



stanmore

# APPENDIX D – MATERIALS CHARACTERISATION AND EROSION ASSESSMENT FOR THE REHABILITATED LANDFORM



## **ASSESSMENT OF LONG-TERM EROSION POTENTIAL FOR THE REHABILITATED LANDFORM AT ISAAC DOWNS EXTENSION**

Stanmore Resources Limited  
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## EXECUTIVE SUMMARY

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### Introduction

The Isaac Downs Extension (IDE) Project (the Project) is a proposed open cut coal mine extension to Isaac Downs Mine (IDM). The Project will be integrated into the Isaac Plains Complex (IPC), comprising IDM and Isaac Plains Mine (IPM) and will extend the life of mining at IPC. The Project includes proposed disturbance areas (e.g. open pit, waste landforms, soil stockpiles, and mining infrastructure) and areas of non-disturbance. Stanmore Resources Ltd (Stanmore) has engaged Landloch Pty Ltd (Landloch) to undertake a rehabilitated landform erosion study for the Project. The study included:

- Review of existing information on soils and wastes.
- Completion of additional testing of wastes and soils.
- Two dimensional (2D) runoff/erosion modelling using the Water Erosion Prediction Project (WEPP) runoff/erosion modelling to define erosionally stable rehabilitation slope geometries.
- Three dimensional (3D) landform evolution modelling of the rehabilitation design.

### Recoverable soils and soils balance

A total 11,587,517 m<sup>3</sup> of soil are recoverable, consisting of 5,108,647 m<sup>3</sup> of good quality topsoil (44.1%), 4,530,750 m<sup>3</sup> of marginal topsoil (39.1%), and 1,948,120 m<sup>3</sup> of subsoil (16.8%).

Taurus, Krongie, Taurus-Teviot Complex, and Teviot SMUs are the dominant recoverable soils, with 85.6% of the recoverable soils captured in these soil types. They represent 78.7% of the recoverable good quality topsoil, 97.5% of the recoverable marginal topsoil, and 76.0% of the recoverable subsoil.

Soils are to be applied to rehabilitation areas where required (all areas except for the final void, Conrock Gully diversion bed and the post mining land use (PMLU) rehabilitation area. Use of an estimated 0.7 m thickness of soil in rehabilitation would fully utilise the good quality topsoil and marginal topsoil and mean the subsoil is not required. If only the good quality topsoil was used in rehabilitation (i.e. not using the marginal topsoil or subsoil), soils could be placed at an estimated thickness of 0.37 m.

In reality, stripping of some areas such as infrastructure areas and roads may simply push soils into windrows ready for their respreading over the same area when rehabilitated. If it is assumed that the only source of soils for use in rehabilitation will come from the waste landform and pit area footprints, the good quality topsoil would result in a 0.23 m thick growth medium layer. If both the good quality topsoil and marginal topsoil is used, it is estimated that a 0.46 m thick soil layer could be used in rehabilitation.

Based on this assessment, it was concluded that creation of a soil layer that is 0.5 m thick is achievable if both good quality topsoil and marginal topsoil is stripped and used in rehabilitation. Sufficient volumes of good quality topsoil and marginal topsoil can be recovered such that recovery and use of the subsoils (that have properties less suited to being a growth medium) is not required.



## Erosion modelling

WEPP runoff/erosion modelling was undertaken to investigate a range of scenarios using erodibility parameters for 5 soils that exist at the Project. These soils are named Taurus, Taurus-Teviot, Krongie, Teviot, and Retro. They account for 89% of the good quality topsoil and marginal topsoil resource.

WEPP modelling used a long-term climate sequence adjusted to reflect the SSP3-7.0 climate scenario assessed at 2090. A range of vegetation groundcover levels (0%, 50%, 65%, and 80%) were also considered. The addition of fresh Permian waste to the soils as a rock armour was also included. The WEPP-predicted maximum erosionally stable slope lengths for each model scenarios considered in shown in the table below.

### Predicted maximum erosionally stable slope lengths for a range of materials, uniform slope gradients and cover conditions.

| Surface Cover                 | Slope Gradient (%) | Maximum Erosionally Stable Slope Length (m)* |               |         |        |       |
|-------------------------------|--------------------|----------------------------------------------|---------------|---------|--------|-------|
|                               |                    | Taurus                                       | Taurus-Teviot | Krongie | Teviot | Retro |
| 0% Groundcover                | 10                 | 35                                           | 30            | 5       | 30     | 30    |
|                               | 15                 | 20                                           | 20            | 5       | 15     | 15    |
| 50% Groundcover               | 10                 | 500                                          | 140           | 100     | 500    | 500   |
|                               | 15                 | 500                                          | 60            | 60      | 500    | 185   |
| 65% Groundcover               | 10                 | 500                                          | 500           | 270     | 500    | 500   |
|                               | 15                 | 500                                          | 335           | 150     | 500    | 500   |
| 80% Groundcover               | 10                 | 500                                          | 500           | 500     | 500    | 500   |
|                               | 15                 | 500                                          | 500           | 500     | 500    | 500   |
| Rock Armour + 30% Groundcover | 10                 | 500                                          | 480           | 485     | 500    | 500   |
|                               | 15                 | 500                                          | 285           | 295     | 350    | 400   |
|                               | 20                 | 500                                          | 205           | 210     | 240    | 305   |
|                               | 25                 | 260                                          | 160           | 165     | 185    | 210   |

\*Based on a target mean average annual erosion rate of <5 t/ha/y and mean peak annual erosion rates <10 t/ha/y.

## Landform evolution modelling

These slope geometries were used to inform that development of the 3D final landform design for the Project. This 3D design was used to model landform evolution over a 300 year period using the SIBERIA landform evolution model. The results of the SIBERIA modelling is discussed separately for the three distinct 3D landforms:

- Main landform – Waste landform associated with the open cut pit comprising majority in-pit dumping, but with some out of pit dumping near the initial strips of mining, with the majority of runoff draining to the final void, and which is the largest Project waste landform.
- South-west (SW) landform – Small out of pit waste landform to the south-west of the final void, which is externally draining.
- East landform – small out of pit waste landform to the east of the final void, which is externally draining.

Statistics of the SIBERIA landform evolution modelling are summarised in the table below.

The three landforms are predicted to typically erode at acceptable erosion rates. The acceptable long-term mean average annual erosion rate was set at 5 t/ha/y for this study, being a rate at which the risk of rill erosion being initiated is low. The mean average annual erosion rate for the main landform is 3.7 t/ha/y after 50 years of simulation, increasing slightly to 4.5 t/ha/y after 300 years of simulation. The mean average annual erosion for the SW landform is 2.9 t/ha/y after 50 years of simulation, increasing slightly to 4.6 t/ha/y after 300 years of simulation. The mean average annual erosion for the east landform is 3.9 t/ha/y after 50 years of simulation, increasing slightly to 5.4 t/ha/y after 300 years of simulation.

The increase in erosion in the longer term is a result of the modelled prediction of formation of gullies as runoff discharges from a lower gradient berm onto the steeper downslope batter. These berms are likely to be removed as a part of progressive rehabilitation and as a result, the landform is likely to be more erosional stable than the modelling indicates.

**Predicted maximum gully depths, average erosion rates, and cumulative average erosion the main landform, SW landform, and east landform.**

| Simulation year                                  | Maximum gully depth (m) | Average annual erosion (t/ha/y) | Cumulative average erosion (mm) |
|--------------------------------------------------|-------------------------|---------------------------------|---------------------------------|
| Main Landform – Taurus with 65% Groundcover      |                         |                                 |                                 |
| 50                                               | 0.3                     | 3.7                             | 12                              |
| 100                                              | 0.6                     | 4.2                             | 40                              |
| 200                                              | 0.8                     | 4.5                             | 100                             |
| 300                                              | 1.0                     | 4.5                             | 190                             |
| SW Landform – Taurus-Teviot with 65% Groundcover |                         |                                 |                                 |
| 50                                               | -                       | 2.9                             | 10                              |
| 100                                              | 0.4                     | 3.8                             | 35                              |
| 200                                              | 0.7                     | 4.4                             | 94                              |
| 300                                              | 0.9                     | 4.6                             | 185                             |
| East Landform – Retro with 65% Groundcover       |                         |                                 |                                 |
| 50                                               | 0.3                     | 3.9                             | 13                              |
| 100                                              | 0.5                     | 4.8                             | 45                              |
| 200                                              | 0.8                     | 5.3                             | 116                             |
| 300                                              | 1.0                     | 5.4                             | 223                             |

## Soil and vegetation groundcover

The WEPP and SIBERIA modelling results indicate that vegetation groundcover is essential to produce an erosionally stable final landform.

Taurus and Teviot soils are considered suitable for use on the slopes of all three landforms (with gradients  $\leq 15\%$ ) except for the steeper (25%) eastern low wall slope of the main landform that drains to the final void. This assumes that  $\geq 50\%$  groundcover is sustained on slopes less  $\leq 15\%$ . This is considered achievable given that vegetation groundcover levels in the vicinity of the Project are  $\sim 80\%$ .

For Retro soils, the vegetation groundcover level needs to be  $\geq 65\%$  for 15% gradient slopes on the main landform and  $\geq 50\%$  on the SW landform and east landform. This is considered achievable given that vegetation groundcover levels in the vicinity of the Project are  $\sim 80\%$ .

For Taurus-Teviot soils, the vegetation groundcover levels needs to be  $\geq 65\%$  for 15% gradient slopes on all landforms. This is considered achievable given that groundcover levels in the vicinity of the Project are  $\sim 80\%$ . That said, to reduce erosion risk, this soil could be preferentially used on either of the two smaller landforms (SW landform or east landform) that have shorter overall slope lengths.

The Krongie soils are the most erodible at the Project. They require a vegetation groundcover level of  $\geq 80\%$  to achieve erosional stability. This is achievable, but gives no allowance for poorer than expected vegetation performance. To reduce the erosion risk posed by this soil, Krongie could be preferentially placed on very low gradient portions of the final landforms such as the landform tops or the southern backfill surface of the final void.

## **Vegetation establishment**

Establishment of vegetation, and in particular groundcover, is critical for long-term erosional stability of the Project landform. There is a period directly after seeding when the landform surface will be unconsolidated and have low vegetation groundcover levels. This period represents a risk to rehabilitation success. Rainfall that leads to significant runoff during this period is likely to lead to the development of rills and potentially gullies. Given the low infiltration capacity of some of the Project soils, it is likely that this will occur.

Consideration should be given to rapid establishment of vegetation groundcover. Seed mixes should include a significant proportion of grasses, preferentially stoloniferous grasses as they spread in contact with the soil surface and provide better erosion control than tussocky grasses.

