsf) is approximately 30 %. However, to achieve maximum bulk density, the ratio can vary greatly depending on the porosity of the coarse fraction. (Coughlan, Loch, & Fox, 1978).

Achieving minimum void ratio in the soil-rock mixture is highly critical to be effective in resisting erosion and supporting plant growth.

When the proportion of coarse particles is greater than required for minimum void ratio, the mixture is a 'coarse particle dominated matrix', with rock particle properties governing detachment by overland flows. Such covers can become more comparable to 'rock armour capping' than 'soil capping' and tend to be porous with water moving more readily through the rocky mix to the underlying wastes and then laterally along the interface between the two layers. This can lead to tunnel erosion under the capping layer. The movement of water can also 'flush' the fines component of the soil-rock matrix deeper into the capping layer and reduce the ability of the matrix to support vegetation.

Conversely, if the proportion of coarse particles is significantly less than that required for minimum void ratio, then the mixture is a 'fine particle dominated matrix', and its erosion potential is greatly increased. The (rock) coarse particles tend to 'float' within the fine particle (soil) matrix and is more susceptible to erosion compared to a matrix near the minimum void ratio.

Therefore, in terms of erosion resistance and management of infiltrated water, it is desirable that the rock-soil mixture be close to the minimum void ratio, as presented in Figure 12.

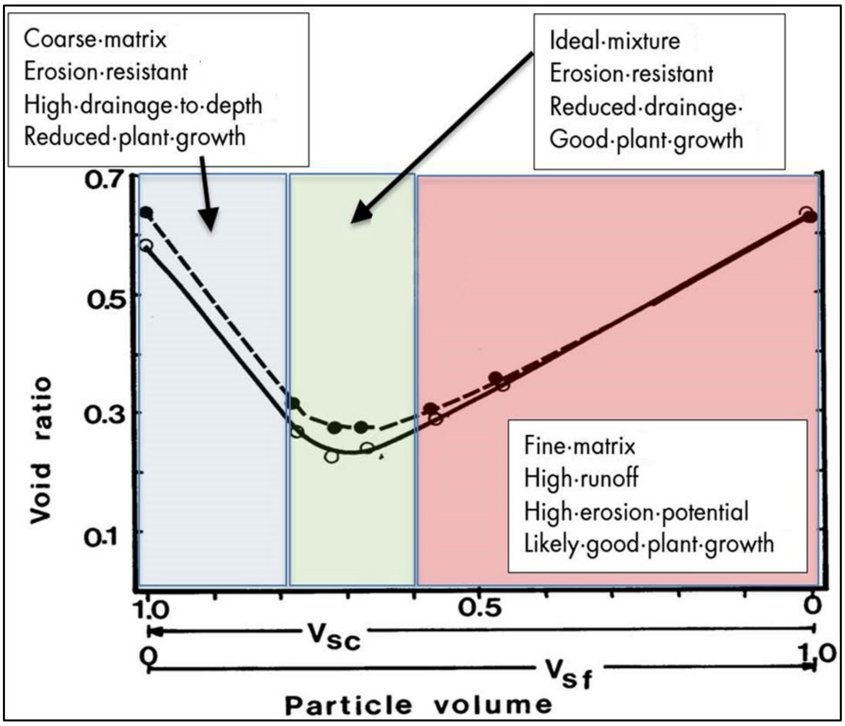


Figure 12. Effect of particle size class ratios on void ratio. In the figure, V_{sc} is the proportion of solid volume that is composed of coarse particles, and V_{sf} is the proportion of that volume composed of fine particles. Effectively, $V_{sc} = 1-V_{sf}$.

9.1 Critical Shear Threshold

The WEPP model was used to determine the threshold value for critical shear of overland flow at the crest-batter transition zone that will trigger particle motion and rill erosion. Modelling identified a critical shear value of 35 Pa, or greater, as sufficient to provide an erosion rate comparable with the lower sections of the batter that are less prone to developing gullies.

9.2 Rock Size

The effect of rock particle size and density on the critical flow shear stress for the initiation of particle motion is described by Shields' equation (Shields 1936). This can be used to predict critical overland flow shear values based on size, content, and specific gravity of the rock present in a surface exposed to flow.

The equation was developed for unisize sediments, however, in mixed sized sediments Shields' equation provides the mean rock size (D_{50}) that corresponds with the critical shear. The key variables required to determine D_{50} are critical shear and specific gravity of rock.

A specific gravity of rock of 2.5 g/cm^3 was used in the Shields' equation as it is suitable for all lithologies at TGO other than alluvium, clay, mylonite, and saprolite (Table 7). Calculations determined soil-rock matrices consisting of rock with mean size D_{50} of 53 mm or greater will provide critical shear values of at least 35 Pa.

Table 7. The specific gravity of lithological units in the open cuts at TGO (Courtesy TGC, 2021).

Lithology	Specific Gravity (g/cm^3)
Alluvium	2.02
Andesite	2.75
Basalt	2.78
Breccia	2.72
Conglomerate	2.77
Clay	2.03
Dolerite	2.77
Diorite	2.71
Fault	2.76
Feldspar-phyric porphyry	2.85
Feldspar-phyric volcanic	2.71
Hornblende-phyric volcanic	2.83
Mylonite	2.33
Monzodiorite	2.73
Quartz	2.52
Saprolite	1.96
Saprock	2.18
Sandstone	2.69
Shale	2.76
Siltstone	2.70
Tuff	2.76
Volcaniclastic conglomerate	2.82
Volcaniclastic breccia	2.74
Volcaniclastic sandstone	2.71
Volcaniclastic siltstone	2.75

10 DISCUSSION

As expected, soil type, cover levels, and slope shape all influence erosion rates on the representative slopes. This study identified that all the soils assessed are sufficiently resistant to erosion, if used in rehabilitation of the WRE on slopes with low gradients (≤ 6 %). However, on portions of batter with appreciable gradient (>6 %), only the

CH/SO Topsoil material is appropriate, <u>provided adequate vegetative cover is achieved.</u>

10.1 Soil Type

The most erosion resistant material tested was the CH/SO Topsoil. From an erosion perspective, this is the only material tested that is suitable for unrestricted use in the rehabilitation of the crest and batters, <u>provided adequate cover is achieved.</u>

The VE Topsoil was the most prone to erosion of the materials tested. For this material, the tolerable soil loss criterion was not achieved on any of the batters tested, even with groundcover levels as high as 90 %.

The CH Subsoil was less prone to erosion than the VE Topsoil.

10.2 Landform Crest

The erosion rates on the portion of crest with low gradient (≤ 6 %) were *very low* for all soils. However, erosion rates increase rapidly as the gradient increases along the convex portion of the slope.