Consideration should also be given to temporary soil stabilisation techniques such as the use of hydromulches, surface tackifiers, or compost blankets. These techniques are able to provide resistance to erosion for the initial 1–2 years as the groundcover develops. The specific techniques used should be trialled, with the results of the trial used to inform progressive rehabilitation plans for the site.

## **Sub-surface growth media**

The wastes below the topsoils (and incorporated into the topsoil for rock-armoured slopes) should be gypsum treated to mitigate the risk posed by clay dispersion. The rate of gypsum should be determined by an appropriately qualified person for the materials that will be placed at the surface. This is most usefully performed just prior to commencement of rehabilitation works when the surface materials that will actually be used are identified and able to be sampled.

## Rock armour materials

Fresh non-carbonaceous sandstone and carbonaceous sandstone could be targeted for use as a rock armouring element in preference over fresh non-carbonaceous and carbonaceous siltstones/mudstones. Approximately half of the fresh waste is non-carbonaceous sandstone and carbonaceous sandstone.

When fresh non-carbonaceous sandstone and fresh carbonaceous sandstone is used as a rock armour element, the rock fraction must have good to marginal durability (or better). For the purpose of this assessment, the rock fraction can be considered particles greater than ~50 mm in diameter. Indicative quality indicators include rock particle density values  $>2.5 \text{ g/cm}^3$  and water absorption values  $<5.0\%$ . The rock fraction should have a mean particle size ( $D_{50}$ ) of at least 75 mm. The rock source should contain less than 40% fines ( $<2 \text{ mm}$  diameter).

The degree to which a rocky waste can successfully mitigate risks associated with erosion is related not only to rock durability, but also to the size and abundance of rock, the geometry of the landforms being considered, and the climate in which the landform is situated. Therefore, the rock durability results provide a useful indication of potential rock armour materials, but more comprehensive particle size distribution and erodibility testing, and landform design modelling would improve the understanding of the limits of its use as a rock armour material.

## Unsuitable wastes

Tertiary sediments and weathered wastes are likely to be highly erodible and not suitable for use at or near the surface of rehabilitated surfaces. As such, fresh non-carbonaceous waste and/or fresh carbonaceous waste should be present below the growth media layer. A recommended thickness is 1.5 m. Tertiary sediments and weathered wastes can be present below this surface layer.

## Slope design

The results of the modelling show that the linear slopes present within the final landform design are predicted to erode at acceptable rates in the long-term when covered with the soils sourced during Project operations and when the required vegetation groundcover levels are achieved. Assuming the Krongie soil is used on very low gradient areas (landform tops or the backfill surface of the southern final void), vegetation groundcover levels  $\geq 50\%$  for Taurus and Teviot and  $\geq 65\%$  for Taurus-Teviot and Retro are required on slopes with  $\leq 15\%$  gradient. Groundcover levels of  $\geq 30\%$  are required on 25% gradient slopes that are also rock armoured.

## Cross-slope berms

The current design includes narrow (~10 m wide) cross-slope berms that store and infiltrate water. They represent points of potential weakness in the design as they may unevenly fill with sediment and overtop. Berms should be monitored on a regular basis during rehabilitation (annually or after a large rainfall event) for signs of tunnel erosion

or uneven settlement/filling. Where these are observed, remedial actions should be undertaken to ensure the continued function of the berms.

Refinement of the design to remove these berms should be considered as future developments allow. Given the erosion modelling results, this could be achieved by removing the berms as part of progressive rehabilitation. For example, the berms (in place to manage runoff and sediment from upslope sections during operations and the initial stages of rehabilitation) could be removed when the lower slopes are rehabilitated and suitably vegetated.

## **Landform tops**

Krongie soils should preferentially be used on very low gradient landform tops or the backfill surface of the southern final void.

Uncontrolled runoff from the landform top is a common cause of gulying and landform failure. This risk could be mitigated by the installation of crest bunds around the perimeter of the landform tops. The bunds are to be thoroughly compacted and constructed of stable (non-dispersive) material. They are to have their outer faces continuous with the outer batter profile and have the same surface treatments applied to it (e.g. soils). They are to have a width across the top of the bund of at least 2 m and are to have their inner face sloping gradually inwards at a gradient of 1V:10H (10%). The gentle inward gradient ensures that any water that ponds will be ponded well away from the outer batter slope, thereby minimising the potential for any sinkhole that may form to reach the outer batter slope and create an "instant gully".

Alternatively, if the landform top is to be free draining and crest bunds are not able to be used, such as on the top of the main landform that drains to the final void, the landform top surface should be roughened to increase its depression storage and reduce the ability of surface water to move laterally across the top and reduce the likelihood that flows can concentrate and discharge at discrete locations onto the downslope slope sections. Roughening of the landform top could be achieved by deep ripping.

## **Surface ripping**

It is critical that flow concentration on the slopes is minimised. Concentration of runoff can be prevented by minimising the size of cross-slope rip lines. Rip lines should be no deeper than 300 mm from peak to trough of the rip line once settlement has occurred. To achieve this, an unconsolidated rip line ~500 mm deep is recommended. Ripping will be desirable to reduce machinery compaction, remove track marks that are not on contour, and incorporate amendments if required, as determined by an appropriately qualified person for the growth media available at the time that rehabilitation occurs encourage repaid vegetation growth.

For more precise results, equipment used for rehabilitation works should have guidance systems installed, and use operators that are highly skilled and experienced. Rehabilitation earthworks require greater levels of precision than mining earthworks, with adherence to the specified designs if successful rehabilitation is to be achieved.

## Landform position and flood scour

The main landform is located within the 1% Annual Exceedance Probability (AEP) Isaac River (northern end) flood area, but not within the 1% AEP flood area for Cherwell Creek. Maximum flow velocities adjacent the main landform are predicted to be 0.5–1.0 m/s. The SW landform and east landform are not positioned within the 1% AEP flood area for either the Isaac River or Cherwell Creek.

The velocities predicted for the northern end of the main landform are likely to lead to scour erosion when the soils are bare of vegetation (which is not the intention for rehabilitation of this area). The *Soil Conservation Guidelines for Queensland* recommend a maximum permissible velocity for easily eroded bare soils on low gradient land (1% is the lowest reported) of 0.5 m/s. When vegetated, the maximum permissible velocity increases. The guideline indicates that the maximum permissible velocity increases to 1.2 m/s (greater than the maximum predicted velocities of the 1% AEP event) for 50% vegetation groundcover and 1.5 m/s for 75% vegetation groundcover. Therefore, the proposed vegetation groundcover of the main landform would mitigate the risk of scour erosion.

## GLOSSARY OF TERMS

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|                                                                 |                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>2D</b>                                                       | Two dimensional                                                                                                                                                                                                                                                                                                 |
| <b>3D</b>                                                       | Three dimensional                                                                                                                                                                                                                                                                                               |
| <b>Acceptable erosion rate</b>                                  | Long-term annual erosion rates at which the risk of rill erosion being initiated is low. In Landloch's experience, long-term annual erosion rates that produce batters with a low tendency to rill are: Mean average annual erosion $\leq 5\text{t/ha/y}$ and mean peak annual erosion $\leq 10\text{t/ha/y}$ . |
| <b>ANC</b>                                                      | Acid Neutralising Capacity                                                                                                                                                                                                                                                                                      |
| <b>ASC</b>                                                      | See Australian Soil Classification system                                                                                                                                                                                                                                                                       |
| <b>Australian Soil Classification system</b>                    | Australia's official, hierarchical national framework for categorising soils using observable soil properties (morphology, chemistry, physics) for scientific, environmental, and land management purposes.                                                                                                     |
| <b>CLIGEN</b>                                                   | Stochastic (random probability distribution) weather generator that produces daily estimates of precipitation, temperature, dewpoint, wind, and solar radiation for a single geographic point, using monthly parameters (means, standard deviations, skewness) derived from the historic climate observations.  |
| <b>Critical shear</b>                                           | See critical shear for rill initiation                                                                                                                                                                                                                                                                          |
| <b>Critical shear for rill initiation (<math>\tau_c</math>)</b> | Shear stress at which soil detachment in concentrated flows rapidly increases                                                                                                                                                                                                                                   |
| <b>ECEC</b>                                                     | Effective Cation Exchange Capacity, the sum of exchangeable cations ( $\text{Ca}^{2+}$ , $\text{Mg}^{2+}$ , $\text{Na}^+$ , $\text{K}^+$ , and $\text{Al}^{3+}$ )                                                                                                                                               |
| <b>EC<sub>1:5</sub></b>                                         | Electrical conductivity (EC) of a sample measured in a solution containing 1 part solids to 5 parts deionised water. EC is a measure of the salinity of a sample.                                                                                                                                               |
| <b>Effective hydraulic conductivity (<math>K_e</math>)</b>      | Infiltration-related parameter for the WEPP model used by the Green-Ampt infiltration equation                                                                                                                                                                                                                  |
| <b>EIS</b>                                                      | Environmental Impact Statement                                                                                                                                                                                                                                                                                  |
| <b>Erodibility</b>                                              | Susceptibility with which soil and rock materials yield and detach from a surface due to erosive forces like water.                                                                                                                                                                                             |
| <b>Erosion</b>                                                  | The detachment and movement of soil or waste by water.                                                                                                                                                                                                                                                          |
| <b>Erosivity</b>                                                | A measure of the erosive power of rainfall. It is a function of the rain's kinetic energy and duration.                                                                                                                                                                                                         |
| <b>ESP</b>                                                      | Exchangeable sodium percent, measured as the ratio of exchangeable sodium and the Effective Cation Exchange Capacity of a sample, expressed as a percent. ESP is a measure of dispersion potential and structural stability.                                                                                    |
| <b>Good quality topsoil</b>                                     | Primary choice for topsoil resources and has negligible limitations to plant growth                                                                                                                                                                                                                             |
| <b>Groundcover</b>                                              | See vegetation groundcover                                                                                                                                                                                                                                                                                      |
| <b>The Project</b>                                              | The Isaac Downs Extension (IDE) Project                                                                                                                                                                                                                                                                         |



|                                                 |                                                                                                                                                                                                                                   |
|-------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Interrill erodibility (<math>K_i</math>)</b> | A measure of sediment delivery rate to rills as a function of rainfall intensity and runoff rate. Parameter that is used to predict erosion that results from shallower surface water flows.                                      |
| <b>Marginal topsoil</b>                         | Soils that have minor limitations to plant growth that can be ameliorated if used.                                                                                                                                                |
| <b>MPA</b>                                      | Maximum Potential Acidity                                                                                                                                                                                                         |
| <b>NAF</b>                                      | Non-acid forming                                                                                                                                                                                                                  |
| <b>PAF</b>                                      | Potentially acid forming                                                                                                                                                                                                          |
| <b>pH<sub>w</sub></b>                           | Acidity of a sample measured in a solution containing 1 part solids to 5 parts deionised water                                                                                                                                    |
| <b>PRC Plan</b>                                 | Progressive Rehabilitation and Closure Plan                                                                                                                                                                                       |
| <b>Project</b>                                  | Isaac Downs Extension (IDE) Project                                                                                                                                                                                               |
| <b>Rill erodibility (<math>K_R</math>)</b>      | A measure of soil susceptibility to detachment by concentrated flow. Parameter that is used to predict erosion that results from concentrated flows in rills.                                                                     |
| <b>Rock particle density</b>                    | Particle density is the mass of a single rock divided by its volume.                                                                                                                                                              |
| <b>Rock water absorption</b>                    | Mass of water that a rock particle absorbs in terms of its dry mass of the rock, expressed as a percent.                                                                                                                          |
| <b>Sediment density distribution</b>            | Density of different sized particles within a sample of sediment in runoff produced by the application of simulated rain.                                                                                                         |
| <b>Sediment particle size distribution</b>      | Amounts (by mass) of different sized particles within a sample of sediment in runoff produced by the application of simulated rain.                                                                                               |
| <b>SIBERIA</b>                                  | Landform evolution model. The word SIBERIA is not a recognised acronym.                                                                                                                                                           |
| <b>SMU</b>                                      | See Soil Mapping Unit                                                                                                                                                                                                             |
| <b>Soil Mapping Unit</b>                        | A specific area of land with soils of relatively uniform physical and chemical characteristics. It is a practical way to divide a larger area into smaller, more manageable parts for effective soil management and conservation. |
| <b>Soil profile</b>                             | A vertical section of the soil through all its horizons and extending into the C horizon.                                                                                                                                         |
| <b>Soil-rock mixture</b>                        | A manufactured material that can potentially be used as a primary growth media. In it created by mixing fresh, benign, durable waste rock with the available topsoils.                                                            |
| <b>Spoil</b>                                    | Rock material overlying and between ‘target’ coal seams, which will report as waste. Waste rock overlying a coal seam is called overburden. Waste rock between mined coal seams is called interburden.                            |

**SSP3-7.0**

A future climate scenario that represents a pathway where emissions rise significantly, leading to a projected global temperature increase of 2.8°C to 4.6°C by 2100 compared to pre-industrial levels. This pathway assumes no additional climate policy and is characterised by high population growth, low technological advancement, and countries prioritising self-reliance and security over global cooperation.

**Subsoil**

Sub-surface growth media that is positioned below topsoils.

**Vegetation groundcover**

Vegetation that is in contact with the land surface. Practically, this means a combination of grass cover and anchored (not readily moved) surface litter. Groundcover impacts do not consider rock cover.

**Waste**

See spoil

**WEPP**

Water Erosion Prediction Project runoff and erosion model

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## 1 INTRODUCTION

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Stanmore Resources Ltd (Stanmore) has engaged Landloch Pty Ltd (Landloch) to undertake a rehabilitated landform erosion study for the Isaac Downs Extension (IDE) Project (the Project). This report is intended to inform the approvals for the Project, including an Environmental Impact Statement (EIS) and Progressive Rehabilitation and Closure Plan (PRC Plan) under the *Environmental Protection Act 1994* (EP Act).

### 1.1 Scope of work

The work completed as part of this landform erosion study included:

- Review of existing information on soils and wastes.
  - For soils, review the soils characterisation data generated as part of the soil survey component of this study (Landloch 2025).
  - For wastes, review the characterisation data generated as part of Terrenus Earth Sciences' (Terrenus 2025) scope of work with specific reference to parameters that indicate their potential for use as a growth media and/or a rock armour.
- Completion of testing of wastes and soils:
  - For soils, laboratory-based erodibility testing using simulated rainfall, overland flows, and settling columns.
  - For wastes, assessment of coarse fraction durability.
- Conduct two dimensional (2D) runoff/erosion modelling and define erosionally stable rehabilitation slope geometries using these erodibility parameters. Modelling also included assessment of the impact of vegetation groundcover on erosion, and considered climate change.
- Conduct three dimensional (3D) landform evolution modelling of the rehabilitation design, including the impact of vegetation groundcover and climate change.
- Report the outcomes of the study (this document).

## 2 BACKGROUND

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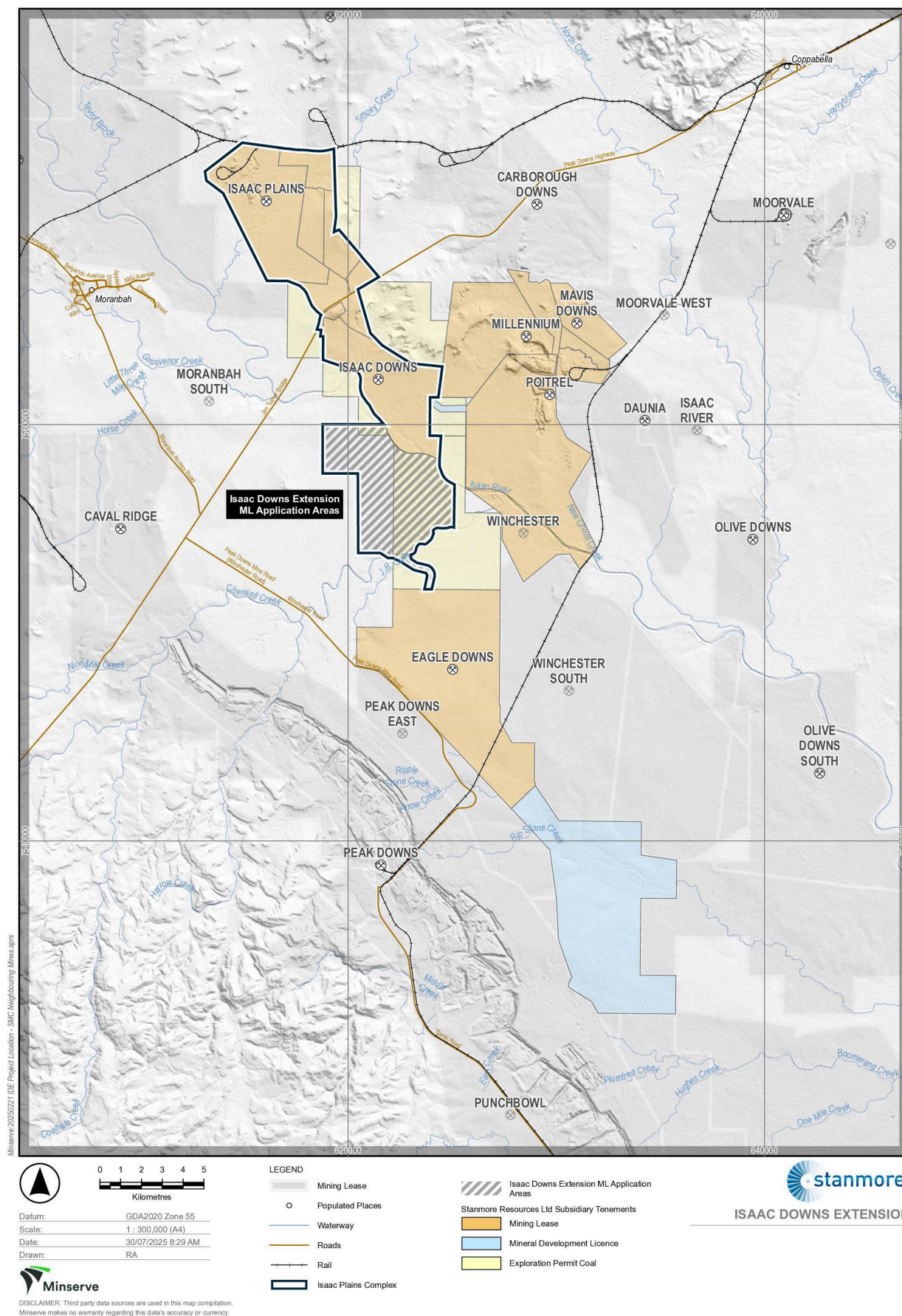
### 2.1 Project description

The Project is a proposed open cut coal mine extension to Isaac Downs Mine (IDM). The Project will be integrated into the Isaac Plains Complex (IPC), comprising IDM and Isaac Plains Mine (IPM) and will extend the life of mining at IPC.

The Project is located in the Bowen Basin of Central Queensland approximately 15 km south-east of Moranbah and 150 km south-west of Mackay. The Project's four mining lease (ML) application areas (together forming the Project area) are shown in Figure 1.

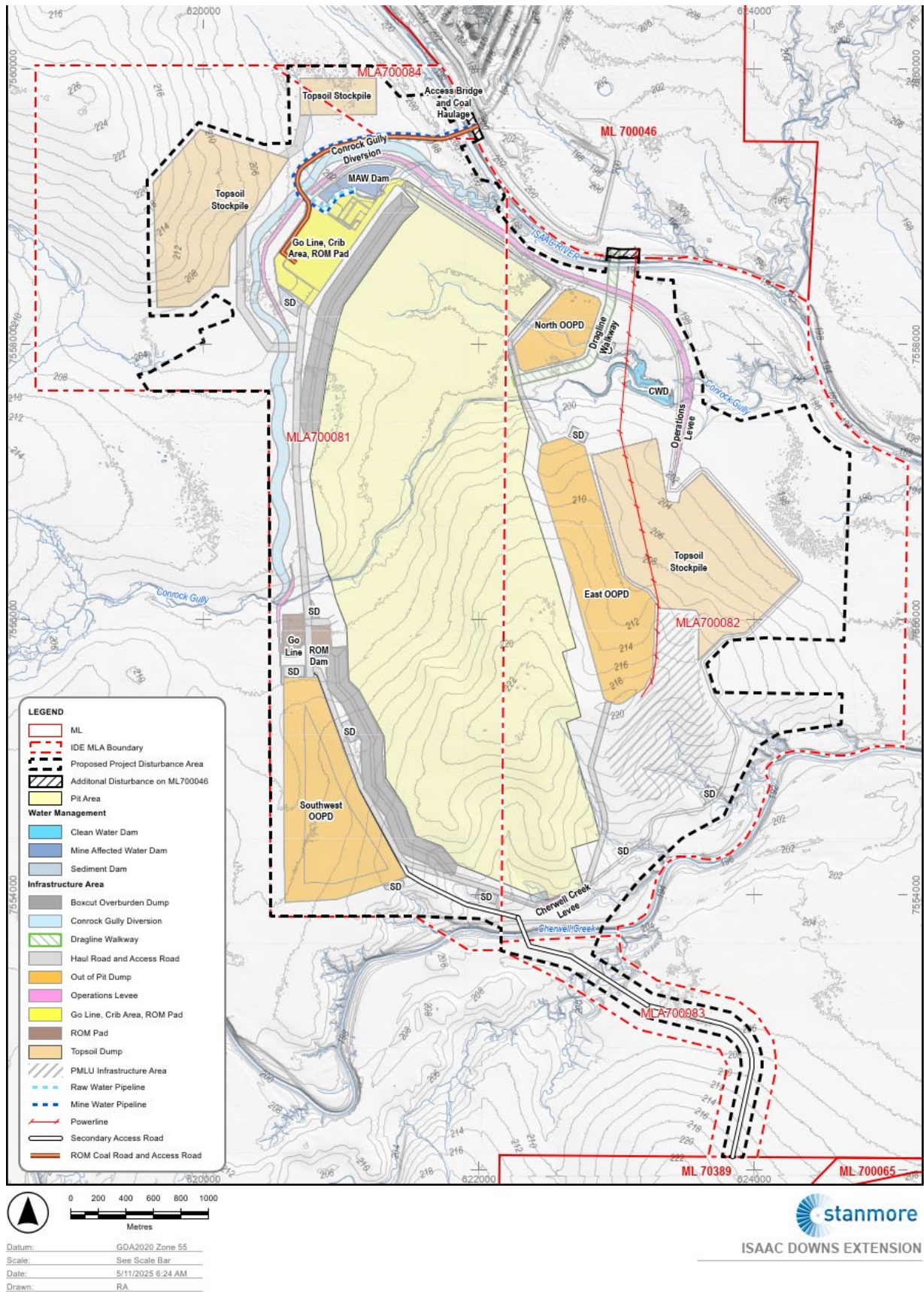
The Project includes proposed disturbance areas (open pit, waste landforms, soil stockpiles, and mining infrastructure) and areas of non-disturbance. The general layout of the Project and the proposed disturbance area is presented in Figure 2.