10.2.1 Crest zones with gradient < 2 %

Predicted soil loss was less than 2 t/ha/y for all soils in the *bare condition* <u>where the gradient was less than 2 %</u>. This portion of the crest applies to the 0 to 100 m section of the representative slopes modelled. It is intended to correspond to the central portion of the crest of the WRE landform with a relatively flat area of approximately 3–4 ha.

All of the soil materials tested could be used in the rehabilitation of this portion of the crest with its low gradient. These flatter areas are well suited to establishing vegetation by broadcasting seed or drill seeding onto a prepared soil bed.

10.2.2 Crest zones with gradient 2 % to 6 %

Soil loss from soils in *bare condition* increases rapidly as the gradient rises above 2 % at distances beyond 100 m (horizontal) from crest centre. Predicted erosion rates on the crest begin to exceed 100 t/ha/y for bare soils when gradients exceed 6 %. This correlates with portions of slopes beyond 150 m from crest centre on the representative slopes (RS #2 $_{\text{Convex 16.7\%}}$, RS #3 $_{\text{S-Shaped 16.7\%}}$, and RS #4 $_{\text{S-Shaped 14.7 \%}}$) with maximum gradients of 14.7 % or 16.7 %. These erosion rates correspond with an average soil loss greater than 1 cm per year, but in practice, the surface will be heavily dissected with rill erosion.

All of the soil materials tested could be used in the rehabilitation of these low gradient portions of the crests, <u>provided 70 % vegetative cover is achieved.</u>

Sowing of seed should be combined with the application of a soil binder or hydromulch, to increase the resistance of the soil surface to erosion. Drill seeding, followed by an application of a soil binder, can provide good seed/soil contact for germination and a soil surface less prone to erosion.

If seed is broadcast, then lightly work it into the soil by harrowing (or raking, tracking, chain dragging, rolling etc.). This improves the seed-soil contact, allowing seed to better absorb moisture for germination. Failure to work broadcast seed into the soil prior to applying the binder will result in much of the seed sticking to the soil surface and reducing seed emergence, due to poor seed-soil contact and predation by insects and birds.

If hydromulching, then the hydromulch application rate should provide at least 70 % groundcover. This will require an application rate of 2–4 t/ha, depending on the degree of soil roughness.

10.3 Landform Batters

The CH/SO Topsoil is the only material tested that is considered to have sufficiently low erodibility for use in the rehabilitation of the representative slopes. Crucial to maintaining soil erosion within the tolerable soil loss rate of 5 t/ha/y is the provision of adequate groundcover. Cover levels of at least 60 % are required on representative slopes with maximum gradients of 14.7 % or 16.7 %. For the representative slope RS #1 $_{\text{Convex 33\%}}$ with a maximum gradient of 33.3 %, cover levels need to be at least 80 %.

Rehabilitation should occur progressively in lifts of 5 to 10 m. Prior to dressing the batter with topsoil, a *temporary* 'top of slope bund' must be installed to prevent uncontrolled discharge of runoff onto the batter being revegetated. This temporary bund is to remain in place until the target vegetation cover is achieved.

The seeding methodology should be as described (above) for *Landform Crests – Gradient 2 % to 6 %,* with the following changes:

- Drill seeding / broadcast seeding with soil binder should be applied to lifts, to a maximum of 5 m height.
- If hydromulching, the lifts can be extended to a maximum of 10 m height. The hydromulching rate should provide at least 90 % groundcover. This will require an application rate of 4–8 t/ha, depending on the degree of soil roughness.

10.4 Landform Crest to Batter Transition Zone

The transition zone between the crest and batter requires reinforcement with a soil-rock capping layer to increase resistance to erosion, and to reduce the potential for gullies to develop. The target area of reinforcement is the convex portion of the slope around the areas of maximum gradient. It should be at approximately 80 m in length and extend approximately 40 m either side the point of maximum gradient (16.7 %) in the crest-batter transition zone (Figure 13).

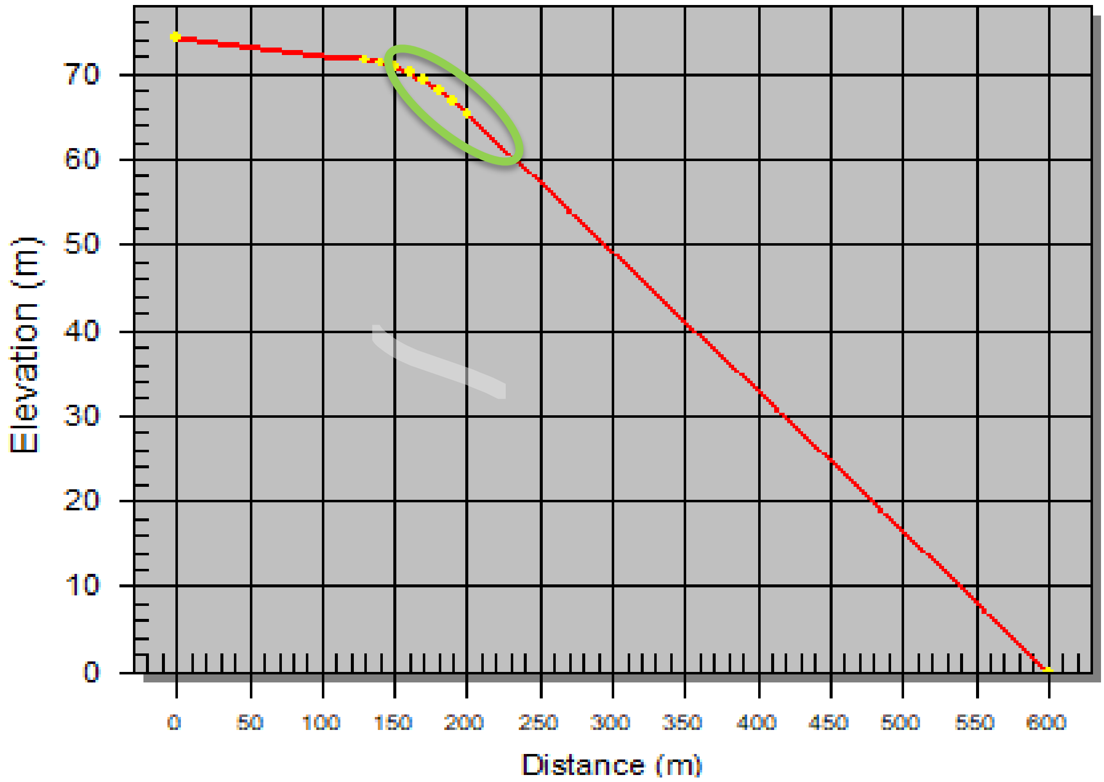


Figure 13. The transition zone between the crest and batter requires reinforcement with a soil-rock growth media capping layer. It should be at least 80 m in length, as indicated by the by the green oblong marked on the graph.