**Figure 1:** Location of the Project within the broader Isaac Plains Complex.





**Figure 2:** Proposed Project layout and disturbance area.



## 2.2 Soils

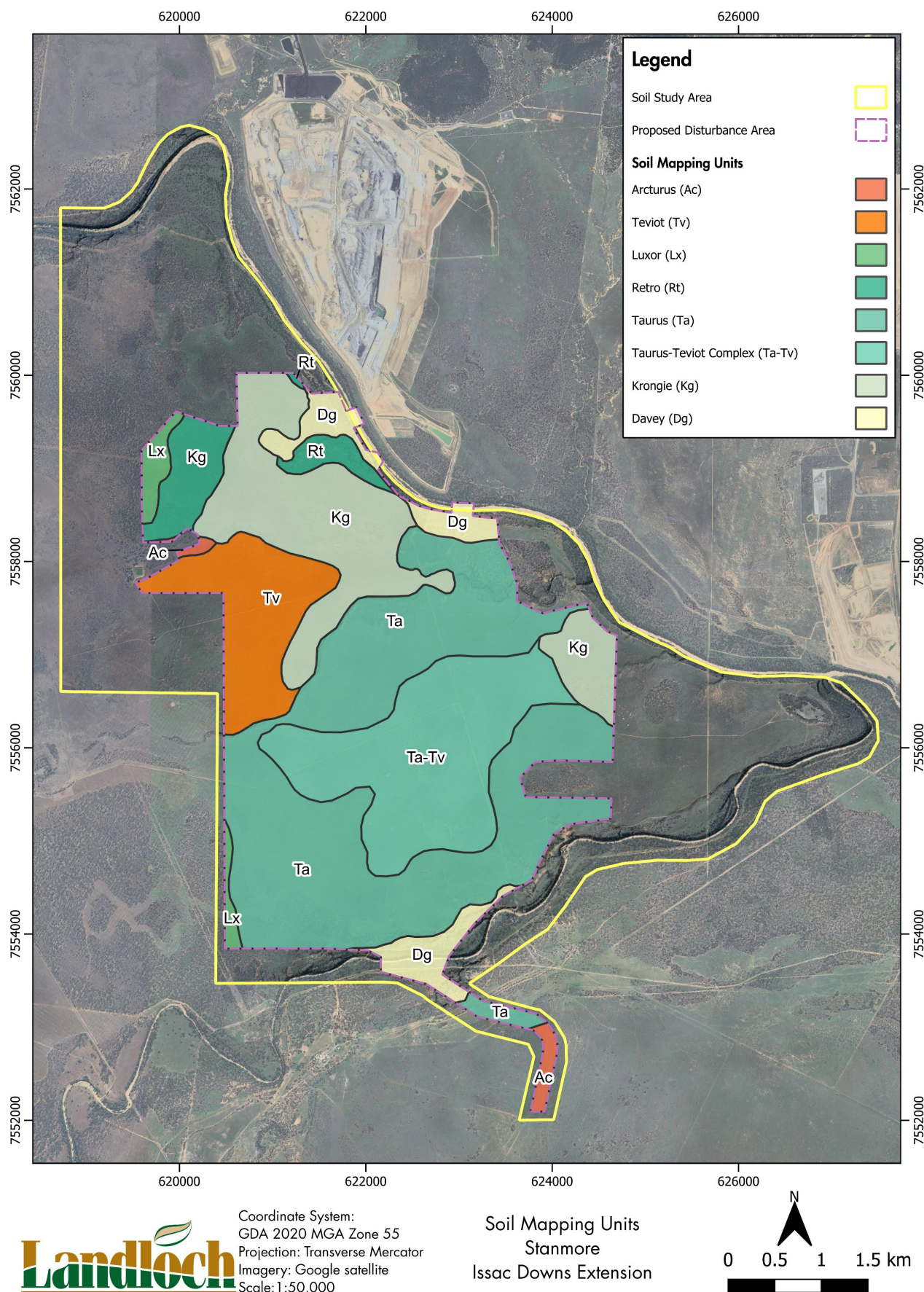
### 2.2.1 Soil management units

Landloch (2025) conducted a soil survey at the Project and surrounds (the soils study area), making 102 detailed observations of soil profiles and 169 brief mapping observations across the study area. An additional 91 existing soil observations across the study area were used to inform the soil types and boundaries. Each soil profile at the detailed sites was classified to the family level using the Australian Soil Classification system (Isbell and NCST 2021) before being aggregated into Soil Mapping Units (SMUs). Each SMU contains a dominant soil profile type and is a distinguishable area of land that shares similar chemical and physical properties.

Not all of the land within the Project area is proposed to be disturbed; only soils within the proposed disturbance area are likely to be disturbed. Furthermore, the proposed disturbance area represents a maximum potential disturbance area, with the actual disturbance based on the infrastructure or mining activity areas shown in Figure 2. Some infrastructure or activity areas shown in Figure 2 will have less impact on soils than other areas, such as topsoil stockpile areas, where existing soils will not be stripped. The spatial distribution of the SMUs within the proposed disturbance area is shown in Figure 3. A description of the SMUs and their extent within the proposed disturbance area are given in Table 1.

**Table 1:** SMUs and the proportion of each within the proposed disturbance area.

| SMU                   | Description                                                                                                                                                                                                                          | Extent Within Proposed Disturbance Area |    |
|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|----|
|                       |                                                                                                                                                                                                                                      | ha                                      | %  |
| Taurus                | Sodic texture contrast soils with moderately thick sandy surfaces. Occurs on gently undulating rises within the southern half of the study area.                                                                                     | 839.9                                   | 40 |
| Taurus-Teviot Complex | Complex soil unit consisting of sodic texture contrast soils (Taurus) with sporadically occurring cracking clay soils (Teviot) in gilgai depressions. Occurs on a gently undulating rise within the southern half of the study area. | 387.6                                   | 19 |
| Krongie               | Cracking clay soils with normal gilgai microrelief. Occurring on alluvial floodplains along the Isaac River.                                                                                                                         | 378.6                                   | 18 |
| Teviot                | Cracking clay soils in the depressions of normal gilgai microrelief. Texture contrast soils on the mounds. Occurs on gently undulating rises, central within the study area.                                                         | 195.6                                   | 9  |
| Davey                 | Deep alluvial sands occurring on the levees along the Isaac River and Cherwell Creek.                                                                                                                                                | 118.8                                   | 6  |
| Retro                 | Sodic texture contrast soils with thin loamy surfaces. Occurs on gently undulating rises on the northern half of the study area.                                                                                                     | 102.8                                   | 5  |
| Luxor                 | Texture contrast soils with thick sandy surfaces and clay subsoils. Occurring on a prominent rise on the northern half of the study area.                                                                                            | 36.7                                    | 2  |
| Arcturus              | Cracking clay soils derived from basalt with crabhole microrelief. Occurs on gently undulating rises and colluvial depositions on the western boundary.                                                                              | 20.0                                    | 1  |



**Figure 3:** Soil mapping units within the proposed disturbance area of the Project.



### 2.2.2 Soil characteristics

The soils within the proposed disturbance area were grouped into 3 classes based on their characteristics (Landloch 2025). The 3 classes were 'good quality topsoil', 'marginal topsoil', and 'subsoil'.

Good quality topsoil is the preferred choice for soil resources for rehabilitation and has negligible limitations to plant growth and nil to low levels of ameliorants required. Marginal topsoil can be used in rehabilitation where there is a deficit in good quality topsoil. Marginal topsoil has minor limitations to plant growth (slightly more acidic or alkaline, slightly elevated salinity, and/or higher sodicity) that can be ameliorated if used. Subsoil is not recommended for use at the surface in rehabilitation but can be placed below good quality topsoil or marginal topsoil.

Key characteristics of the good quality topsoil and marginal topsoil within the proposed disturbance area at the Project are summarised in Table 2. The numbers in brackets are median values. This data was sourced from Landloch (2025) and was limited to soils in the surface 0.6 m for all soil except for Retro (limited to 0.25 m) and Arcturus (limited to 0.3 m).

**Table 2:** Good quality topsoil and marginal topsoil characteristics for soil types within the proposed disturbance area of the Project.

| Property          | Unit     | Taurus              | Krongie            | Teviot              | Davey               | Retro               | Luxor               | Arcturus            |
|-------------------|----------|---------------------|--------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Depth             | m        | 0.0–0.6             | 0.0–0.6            | 0.0–0.6             | 0.0–0.6             | 0.0–0.25            | 0.0–0.6             | 0.0–0.3             |
| Extent            | %        | 59*                 | 18                 | 9                   | 6                   | 5                   | 2                   | 1                   |
| pH <sub>w</sub>   | pH Unit  | 5.9–7.6<br>(6.6)    | 5.8–8.9<br>(7.7)   | 6.2–8.7<br>(7.6)    | 6.2–7.6<br>(6.7)    | 5.8–8.5<br>(6.7)    | 6.2–7.8<br>(6.9)    | 6.4–8.3<br>(7.7)    |
| EC <sub>1:5</sub> | dS/m     | 0.02–0.21<br>(0.07) | 0.05–4.1<br>(0.18) | 0.04–0.48<br>(0.15) | 0.02–0.07<br>(0.03) | 0.03–0.36<br>(0.08) | 0.02–0.10<br>(0.04) | 0.04–0.27<br>(0.10) |
| ECEC              | meq/100g | 2.4–13<br>(6.2)     | 18–36<br>(26)      | 14–23<br>(21)       | 2.1–7.7<br>(2.3)    | 7.7–23<br>(12)      | 2.0–13<br>(5.3)     | 16–42<br>(36)       |
| ESP               | %        | 0.7–11<br>(2.7)     | 0.7–13<br>(4.9)    | 0.7–13<br>(3.6)     | 1.8–2.4<br>(1.9)    | 0.6–12<br>(1.9)     | 0.9–7.6<br>(2.1)    | 1.3–5.3<br>(2.4)    |
| Clay              | %        | 13–48<br>(27)       | 43–66<br>(55)      | 25–42<br>(34)       | <10 <sup>^</sup>    | 22–35<br>(27)       | 5–46<br>(26)        | >30 <sup>†</sup>    |

\* Includes both the Taurus and Taurus-Teviot Complex extent. <sup>^</sup> Clay content was not measured for Davey. However, the SMU contains sandy soils which typically have clay contents <10%. <sup>†</sup> Clay content was not measured for Arcturus. However, the SMU contains vertosols, which by definition are clay soils, Vertosols typically have clay contents >30%.

Good quality topsoils and marginal topsoils have pH<sub>w</sub> values that range from moderately acid to moderately alkaline (5.8–8.9), though (based on the median values) they are more commonly slightly acid to slightly alkaline (6.6–7.7). Salinity is commonly low, with median EC<sub>1:5</sub> values ranging from 0.03–0.15 dS/m. Effective Cation Exchange Capacity (ECEC) tends to vary with clay content, indicating that the more clay-rich soils are able to store and supply more nutrients than the soils with lower clay contents. Exchangeable Sodium Percent (ESP, a measure of sodicity) is commonly low, with median ESP values ranging from 1.9–4.9%. Clay content varies between soil types. Krongie, Teviot, and Arcturus soils are clay textured and were observed to contain self-mulching (cracking) clays. Taurus soil commonly has a sandy loam texture, Retro soil a sandy clay loam texture, Luxor soil a clayey sand texture, and Davey soil a loamy sand texture.

### 2.2.3 Depths of different soil classes

The depth of each class of soil within the proposed disturbance area is summarised in Table 3 (Landloch 2025). For the common soil types (Taurus, Krongie, and Taurus-Teviot Complex, comprising 77% of the soil within the proposed disturbance area) good quality topsoil exists in the surface 0.3 m of the soil profile, and marginal topsoil exists from 0.3 m to ~0.6 m below ground level. Good quality topsoil from the other soil types exist at variable depths, ranging from 0.1 m (Arcturus) to 1.5 m (Davey). The depth of marginal topsoil is also variable.

For the purpose of assessing erosion potential, it was assumed that both good quality topsoil and marginal topsoil (with suitable amelioration) may be used during future rehabilitation of the Project landform.

**Table 3:** Depth of soil resources within the proposed disturbance area at the Project.

| SMU                    | Extent in Proposed Disturbance Area (%) | Source Depth Below Ground Level (m) <sup>^</sup> of: |                  |          |
|------------------------|-----------------------------------------|------------------------------------------------------|------------------|----------|
|                        |                                         | Good Quality Topsoil                                 | Marginal Topsoil | Subsoil  |
| Taurus                 | 40                                      | 0.0–0.3                                              | 0.3–0.6          | -        |
| Taurus-Teviot Complex* | 19                                      | 0.0–0.3                                              | 0.3–0.6          | -        |
| Krongie                | 18                                      | 0.0–0.3                                              | 0.3–0.65         | 0.65–1.0 |
| Teviot                 | 9                                       | 0.0–0.2                                              | 0.2–0.6          | 0.6–1.0  |
| Davey                  | 6                                       | 0.0–1.5                                              | -                | -        |
| Retro                  | 5                                       | 0.0–0.15                                             | 0.15–0.25        | 0.25–1.3 |
| Luxor                  | 2                                       | 0.0–0.4                                              | 0.4–0.8          | -        |
| Arcturus               | 1                                       | 0.0–0.1                                              | 0.1–0.3          | 0.3–0.7  |

\* The recovery depth for the Taurus-Teviot Complex SMU is not given in Landloch (2025). The values reported here are those of the Taurus SMU. <sup>^</sup> A cell marked with a '-' indicates that this class of soil was not identified for the given SMU.

### 2.2.4 Recoverable soil volumes

Soil will be recovered from all activity and infrastructure areas within the larger proposed disturbance area, including the pit area, waste landforms, infrastructure areas (e.g. haul roads, diversion, levees and dams) and the proposed post mining land use (PMLU) area. Table 4 shows the volume of recoverable soils. The same data expressed as percentages of the total volume are given in brackets. The recoverable soil volume was calculated for each part of the disturbance area as follows:

- Divide the polygon that represents a specific area (e.g pit area) into sub-polygons based on the boundaries of the different soil types.
- Determine the area of each sub-polygon and calculate the recoverable volume of each sub-polygon by multiplying the sub-polygon area by the recoverable depth for each soil type and soil quality class outlined in Table 3.
- Add the sub-polygon volumes for each soil type and quality class to determine the estimated total recoverable soil volume for each soil type and quality class.
- No swell factor was used to adjust the calculated volumes. This was done acknowledging that swelling will occur due to stripping, but assuming that the swelling will reduce over time within soil stockpiles and largely disappear once respread to rehabilitation areas.

**Table 4:** Estimated recoverable soil volume from areas within the proposed disturbance area in which disturbance will likely occur. Data expressed as percentages of the total volume are given in brackets.

| SMU                      | Estimated Recoverable Volume (m <sup>3</sup> ) of: |                              |                              |
|--------------------------|----------------------------------------------------|------------------------------|------------------------------|
|                          | Good Quality Topsoil                               | Marginal Topsoil             | Subsoil                      |
| Arcturus                 | 11,769<br>(0.1%)                                   | 23,538<br>(0.2%)             | 47,076<br>(0.4%)             |
| Davey                    | 968,051<br>(8.4%)                                  | 0<br>(0%)                    | 0<br>(0%)                    |
| Krongie                  | 819,944<br>(7.1%)                                  | 956,602<br>(8.3%)            | 956,602<br>(8.3%)            |
| Luxor                    | 50,208<br>(0.4%)                                   | 50,208<br>(0.4%)             | 0<br>(0%)                    |
| Retro                    | 60,129<br>(0.5%)                                   | 40,086<br>(0.3%)             | 420,903<br>(3.6%)            |
| Taurus                   | 2,023,299<br>(17.5%)                               | 2,023,299<br>(17.5%)         | 0<br>(0%)                    |
| Taurus-Teviot<br>Complex | 913,478<br>(7.9%)                                  | 913,478<br>(7.9%)            | 0<br>(0%)                    |
| Teviot                   | 261,770<br>(2.3%)                                  | 523,539<br>(4.5%)            | 523,539<br>(4.5%)            |
| <b>Total</b>             | <b>5,108,647<br/>(44.1%)</b>                       | <b>4,530,750<br/>(39.1%)</b> | <b>1,948,120<br/>(16.8%)</b> |

As a result of the adoption of a 0% swell factor, the volume of storage required within the topsoil stockpiles will be greater than the soil volumes listed in Table 4. To estimate stockpile storage volume requirements, the volume in Table 4 could be increased by 20% (given as a guide only).

A total 11,587,517 m<sup>3</sup> of soil are recoverable, consisting of 5,108,647 m<sup>3</sup> of good quality topsoil (44.1%), 4,530,750 m<sup>3</sup> of marginal topsoil (39.1%), and 1,948,120 m<sup>3</sup> of subsoil (16.8%).

Taurus, Krongie, Taurus-Teviot Complex, and Teviot SMUs are the dominant recoverable soils, with 85.6% of the recoverable soils captured in these soil types. They represent 78.7% of the recoverable good quality topsoil, 97.5% of the recoverable marginal topsoil, and 76.0% of the recoverable subsoil.

### 2.2.5 Soil resource balance

The recoverable soils are to be placed on rehabilitated areas as part of rehabilitation works. This requires determination of the surface area of the areas to which soil will be applied as part of rehabilitation. It was assumed that all rehabilitation areas except for the Conrock Gully diversion bed, the pit lake, and the proposed PMLU area will have soil reapplied.

The rehabilitation surface area was determined by calculating the 3D surface area of the landform rehabilitation design that contained the proposed waste landform shapes, which will increase the surface area of the final landform compared to its pre-mining



surface area. The surface areas of the proposed Conrock Gully diversion bed, pit lake and proposed PMLU area shapes will not be covered in soil, which will decrease the surface area of the final landform that requires soil to be applied.

Using this surface area, use of an estimated 0.7 m thickness of soil in rehabilitation would fully utilise the good quality topsoil and marginal topsoil and mean the subsoil is not required. If only the good quality topsoil was used in rehabilitation (i.e. not using the marginal topsoil or subsoil), soils could be placed at an estimated thickness of 0.37 m.

In reality, stripping of some areas such as infrastructure areas and roads may simply push soils into windrows ready for their respreading over the same area when rehabilitated. If it is assumed that the only source of soils for use in rehabilitation will come from the waste landform and pit area footprints, the good quality topsoil would result in a 0.23 m thick growth medium layer. If both the good quality topsoil and marginal topsoil is used, it is estimated that a 0.46 m thick soil layer could be used in rehabilitation.

Based on this assessment, it was concluded that creation of a soil layer that is 0.5 m thick is achievable if both good quality topsoil and marginal topsoil is stripped and used in rehabilitation. Sufficient volumes of good quality topsoil and marginal topsoil can be recovered such that recovery and use of the subsoils (that have properties less suited to being a growth medium) is not required.

More detail on the soil balance is given in Appendix E.

## **2.3 Wastes**

### ***2.3.1 Waste types***

For the purpose of this study, wastes have been considered in 2 groups that align with material groups used by Terrenus Earth Sciences (Terrenus) in the waste characterisation study for the Project (Terrenus 2025):

- Fresh, non-carbonaceous; and
- Fresh, carbonaceous.

Other groups considered by Terrenus but not considered in this report include weathered non-carbonaceous wastes, and coal. Weathered wastes are not considered because they are unlikely to be used as rock armouring at the surface of the rehabilitated landform to increase erosion resistance. Coal was not considered as it will not form part of the waste stored in the final landforms.