10.4.1 Preparation of overburden waste for capping

The overburden layer will need to be prepared prior to placement of the soil-rock-capping layer. The intent is to –

1. provide a roughened interface to key the capping layer and clay layer together, thereby reducing the potential for slippage of the capping layer; and
2. to increase the rooting depth available for vegetation, as much as is practicable.

The surface of the overburden layer is to be scarified along the contour with tined implements on a dozer (or similar) at intervals of 0.3–0.6 m. Multiple passes may be necessary depending on the spacing of the tines on the available equipment.

The minimum depth of ripping is 500 mm.

10.4.2 Rock materials

Quality control of the soil and rock material properties, and the mixing proportions, is critical to the success of the cover.

The ratio of soil to rock required to achieve the minimum void ratio is to be determined based on further testing of material mixtures. However, for budgeting purposes allow for a mixture of 1 part soil to 2 parts rock.

The rock component shall be clean, angular, and durable, of uniform quality, free from deleterious material and without an excess of flat or laminate pieces. Shale, claystone, siltstone or mudstone shall not be used as rock fill unless it has been demonstrated by degradation tests that the rock fragments will remain stable under the action of load or water. Rock fill material shall not disintegrate in water or when exposed to weather.

The grading limits for clean rock size D_{50} > 53 mm are provided in Table 8. A soil-rock matrix consisting of coarse rock size is also suitable for capping the crest-batter transition zone.

Table 8. Grading limits for clean rock size D_{50} > 53 mm to be mixed with soil.

Sieve Size	% passing by mass D_{50} > 53 mm
100	100
75	85–100
53	0–50
37	–
9.5	0–5

10.4.3 Soil-Rock placement

All topsoil soil materials assessed in this study are considered suitable for mixing with rock to produce a soil-rock growth medium.

A soil-rock layer thickness of 400 mm, or greater, should be adopted. This will provide an equivalent depth of topsoil of at least 100 mm.

For construction purposes, a rock-soil mixture for batters to a "**depth no less than 400 mm**" is suitable.

It is preferable to mix rock and soil prior to spreading it on the batter as it provides a more thorough blending of rock and soil materials than blending on a batter. To prepare a mixture, place soil and rock in windrows or stockpiles near each other, in the appropriate ratio, and mix with a loader, or similar. The soil-rock mixture is then pushed down/up the slope with a dozer, or similar (Photographs 7–10).

If pre-blending of soil-rock- materials is not practicable, then an alternative method of mixing rock and soil materials on the batter is possible. Blending on the batter is less desirable when mixing is poor.

Photograph 7. Soil-rock mixture placed at the toe of the batter, prior to spreading.

Photograph 8. Soil-rock mixture.

Photograph 9. Batter partially covered with soil-rock mixture (left).

Photograph 10. Spreading of soil-rock mixture on the batter with a D9 dozer.

10.5 Groundcover

During the site inspection, the existing cover levels of vegetation were observed to be greater than 90 %. It is understood that the area had received favourable growing conditions in the six months prior to the inspection. It is expected that in 'poor seasons' groundcover will likely be less. Hence the cover conditions of 0 %, 50 %, 70 %, and 90 % used in modelling aimed to provide information for the range of conditions that may be experienced by the Mine.

There is an onus on the Mine personnel to identify the level of cover that can be regularly achieved, as this will determine the acceptable shape of landform batters. For example, if it is unrealistic to maintain a long-term cover greater than 80 %, then the representative slope RS #1 $_{\text{Convex 33 \%}}$ would be unsuitable. If cover levels of 60 % are more achievable, then representative slopes RS #3 $_{\text{S-shaped 16.7 \%}}$ and RS #4 $_{\text{S-shaped 14.7 \%}}$ would be suitable. However, if a long-term cover of at least 60 % cannot be achieved, then the Project may consider alternative landform design options such as:

- increasing surface roughness;
- constructing batters with shallower gradients; or
- the establishment of vegetation in a topsoil /rock blend cover.

It is important to note that the adopted modelling scenarios of 50 %, 70 %, and 90 % cover, assumed that cover is mainly annual or perennial vegetation, with some inclusion of dry vegetative litter and rock fragments. Hence, it is expected that a batter surface covered with 70 % straw will have a higher rate of erosion than a batter with 70 % vegetative cover because the roots of vegetation increase soil infiltration, which in-turn reduces runoff and the potential for soil to erode.

10.6 Surface Roughness

Modelling indicates increasing surface roughness will reduce erosion (Figure 4). This is more effective on slopes with appreciable gradient, but provides little advantage on slopes with low gradients, given the rates of soil loss are already low.

On representative slopes RS #3 $_{\text{S-shaped 16.7 \%,}}$ increasing the surface roughness reduced erosion rates to a degree that allowed the soil loss target to be achieved with cover levels as low as 50 %. It is expected this would also apply to all other representative slopes.

Surface roughness can be provided a number of ways. If wastes are rocky, then deep ripping along the contour will bring the coarse fragments to the surface (Photograph 11). Alternatively, rock can be added to the surface by placing it with the topsoil and pushing down (or up) the batter (Photograph 12).

Photograph 11. Example of a rehabilitated batter with a high degree of surface roughness due to the appreciable rock content in the spoil materials that have been ripped along the contour. Location near Cobar, NSW.

Photograph 12. Example of a batter with a high degree of surface roughness in the early stages of rehabilitation. Roughness was created by placing mixing rock with topsoil then pushing it down the batter. Location near Mudgee, NSW.

Applying timber debris or deep ripping to form mounds are other options to increase surface roughness. However, such roughness has much less longevity than rock, and is therefore considered unsuitable for this application.

10.7 Soil Binders and Hydromulch

Soil binders are hydraulically applied to the soil surface to provide a thin veneer that is more resistant to erosion than bare soil. When used in revegetation works, they are applied after the application of fertiliser and seed, with the aim of providing a 'temporary soil cover' until vegetation establishes. Their lifespan varies, depending on the application rate and the product selected, but a period of effectiveness of several months can be expected.

Example products include *Vital Bon-Matt Stonewall* (Supplier: Vital Chemical) and EnviroBinder (Supplier: GRT).

Hydromulching is the hydraulic application of a seed and mulch mixture. Fertiliser, colouring, soil amendments and conditioners can be included in the mixture sprayed onto the soil surface or applied separately. The degree of surface protection and longevity of the product are largely dependent upon the application rate, the type of fibre, and the tackifiers used. Product suppliers and installers use these factors to differentiate their product in the marketplace.

Sections of batters with gradients steeper than 6 % are well suited to seeding by hyromulching and will benefit greatly with the application of a surface layer of mulch. The mulch (and tackifiers) provide the soil surface with an initial level of protection against rain drop impact and sheet erosion until vegetation is established, after which long-term stabilisation is provided by plants, roots, and leaf litter. The mulch layer also provides favourable conditions for plant establishment by reducing water loss via evaporation and providing good seed/soil contact for germination, and protects seeds from predation and being washed away.

Under dry land conditions (i.e. not irrigated), hydromulch should have <u>a longevity of six months or greater</u>, such as a *bonded fibre matrix* (BFM) hydromulch, with longevity properties supported by test data. Example products include *EnviroStraw BFM* (Supplier: EnviroStraw) and ProMatrix EFM (Supplier: DuraVeg).

10.8 Landform Evolution

Landform evolution modelling revealed some key features of the SAR WRE.

Firstly, the images of erosion development over time (Appendix C) support the design intent to avoid concentration of runoff. Runoff on the landform occurs as broad unidirectional flows of low energy and does not converge into high energy channels or first order streams. As a result, the landform does not require any reinforced drainage networks or chutes to carry channel flows.

Secondly, depositional areas occur only at toe of the WRE batters and are not predicted to develop in any low gradient drainage structures. The absence of benches, contour banks, berms and similar structures reduces the potential for scouring and gully formation where concentrated flows are unintentionally directed onto the batter. This can happen where drains overflow due to deposition or during rainfall events with higher intensities than the adopted design standard. Failure may also occur due to slumping in poorly consolidated areas or where tunnels develop in dispersive materials or wastes with poor coherence (e.g. rocky sands and silts). Unless maintained, these gullies continue to develop in time.

Thirdly, predicted depths of scour and gully formation should be interpreted cautiously. Erosion rates are based on the properties of the topsoil capping layer rather than those of the underlying waste materials. Hence the predicted scour depths within the topsoil capping layer (i.e. less than 0.3 m) are considered more reliable forecasts than predicted depth values for gullies that extend into the underlying waste rock.

This last feature is of prime importance if hazardous wastes are encapsulated in the WRE (e.g. potential acid forming materials, or saline wastes). To prevent exposure due to erosion, an intermediary rock armouring layer between the growth media and hazardous waste materials, is likely to be needed in the capping sequence.

Relying solely on the depth of gully erosion predicted by landform evolution modelling in this study, as a means to determine cover depth for hazardous materials should be avoided.

It is also critical that waste materials in the root zone can support plant growth, and if exposed where gullies form, they do not present major limitations to inhibit passive regeneration and plant growth. Determination of root zone depth for the target vegetation communities is beyond the scope of this assessment, but it is expected that the required depth for plant growth should be approximately 0.8 to 1.0 m below surface level. This depth will need to be revised by additional studies.

11 CONCLUDING REMARKS AND RECOMMENDATIONS

This Erodibility Testing and Modelling Program details the laboratory-based erodibility testing on bulk samples of three materials and derived input parameters for the erosion modelling. It considered five different representative slopes to cover a range of levels, and a number of surface conditions relevant to the Project.

The following recommendations are provided.

11.1 Landform Design Criteria

Design criteria are summarised below.

a) Runoff off the WRE is unidirectional and does not converge flows into channels or first order streams.

b) The WRE does not include any engineered drainage structures (e.g. chutes, berms, or contour banks).

c) The adopted soil loss target is a mean maximum erosion rate of < 5 t/ha/y at any point on the slope.

d) Bare (unvegetated) slopes are predicted to be highly prone to erosion until permanent vegetation is established, except on the crest of the WRE where gradient is less than 2 %.

e) All of the soils are sufficiently resistant to erosion for use in rehabilitation of the crest of the WRE, provided the gradient is no greater than 6 %.

f) The CH/SO Topsoil is the only material sufficiently resistant to erosion for use in the rehabilitation of batter slopes at gradients 6 % to 16.7 %, <u>provided at least 60 % vegetative cover is achieved.</u>

g) Reducing the maximum gradient of slopes from 16.7 % (1H:6V) to 14.7 % (1H:7V) provides a further reduction in predicted erosion rates. Similar reductions in predicted erosion were achieved by increasing surface roughness.

h) Increasing surface roughness with rock has the potential to reduce the minimum vegetative cover level requirement to 50 %.

i) Progressive rehabilitation of the batters is recommended to occur in lifts of 5 to 10 m. Temporary 'top of slope bunds' are required with each lift and must remain in place until target cover level is achieved.

j) The convex portions of the landform have a high erosion hazard where the crest transitions to batters and gradient increases from 5 % to 16.7 %. Reinforcing these areas with a soil/rock matrix will reduce the erosion potential in these areas.

11.2 Target Cover Level

Based on this assessment, a target level for vegetative ground cover of 60 % or greater, across the SAR WRE is required to achieve the soil loss target of < 5 t/ha/y.

It is recommended that work be undertaken to verify that this target cover level is achievable. This could be determined by reviewing monitoring records on similar landforms in the region, or by establishing a monitoring program.

11.3 Capping Layers

The features of the capping layers required to maintain the target cover level need to be determined. They should include the depth and soil quality required for the CH/SO Topsoil surface layer, and depth of rooting zone in the underlying waste materials.

Waste materials in the root zone should be absent of soil hazards such as extremes of pH, salinity, and dispersive materials so that there are no major limitations to plant growth that would inhibit passive regeneration and would exacerbate erosion at locations where gullies form.

For planning purposes, it is expected that the required depth to any physical or chemical barriers to plant growth would be approximately 0.8 to 1.0 m below surface level. This will need to be revised based on additional studies.

11.4 Soil-Rock Capping

A soil-rock growth medium is recommended as the capping layer at the crest-batter transition zone of the SAR WRE. Modelling indicates the length of reinforcement should be at approximately 80 m.

This length should be revised at construction based on the 'as-built' landform. In this assessment the erosion modelling is based on a digital elevation model derived on the conceptual design. Revision of the modelling at construction will allow determination of more targeted coverage areas and optimisation of soil-rock cover placement.

11.5 Characterisation of Spoil/Wastes

The growth media quality of materials placed near the surface of landforms to be revegetated needs to be assessed for suitability to ensure it supports the vegetation required for the post-mining land use. A sampling and analysis program of soils/wastes should be undertaken to evaluate potential soil hazards in spoil such as salinity, extremes of pH, clay dispersion, and nutrient deficiency/toxicities. All of these can be detrimental to plant growth if placed within the vegetation rooting zone.