Characterisation data was sourced from samples taken from 4 drill holes. Details on these drill holes are given in Table 5. Fresh non-carbonaceous wastes account for 65.9–80.9% of the wastes encountered in the drill cores (73% when all 4 holes are considered together). The remaining waste is weathered non-carbonaceous wastes (22.3%) and fresh carbonaceous waste (4.7%). The fresh wastes account for 77.7% of the waste from the 4 drill holes, and the weathered wastes account for the remaining 22.3% of waste.

Based on this, it was concluded that fresh waste, and particularly fresh non-carbonaceous wastes are very common and potentially available for use as part of rehabilitation as a rock armouring element.

**Table 5:** Details of the wastes in the 4 drill holes assessed.

| Hole ID   | Hole Depth (m) | Hole Depth That Is Waste (m) | Proportion (%) of Drill Hole Waste: |                        |                    |
|-----------|----------------|------------------------------|-------------------------------------|------------------------|--------------------|
|           |                |                              | Weathered Non-carbonaceous          | Fresh Non-carbonaceous | Fresh Carbonaceous |
| CCIS0047  | 119.66         | 110.4                        | 19.9                                | 65.9                   | 14.2               |
| CCIS0048  | 107.29         | 101.0                        | 27.9                                | 70.2                   | 1.9                |
| CCIS0049  | 103.64         | 96.7                         | 22.8                                | 76.1                   | 1.1                |
| CCIS0050  | 101.52         | 97.0                         | 18.6                                | 80.9                   | 0.5                |
| All Holes | 432.11         | 405.1                        | 22.3                                | 73.0                   | 4.7                |

### 2.3.2 Geochemical properties

The acid producing potential of 185 fresh non-carbonaceous waste samples was assessed, and it was found that 183 samples (99%) were non-acid-forming (NAF), 1 sample was PAF (low capacity), and 1 sample had an uncertain classification. The geochemical properties of the NAF fresh non-carbonaceous waste and NAF fresh carbonaceous waste are summarised in Table 6.

The risk of these wastes producing acid is considered low. The Maximum Potential Acidity (MPA) is lower than the Acid Neutralising Capacity (ANC), indicating that any acid that might be produced can be effectively neutralised.

The fresh non-carbonaceous waste has  $pH_w$  values that are commonly strongly alkaline (mean  $pH_w$  9.9). This is higher than the  $pH_w$  commonly found in topsoils ( $pH_w$  6.6–7.7) at the Project. The subsoils at the Project are commonly moderately alkaline (mean  $pH_w$  8.2). The pH of the fresh non-carbonaceous waste will impact the pH of the surface layer if it is used as an armouring element as part of rehabilitation. Assuming a 0.2 m thick layer of soil ( $pH_w$  ~7.0) is mixed into a 0.3 m thick layer of fresh non-carbonaceous waste that is 40% fines (60% rock) with a  $pH_w$  of 9.9, the volume-weighted  $pH_w$  of the resultant soil-rock mixture would be 8.3 (moderately alkaline), similar to the mean  $pH_w$  of the subsoils and within the measured  $pH_w$  values for the topsoils at the Project (Table 2). Therefore, it is concluded that the elevated  $pH_w$  of the fresh non-carbonaceous waste does not preclude its use as a rock armouring element. However, it would be prudent to assess the impact of elevated pH of vegetation growth if a soil-rock mixture is adopted as a rehabilitation surface on the final landform.

The fresh non-carbonaceous waste has  $EC_{1:5}$  values slightly higher (0.15–0.36 dS/m) than the topsoils (0.03–0.15 dS/m). This elevated  $EC_{1:5}$  is not likely to significantly limit vegetation growth if the fresh non-carbonaceous waste is used as a rock armouring element.

The fresh non-carbonaceous waste has ESP values that are commonly extremely sodic (mean ESP 28.3%) and higher than the ESP commonly found in topsoils (ESP 1.9–4.9%) at the Project. The impact of the sodicity of the fresh waste non-carbonaceous waste will be reduced by the waste's abundant coarse fragment content. The structural stability of

materials with coarse fragment contents greater than ~60% is maintained by the coarse fraction and it is possible that a rocky waste can remain structurally stable even with a fine fraction that is sodic. Therefore, it is concluded that the sodicity of the fresh non-carbonaceous waste does not preclude its use as a rock armouring element.

**Table 6:** Summary of the geochemical properties of the NAF fresh non-carbonaceous waste and NAF fresh carbonaceous waste.

| Property          | Unit                                 | Fresh Non-Carbonaceous |      |       | Fresh Carbonaceous |      |       |
|-------------------|--------------------------------------|------------------------|------|-------|--------------------|------|-------|
|                   |                                      | Range                  | Mean | Count | Range              | Mean | Count |
| MPA               | kg H <sub>2</sub> SO <sub>4</sub> /t | 0.2–12.3               | 1.1  | 183   | 0.2–9.2            | 2.9  | 22    |
| ANC               | kg H <sub>2</sub> SO <sub>4</sub> /t | 5.8–546                | 68.4 | 183   | 3–70               | 20   | 22    |
| pH <sub>w</sub>   | pH Unit                              | 9.6–10.2               | 9.9  | 22    | 8.4–9.6            | 9.2  | 4     |
| EC <sub>1:5</sub> | dS/m                                 | 0.15–0.36              | 0.25 | 22    | 0.16–0.36          | 0.24 | 4     |
| ECEC              | meq/100g                             | 3.0–21.3               | 7.7  | 22    | 2.6–10.5           | 7.3  | 4     |
| ESP               | %                                    | 19.2–39.9              | 28.3 | 22    | 26.8–38.9          | 35.2 | 4     |

### 2.3.3 Physical properties

Understanding the susceptibility to breakdown of the rock fraction of a waste is important when considering them in rehabilitation plans as a potential armour against erosion. Where rock particles are observed to break down, this can result in an increase in the proportion of fines over time, which would either increase erosion potential in the long-term or sustain elevated erosion rates for longer periods (i.e. surface armouring by raindrop impact and washing of the fines from the surface that can lead to a reduction in erosion would be impeded). The breakdown of rock particles can also occur during landform re-shaping using heavy machinery, whereby rock particles of a certain size become smaller as machinery traverses over them, push them, and rip into them. Where rocks are shown to be durable, they could be considered for use as a rock armour to reduce erosion potential of rehabilitation landform batters if required.

The degree to which a rocky waste can successfully mitigate risks associated with erosion is related not only to rock durability, but also to the size and abundance of rock, the geometry of the landforms being considered, and the climate in which the landform is situated. Therefore, the rock durability results provide a useful indication of potential rock armour materials, but more comprehensive particle size distribution and erodibility testing, and landform design modelling would improve the understanding of the limits of its use as a rock armour material.

In this study the durability of rock particles is classed as ‘excellent’, ‘good’, ‘marginal’, or ‘poor’ based on their lithology, particle density, and water absorption values (Table 7). This rating system is based on CIRIA *et al.* (2007) criteria for determining the quality and durability of armour-stone from a quarry source.

Forty (40) samples of the NAF fresh non-carbonaceous waste and fresh carbonaceous waste were assessed for particle density and water absorption (Table 8). These properties are related to a material’s durability. For the 40 samples (both fresh non-carbonaceous waste and fresh carbonaceous waste), the lithology (sandstones, siltstones, mudstones), mean particle density (2.4 g/cm<sup>3</sup>) and water absorption (5.0%)

values are consistent with a material of marginal durability. Of the 40 samples assessed 18 were sandstones and 22 were siltstones/mudstones. The sandstone samples had a mean particle density of 2.5 g/cm<sup>3</sup> and water absorption of 3.6% and the siltstone/mudstone samples had a mean particle density of 2.3 g/cm<sup>3</sup> and water absorption of 6.3%. Further, 9 of the 22 siltstone/mudstone samples cracked while drying (i.e. during the test). This indicates that the fresh sandstones are more durable than the fresh siltstones/mudstones.

**Table 7:** Rock durability rating system (adapted from CIRIA *et al.* (2007)).

| Criteria                              | Excellent                                                                                                                | Good                                                                                 | Marginal                                                                                   | Poor                                                                                           |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Lithology                             | Unfoliated igneous and metamorphic rocks, quartzites and high silica cemented sandstones, compact crystalline limestones | Crystalline dolomites, crystalline limestone and moderately well cemented sandstones | Argillaceous limestones, poorly cemented sandstones, dolomite reef rock with void cavities | Shaly limestones, reef breccia, shale, siltstone, slate, schist, chalk, gypsiferous carbonates |
| Particle density (g/cm <sup>3</sup> ) | >2.7                                                                                                                     | 2.5-2.7                                                                              | 2.3-2.5                                                                                    | <2.3                                                                                           |
| Water absorption (%)                  | <0.5                                                                                                                     | 0.5-2.0                                                                              | 2.0-6.0                                                                                    | >6.0                                                                                           |

**Table 8:** Summary of the physical properties of the NAF fresh non-carbonaceous waste and NAF fresh carbonaceous waste.

| Property         | Unit              | Fresh Non-Carbonaceous |      |       | Fresh Carbonaceous |      |       |
|------------------|-------------------|------------------------|------|-------|--------------------|------|-------|
|                  |                   | Range                  | Mean | Count | Range              | Mean | Count |
| Particle Density | g/cm <sup>3</sup> | 1.9–3.1                | 2.4  | 38*   | 1.8–2.3            | 2.0  | 2^    |
| Water Absorption | %                 | 1.9–14.1               | 5.0  | 38*   | 6.1–7.4            | 6.7  | 2^    |

\* 24% of the samples cracked while drying. ^ 50% of the samples cracked while drying

### 2.3.4 Summary

The fresh wastes are overwhelmingly NAF. Their pH is higher than the topsoils, but this does not preclude their use as a rock armouring element when mixed with soil. However, it would be prudent to assess the impact of elevated pH on vegetation growth if a soil-rock mixture is adopted as a rehabilitation surface on the final landform (e.g. on 25% gradient low wall slopes). They are slightly more saline than the topsoils, but this is not likely to significantly limit vegetation growth if the fresh non-carbonaceous waste is used as a rock armouring element. The fine fraction is extremely sodic. However, their structural stability will likely be maintained by the abundant coarse fraction. The coarse fraction of the fresh sandstone is more durable than the coarse fraction of the fresh siltstone/mudstone.

It is concluded that fresh non-carbonaceous sandstone and carbonaceous sandstone could be targeted for use as a rock armouring element in preference over fresh non-carbonaceous and carbonaceous siltstones/mudstones. Of the 4 drill holes assessed, approximately half of the fresh waste is non-carbonaceous and carbonaceous sandstone.

Given this, a soil-rock mixture was considered as part of the erosion modelling completed in this study. The soil-rock mixture aims to represent a mixture of a good quality topsoil or marginal topsoil mixed with a fresh non-carbonaceous or carbonaceous sandstone. Detail on how the effect of rock armouring was accounted for is given in Section 3.2.