11.6 Gypsum Application

Gypsum rates should aim to reduce sodicity of the soil to an ESP < 4 % in the surface materials, and be applied to a depth of 0.3–0.5 m. It is possible that the default rate of 10 t/ha currently adopted by the mine may be sub-optimal. Rates should be based on laboratory analysis of soil and spoil materials.

Where gypsum is applied, it should be mixed as evenly as practicable to the target depth. Surface application of gypsum to batters, without incorporation, will generally result in gypsum being washed off the slope and have little to none of the intended effect.

Gypsum should be incorporated with tillage equipment or by ripping along the contour. The broad distance between tillage/rip lines should be ~0.5 m. Multiple passes along the contour may be required, depending on the equipment being used to incorporate the gypsum effectively.

If spoil is to be ameliorated, the best results are achieved by incorporating gypsum into the spoil prior to placement of the topsoil.

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APPENDIX A: FIGURES AND MAPS

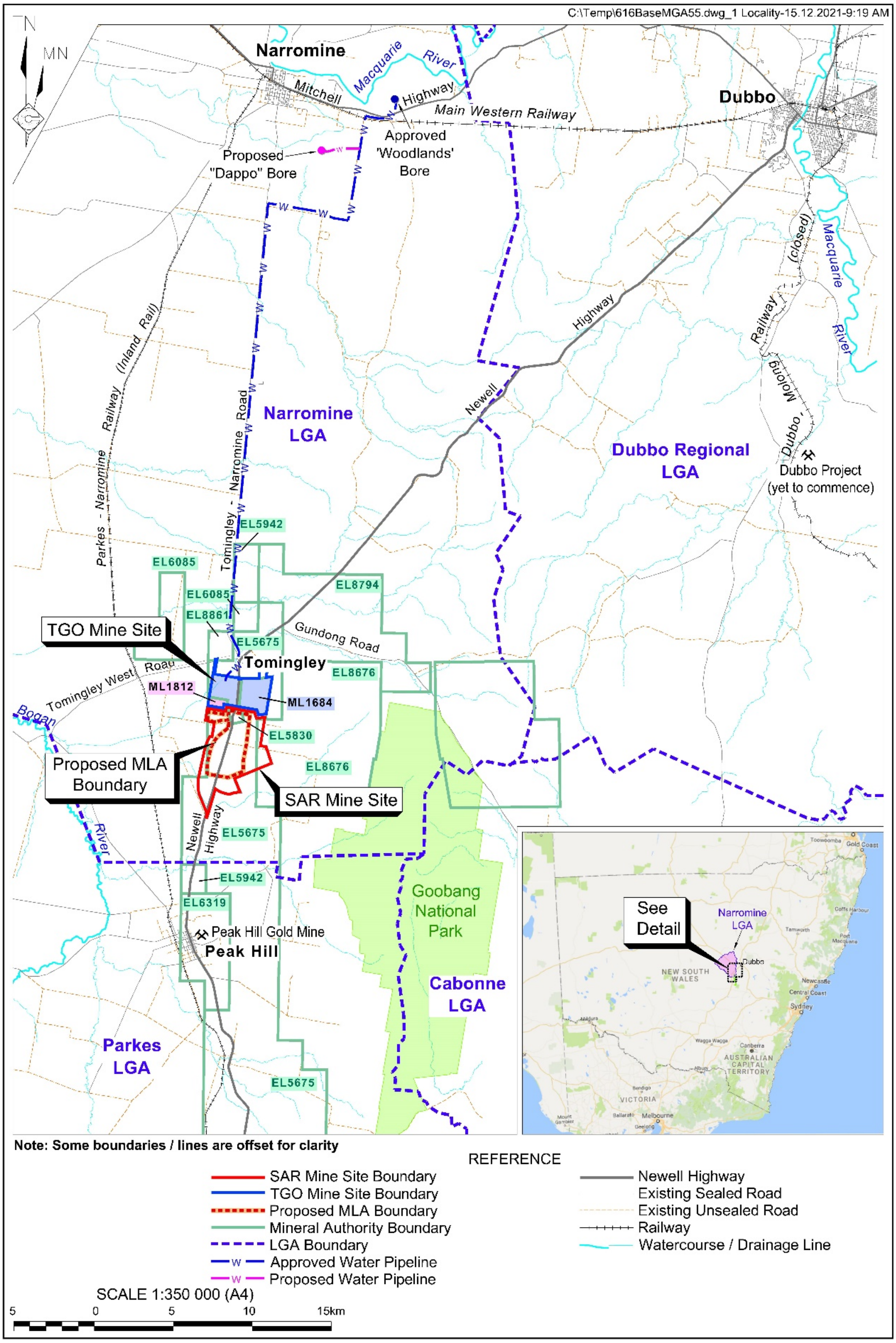

Figure A 1. Locality plan of the Project (Courtesy RW Corkery, 2021).

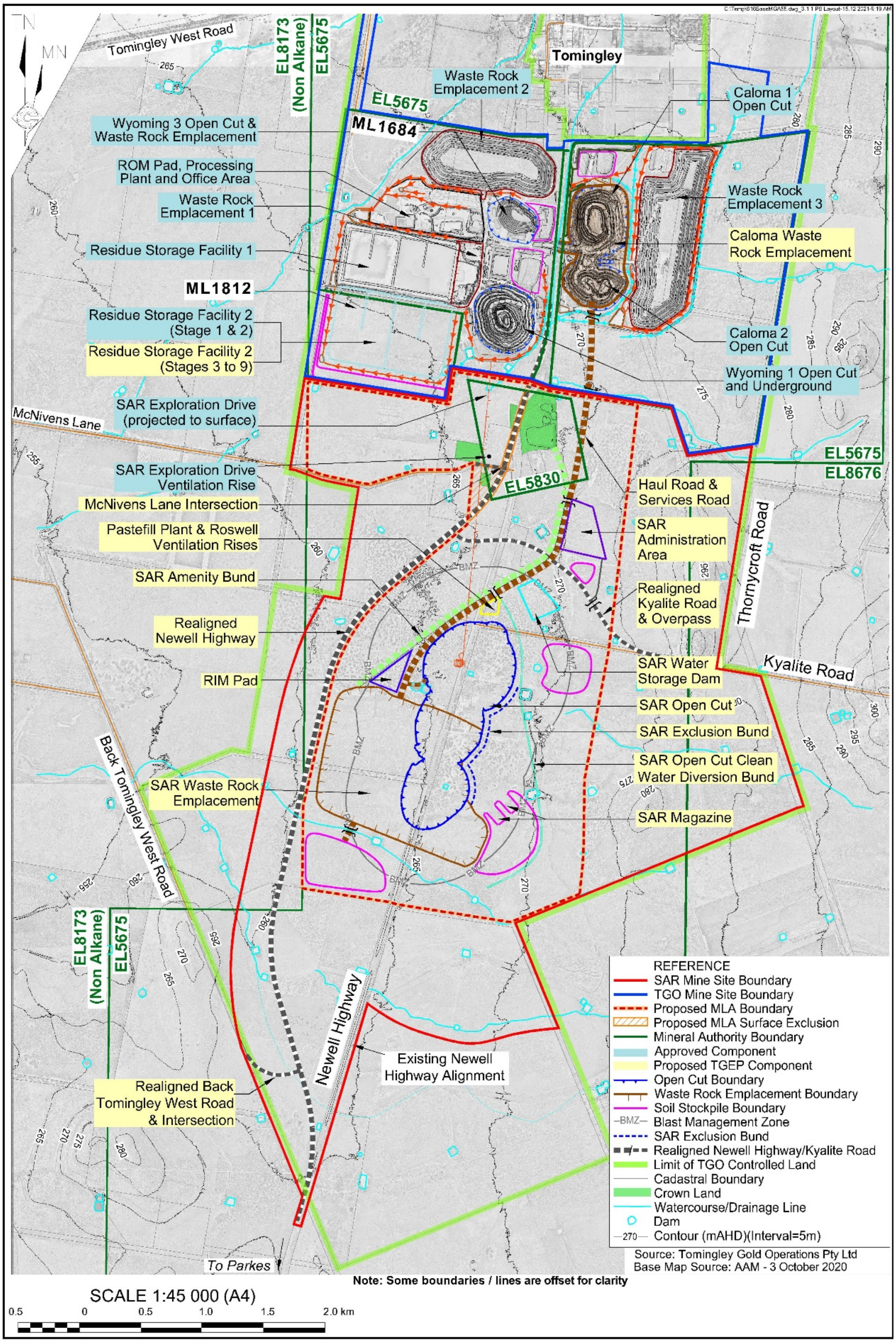

Figure A 2. Project site layout (Courtesy RW Corkery, 2021).

APPENDIX B: PHOTOGRAPHS – EROSION TESTING

Photograph B 1. Chromosol/Sodosol Topsoil test plot prior to rainfall simulation.

Photograph B 2. Chromosol/Sodosol Topsoil test plot after receiving simulated rain at 100–125 mm/hr.

Photograph B 3. Chromosol Subsoil test plot prior to rainfall simulation.

Photograph B 4. Chromosol Subsoil test plot after receiving simulated rain at ~100–125 mm/hr.

Photograph B 5. Gilgai Topsoil test plot prior to rainfall simulation.

Photograph B 6. Gilgai Topsoil test plot after receiving simulated rain at ~100–125 mm/hr.

Photograph B 7. Chromosol/Sodosol Topsoil plot prior to being subjected to overland flows.

Photograph B 8. Chromosol/Sodosol Topsoil plot tested to failure with overland flows.

Photograph B 9. Chromosol Subsoil plot prior to being subjected to overland flows.

Photograph B 10. Chromosol Subsoil plot tested to failure with overland flows.

Photograph B 11. Gilgai Topsoil plot prior to being subjected to overland flows.

Photograph B 12. Gilgai Topsoil plot tested to failure with overland flows.

APPENDIX C: SIBERIA OUTPUT IMAGES

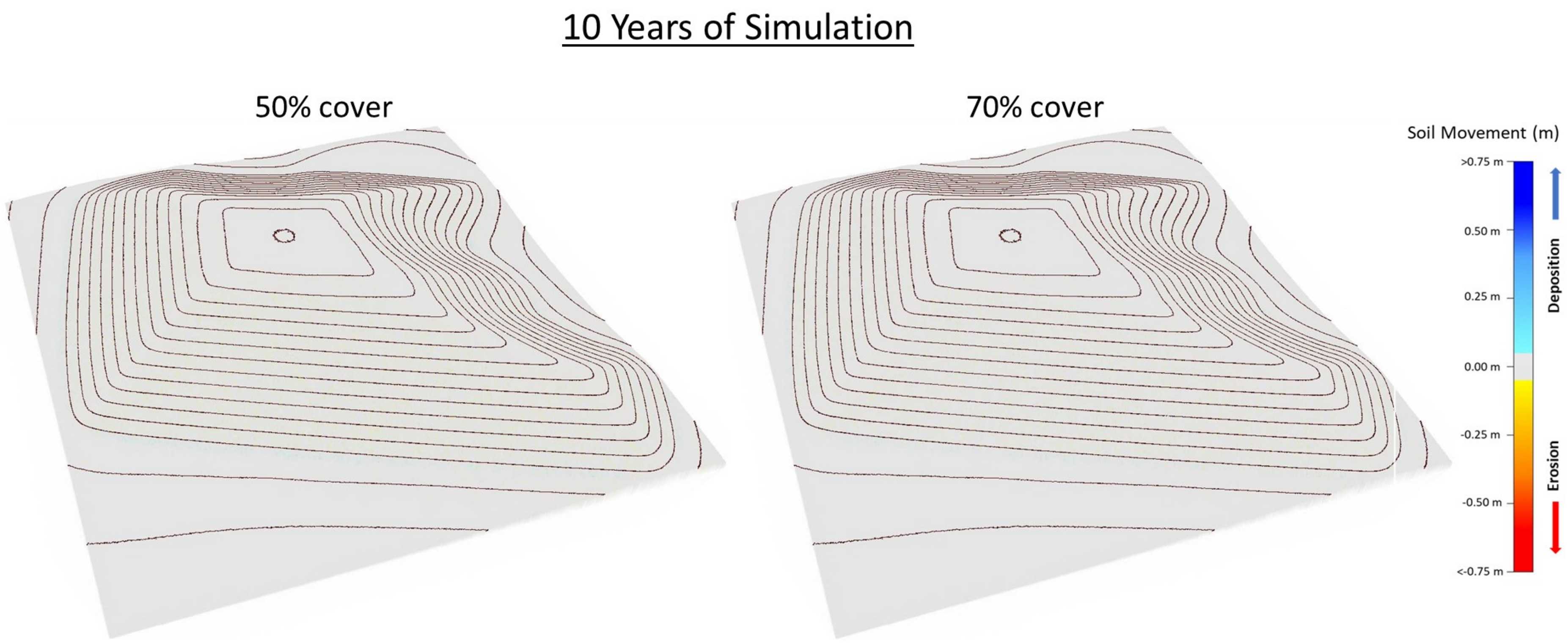

Figure C 1. Landform evolution model after 10 years of the SAR WRE covered with CH/SO Topsoil cover 0.3 m thick and vegetation cover of 50 % and 70 %. There are negligible areas where appreciable erosion or deposition is predicted to occur.