### 3 EROSION MODELLING METHOD

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#### 3.1 Long-term runoff/erosion modelling

##### *3.1.1 The WEPP model*

The WEPP (Water Erosion Prediction Project) runoff/erosion model was developed by the United States Department of Agriculture to predict runoff, erosion, and deposition for hillslopes akin to mine landform batter slopes (Flanagan and Livingston 1995). WEPP is a simulation model with a daily input time step, although shorter time steps are used by internal calculations on days when rainfall occurs. Plant and soil characteristics important to erosion processes are updated every day. When rainfall occurs, those plant and soil characteristics are considered in determining the likelihood of runoff. If runoff is predicted to occur, the model computes sediment detachment, transport, and deposition at points along the batter slope profile.

The erosion component of WEPP uses a steady-state sediment continuity equation as the basis for the erosion computations. Erosion in interrill areas is calculated as a function of the effective rainfall intensity and runoff rate. Soil erosion in rills is predicted to occur if the flow shear stress is greater than the soil's critical flow shear stress, and when the sediment load of the flow is below its transport capacity. Deposition in rills is computed when the sediment load is greater than the capacity of the flow to transport it.

##### *3.1.2 Climate sequence*

Apart from information on the slope profile geometry and the surface materials, modelling of long-term erosion with WEPP requires a long-term climate sequence for the site. A climate sequence was developed from historical data that was then adjusted to represent the SSP3-7.0 climate predictions for the region in which the Project is situated.

##### *3.1.2.1 Historical climate sequence*

For each day of simulation, WEPP requires 10 daily climate variables:

- Rainfall,
- Rainfall duration,
- Peak rainfall intensity,
- Time to rainfall peak,
- Solar radiation,
- Minimum temperature,
- Maximum temperature,
- Dew point temperature,
- Wind speed, and
- Wind direction.



Of these, the four rainfall-related variables (underlined in the list above) are vital as previous studies have shown that predicted runoff and erosion are most sensitive to these variables (Nearing *et al.* 1990; Chaves and Nearing 1991).

Complete historical datasets on these 10 climate variables are not available for most sites. Completion of WEPP for runoff/erosion predictions requires synthetic climate sequences that statistically preserve the mean and variations in climate datasets sourced from nearby climate observation stations.

CLIGEN is a stochastic weather generator that can be used to provide the necessary WEPP climate input files. CLIGEN has been assessed for a wide range of climates, and it was found that it was suitable for providing the required climate input for WEPP to predict runoff and erosion (Yu 2003).

Daily rainfall data for the Project were sourced from the Australian Bureau of Meteorology (BoM) through the SILO patched point facility. Patched point data provides a continuous daily data set of observed rainfall, temperature, and solar radiation data that has had missing data patched with synthetic data derived from nearby stations. The patched point data was sourced from Moranbah Water Treatment Plant (station 34038, -21.9947, 148.0308) ~16 km north-east from the Project. Data for the period 1920–2020 were used. Climate statistics created for this station include<sup>1</sup>:

- Mean daily rainfall on wet days for each month;
- Standard deviation and skewness coefficient of daily rainfall for each month;
- Probability of a wet day following a dry day for each month;
- Probability of a wet day following a wet day for each month;
- Mean daily max. temperature for each month;
- Standard deviation of daily max. temperature for each month;
- Mean daily min. temperature for each month; and
- Standard deviation of daily min. temperature for each month.

Pluviograph (6-minute) rainfall data was also available for BoM's site at the Moranbah Water Treatment Plant. At the time the file was created, pluviograph data records existed for this site from January 1986 to June 2012. Similar to the daily climate statistics, sub-daily rainfall statistics were created for this site. They include:

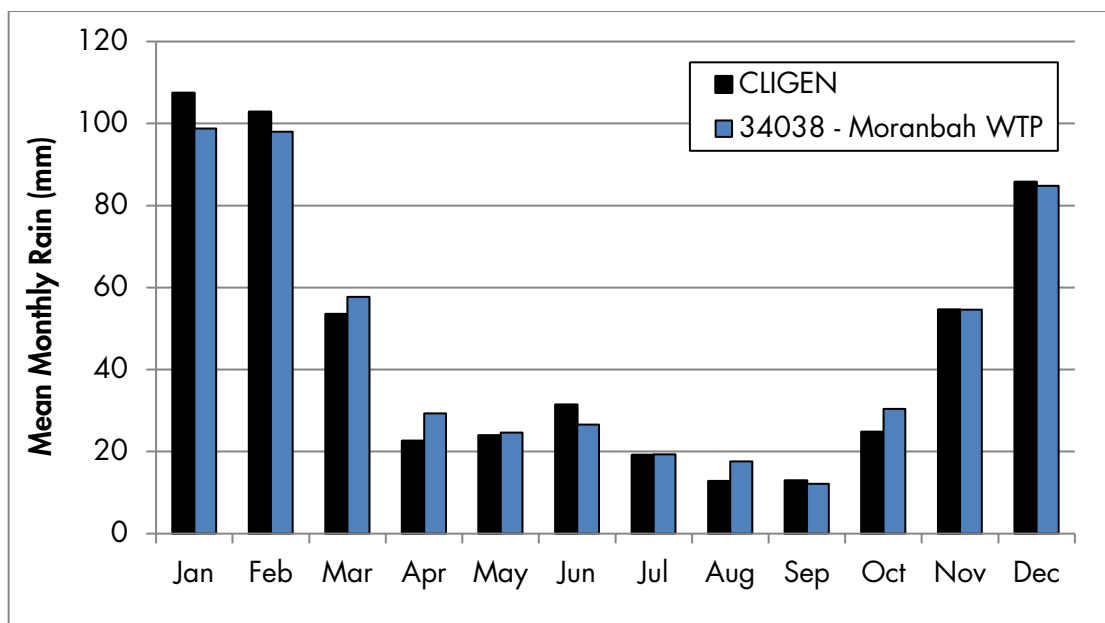
- Mean maximum 30-min rainfall intensity for each month, and
- Probability distribution of the dimensionless time to peak storm intensity.

A 100-year climate sequence was generated from these daily and sub-daily statistics using CLIGEN version 5.1. The resultant climate sequence has sub-daily rainfall, and daily, monthly, and annual climate statistics that are consistent with Moranbah.

The average annual rainfall for the patched point data is 554 mm. This compares well with the CLIGEN sequence which has an average annual rainfall of 552 mm. Average monthly rainfall for the data drill data and CLIGEN are shown in Figure 4. The data show good agreement between the observed and CLIGEN monthly rainfall values.

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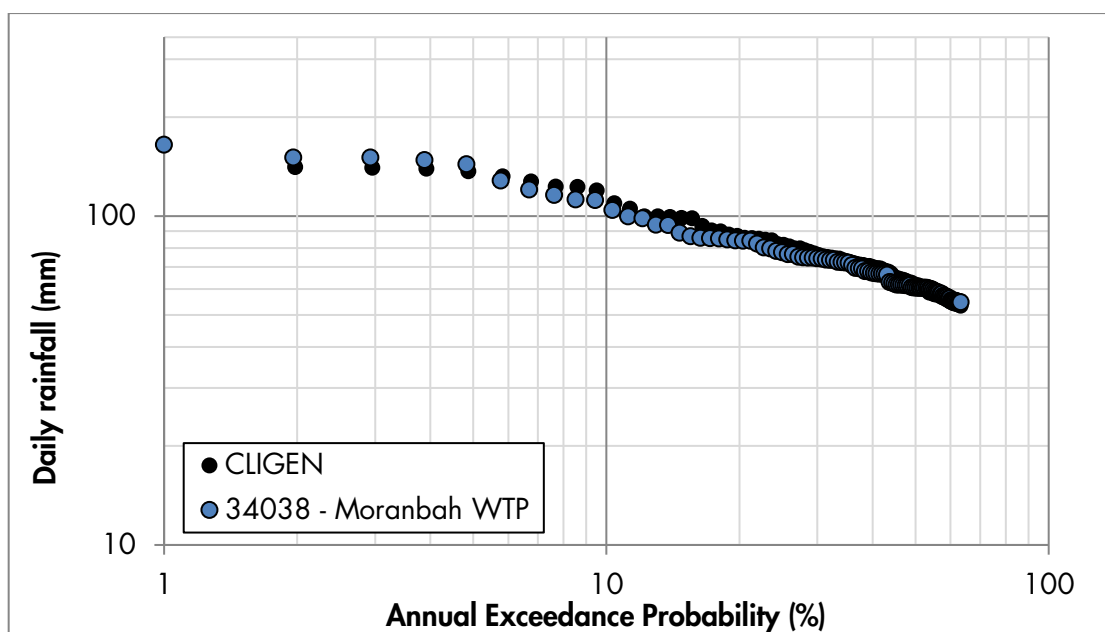
<sup>1</sup> The Priestley-Taylor method for estimating potential soil evaporation is automatically used by WEPP, and as such wind data are not required.



**Figure 4:** Average monthly rainfall for Moranbah (patched point data) and the CLIGEN sequence.

The magnitudes of the observed and CLIGEN daily events are compared against the Annual Exceedance Probability (AEP) for that event, assuming each event has a 24 hour storm duration. Figure 5 shows good agreement between the patched point data and the CLIGEN sequence.

Based on this analysis it is concluded that the CLIGEN climate sequence accurately reproduces average annual rainfall totals, accurately reproduces mean monthly rainfall totals, and can be used within WEPP to predict long-term erosion for the Project.



**Figure 5:** Daily rainfall compared to annual exceedance probability for Moranbah (patched point data) and the CLIGEN sequence.

### 3.1.2.2 Climate change adjustment

The rainfall within the historical climate sequence was adjusted to reflect the SSP3-7.0 climate scenario assessed at 2090. Data on climate projections were sourced from Queensland Future Climate (<https://longpaddock.qld.gov.au/qld-future-climate/>).

Rainfall at the Project (based on the regional summary data for the Isaac local government area) is predicted to slightly decrease by 2090. Annual rainfall is predicted to decrease on average by 0.2 mm/day. When considered on a seasonal basis, a rainfall reduction of 0.2 mm/day is predicted for summer, 0 mm/day for winter, 0.4 mm/day for autumn, and 0.1 mm/day for spring. For rain days (>1 mm of rain on a given day) within each of the four seasons, these values were used to change the daily rainfall totals within the historical sequence.

The wettest 1% of rain days were then flagged and scaled to account for the projected increase in rainfall intensity due to increased temperature. Scaling factors were sourced for Moranbah from Australian Rainfall & Runoff Data Hub (<https://data.arr-software.org/>).