50 Years of Simulation

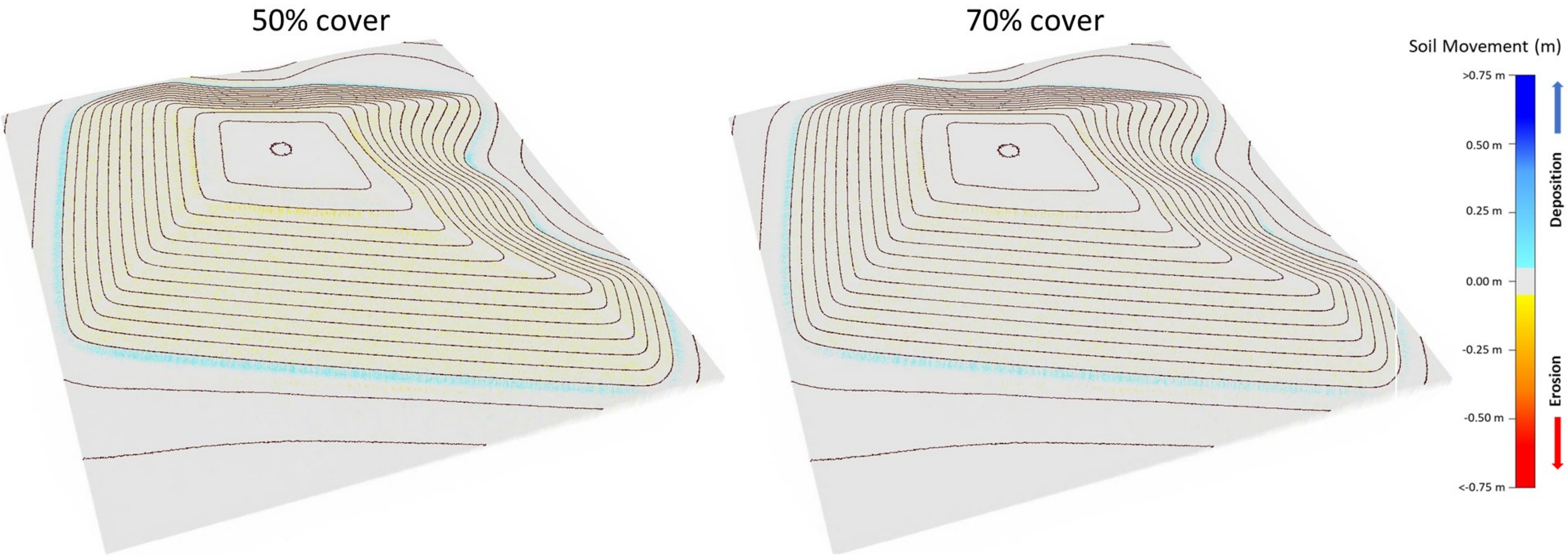

Figure C 2. Landform evolution model after 50 years of the SAR WRE covered with CH/SO Topsoil cover 0.3 m thick and vegetation cover of 50 % and 70 %.

100 Years of Simulation

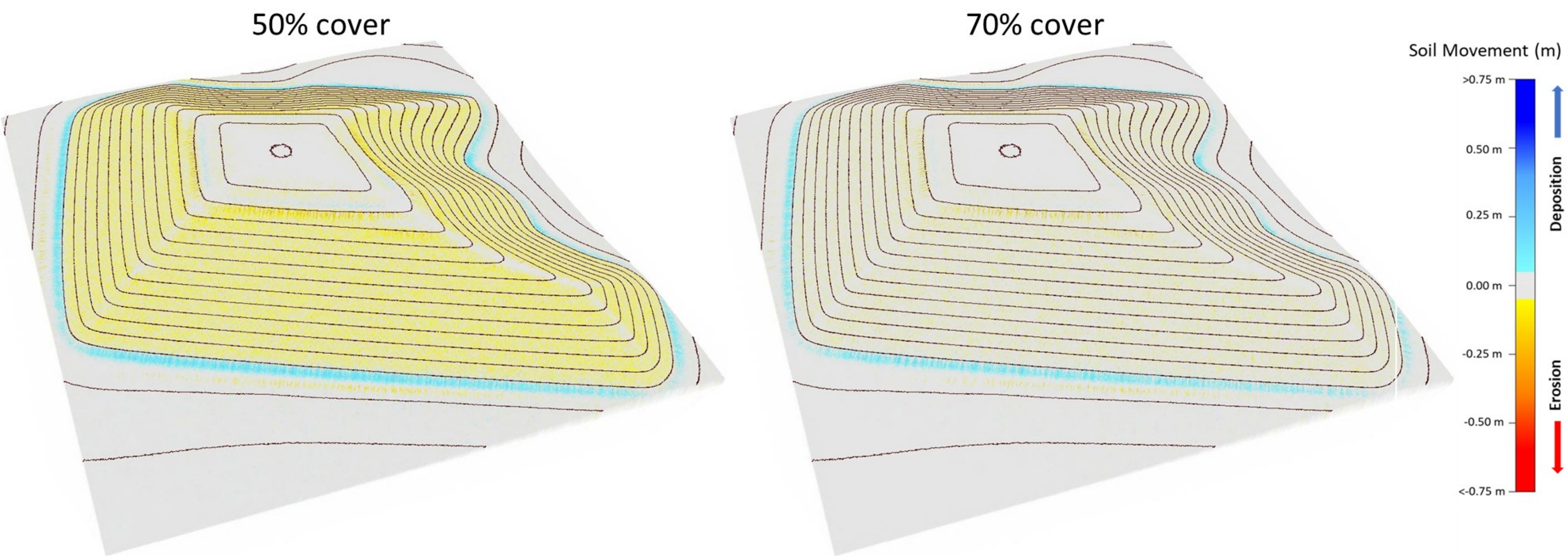

Figure C 3. Landform evolution model after 100 years of the SAR WRE covered with CH/SO Topsoil cover 0.3 m thick and vegetation cover of 50 % and 70 %.

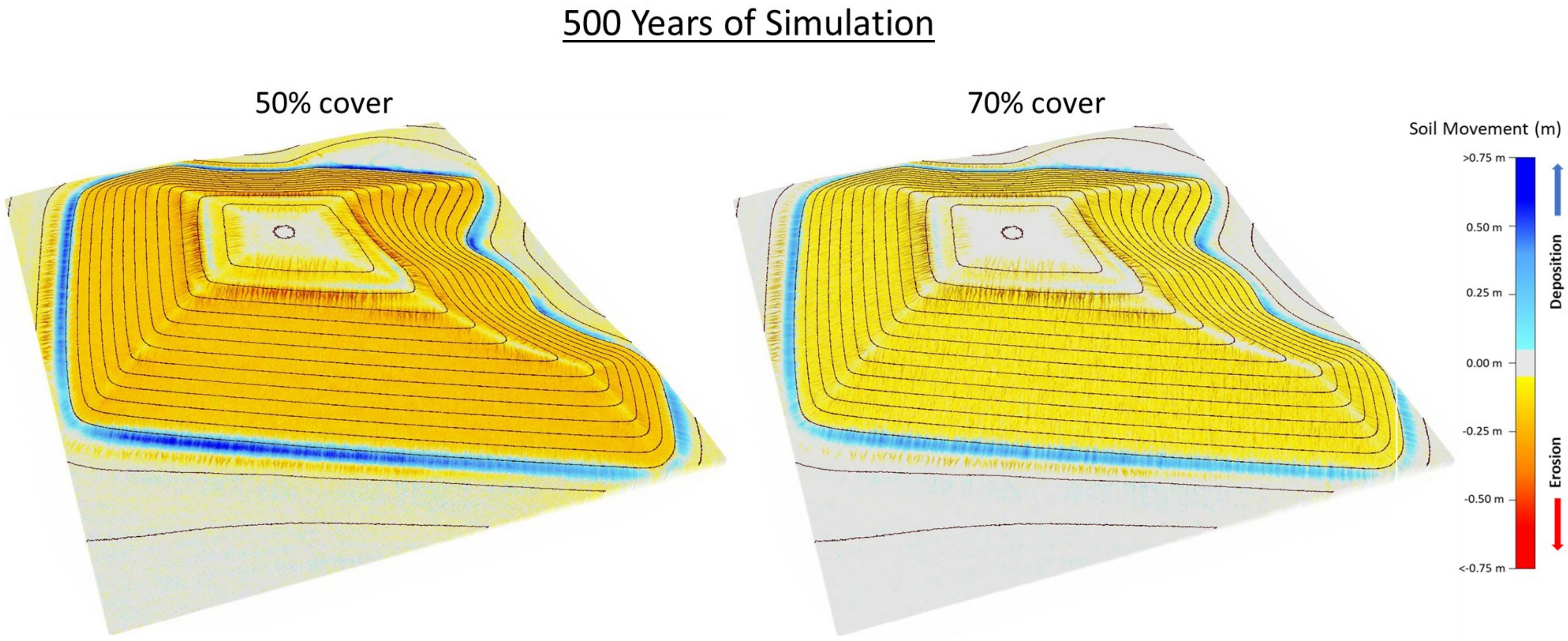

Figure C 4. Landform evolution model after 500 years of the SAR WRE covered with CH/SO Topsoil cover 0.3 m thick and vegetation cover of 50 % and 70 %.

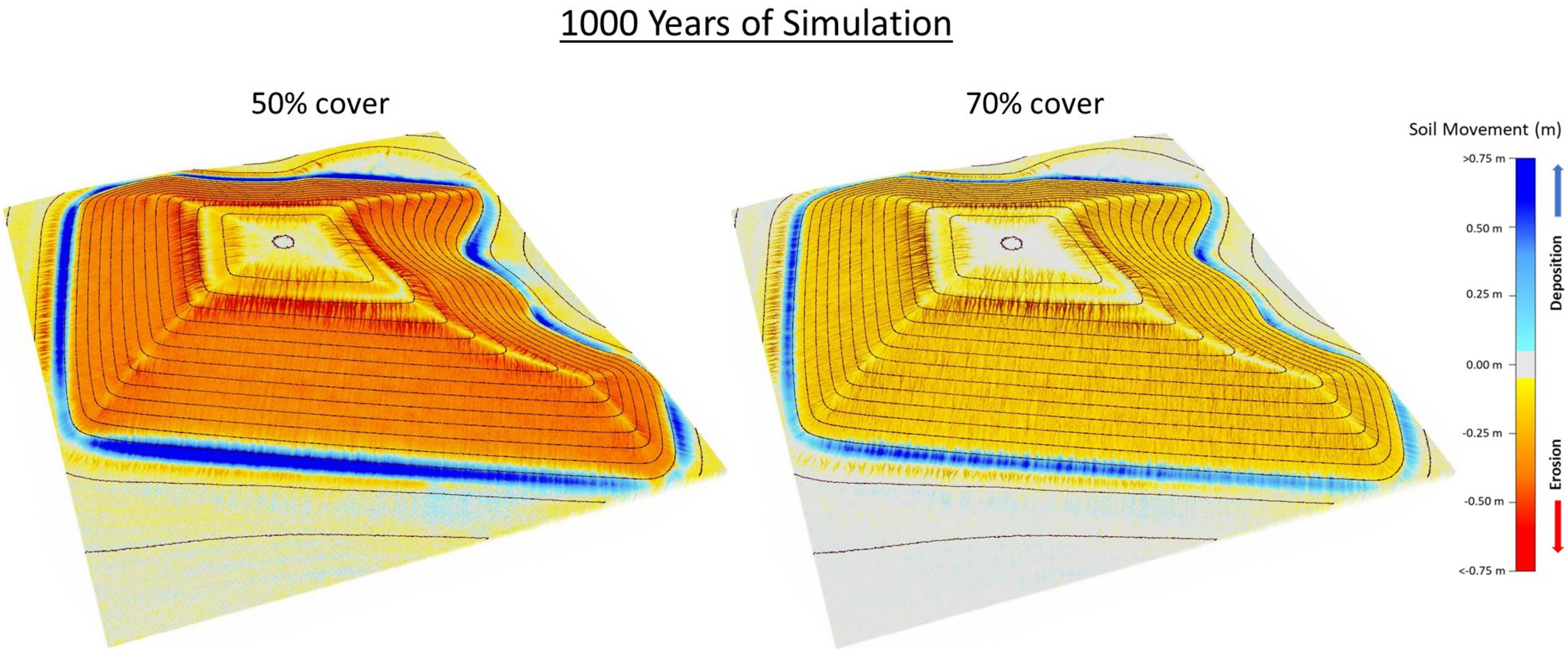

Figure C 5. Landform evolution model after 1000 years of the SAR WRE covered with CH/SO Topsoil cover 0.3 m thick and vegetation cover of 50 % and 70 %.

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