The resultant climate sequence was used to model erosion in WEPP and to generate the time series runoff and erosion data needed to generate parameters for the SIBERIA landform evolution model.

### 3.1.3 Soil erodibility

#### 3.1.3.1 Samples supplied

Stanmore supplied ten 1 m<sup>3</sup> bulk samples of different topsoil (Table 9). These samples were used to create 5 surfaces that were tested for erodibility. These surfaces are detailed in Table 10. The Teviot topsoil initially supplied to create the Taurus-Teviot Complex was not a cracking clay as it should have been. The Krongie soil (a cracking clay similar to Teviot) was instead mixed with Taurus to create a topsoil representative of the Taurus-Teviot Complex. Examples of the surfaces subjected to simulated rainfall and overland flow are given in Appendix A.

**Table 9:** Primary and secondary bulk sample location (MGA Zone 55, GDA 2020).

| SMU     | Site ID | Easting (m) | Northing (m) | Bulk Sample Supplied |
|---------|---------|-------------|--------------|----------------------|
| Taurus  | Ta1     | 621,472     | 7,555,029    | 2m <sup>3</sup>      |
|         | Ta2     | 622,138     | 7,556,995    | 1m <sup>3</sup>      |
| Krongie | Kg1     | 621,619     | 7,558,062    | 1m <sup>3</sup>      |
|         | Kg2     | 621,988     | 7,558,340    | 1m <sup>3</sup>      |
| Teviot  | Tv1     | 620,895     | 7,557,361    | 2m <sup>3</sup>      |
|         | Tv2     | 620,471     | 7,557,278    | 1m <sup>3</sup>      |
| Retro   | Rt1     | 620,151     | 7,558,828    | 1m <sup>3</sup>      |
|         | Rt2     | 619,873     | 7,558,867    | 1m <sup>3</sup>      |

**Table 10:** Surfaces created and tested for erodibility.

| Surface                    | Bulk Sample Used       |
|----------------------------|------------------------|
| Taurus                     | 1:1 mix of Ta1 and Ta2 |
| Taurus-Teviot <sup>^</sup> | 1:1 mix of Ta2 and Kg1 |
| Krongie                    | 1:1 mix of Kg1 and Kg1 |
| Teviot                     | 1:1 mix of Tv1 and Tv2 |
| Retro                      | 1:1 mix of Rt1 and Rt2 |

<sup>^</sup> Generated using a sample of Taurus soil mixed with a sample of Krongie, which is a cracking clay soil similar to Teviot.

### 3.1.3.2 Properties of bulk samples

The basic properties of the soils sampled for erodibility testing are given in Appendix B. The results are discussed below.

The bulk topsoil samples have similar  $pH_w$  to the median values of their respective soil types. The  $EC_{1:5}$  values recorded for all bulk samples are considered to be non-saline and consistent with the median values of their respective soil types.

The soils had particle size distributions consistent with their field textures. Taurus was described in the field as a sandy loam and the bulk samples had a sandy loam texture. Teviot was described in the field as a light sandy clay and the bulk samples had a sandy clay texture. Krongie was described in the field as a medium clay and the bulk samples had a medium clay texture. Retro was described in the field as a sandy clay loam and the bulk samples had a sandy loam texture.

The basic properties of the bulk samples indicate that they are similar and representative of the broader soils identified in the field as part of the soil assessment (Landloch 2025).

### 3.1.3.3 Erodibility testing

Laboratory-based erodibility testing was conducted on the Project topsoils, selected based on their abundance. Erodibility testing enabled parameterisation of WEPP. Key material input parameters for WEPP include:

- Interrill erodibility ( $K_i$ ),
- Rill erodibility ( $K_R$ ),
- Critical shear for rill initiation ( $\tau_c$ ),
- Effective hydraulic conductivity ( $K_e$ ), and
- Sediment particle size and density distributions.

These material input parameters were derived from experimental methods involving the application of:

- Simulated rain and measurement of runoff rates and sediment loads in runoff to obtain estimates of  $K_i$  and  $K_e$ ;
- Concentrated surface water flows and measurement of flow characteristics and sediment loads to obtain estimates of  $K_R$  and  $\tau_c$ ; and
- Automated settling columns to obtain estimates of sediment particle size and density distributions.

$K_e$  defines the rate of water movement through a defined soil profile in response to wetting by rainfall, and is derived through analysis of a material's steady infiltration and runoff rates.  $K_i$  describes the detachment and movement of particles by the combined action of raindrops and shallow overland flows.  $K_R$  describes the detachment of particles by shear stresses caused by concentrated flows.  $\tau_c$  is the shear stress applied by concentrated flows to the surface above which particle detachment and transport by flow rapidly increases and by which rills are initiated.

Erosion predictions are sensitive to the particle size and density distributions of the eroded sediment. Samples of the rain-impacted surface from all soils were taken using the methods described by Loch (1994). These samples were placed into automated settling columns that provide equivalent sand size distributions for the generated sediment (Loch 2001). Equivalent sand size distributions integrate both particle size and density distributions into a single distribution that is representative of the sediment and that can be readily input to WEPP.

### 3.1.3.4 Erodibility parameters and sediment properties

WEPP erodibility parameters were derived for the 5 soils (Table 11). As mentioned in Section 3.1.3.1, the Teviot topsoil supplied to create the Taurus-Teviot mixture was not a cracking clay as it should have been and the Krongie soil (a cracking clay similar to Teviot) was mixed with Taurus to create a topsoil representative of the Taurus-Teviot Complex. The Taurus-Teviot parameters given in Table 11 are those of this mixture.

**Table 11:** WEPP parameters for the 6 soils, without vegetation or addition of rock.

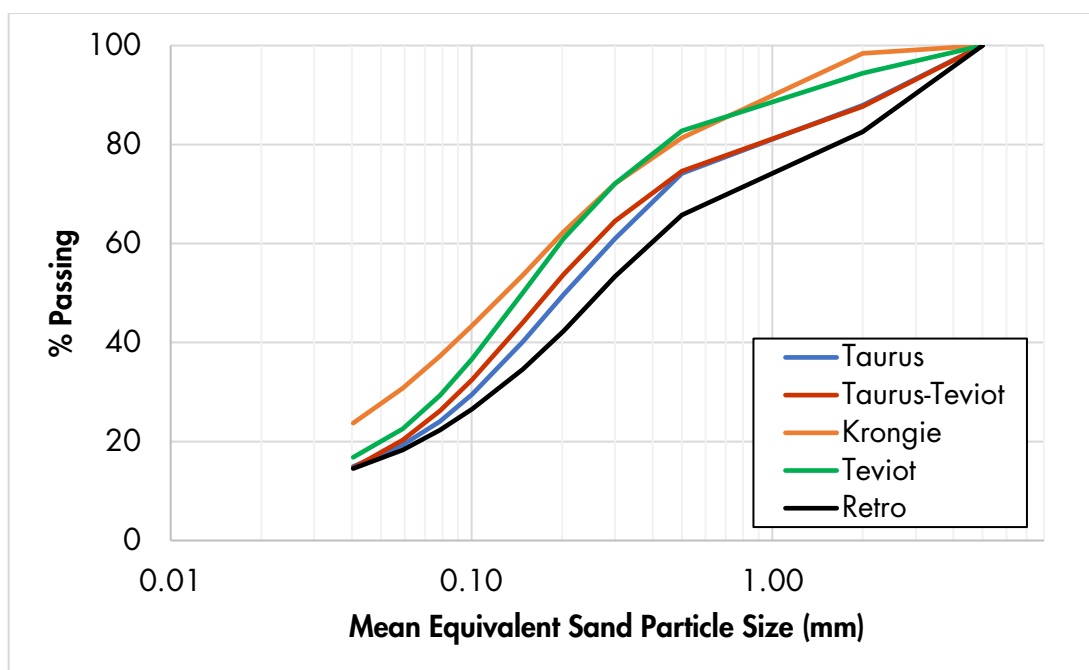
| SMU                         | Code  | Effective hydraulic conductivity*, $K_e$ | Interrill erodibility, $K_i$ | Rill erodibility, $K_R$ | Critical shear, $\tau_c$ |
|-----------------------------|-------|------------------------------------------|------------------------------|-------------------------|--------------------------|
|                             |       | mm/h                                     | kg.s/m <sup>4</sup>          | s/m                     | Pa                       |
| Taurus                      | Ta    | 18                                       | 1,427,300                    | 0.0088                  | 12                       |
| Taurus- Teviot <sup>^</sup> | Ta-Kg | 2                                        | 1,597,270                    | 0.0071                  | 13                       |
| Krongie                     | Kg    | 1                                        | 1,616,180                    | 0.0061                  | 13                       |
| Teviot                      | Tv    | 19                                       | 1,807,156                    | 0.0176                  | 11                       |
| Retro                       | Rt    | 5                                        | 1,160,328                    | 0.0023                  | 10                       |

\* Assuming 0% groundcover. <sup>^</sup> Generated using a sample of Taurus soil mixed with a sample of Krongie, which is a cracking clay soil similar to Teviot.

The equivalent sand sediment size distributions input to the WEPP models for the materials tested are shown in Figure 6. Broadly, particles with an equivalent sand particle size <0.1 mm are difficult to settle in slow moving, low turbulence runoff. These finer sediments are likely to be mobile and readily transported in runoff. Sediments that have larger equivalent sand particle sizes tend to settle and deposit close to the toe of the landform or within runoff control structures such as toe drains.

For all soils, 27–44% of the sediment produced will be easily mobilised, likely leading to runoff with relatively low suspended sediment concentrations. Runoff generated from these soils when bare would likely be turbid. Establishment of vegetation would trap much of the sediment and reduce the turbidity of the runoff generated from the waste landforms.





**Figure 6:** Sediment size distribution for the 5 soils from the Project.

### 3.1.4 Vegetation groundcover impacts on erosion

The impacts of vegetation on erosion were considered, specifically the impacts of surface groundcover. Vegetation groundcover includes any plant material, living or dead, that lies on or near the soil surface. In this study, it includes living vegetation (e.g. grasses), leaf litter, and other plant residues. It excludes other non-vegetative cover such as rock. The terms vegetation groundcover and groundcover are used interchangeably in this report.

Estimates of groundcover on soil surfaces near the Project were sourced from the pasture groundcover dataset supplied by the QLD Government's FORAGE data service<sup>2</sup>. Groundcover was assessed for a 35,275 ha parcel of land at and adjacent to the Project. Average groundcover from 1988 through to 2024 was 87% and the 20<sup>th</sup> and 80<sup>th</sup> percentile values are 84% and 94%, respectively. Consequently, it was concluded that groundcover levels  $\geq 80\%$  are achievable on rehabilitation carried out using topsoil at the Project. Erosion simulations considered groundcover levels 80% for soil covered surfaces. Two lower groundcover levels along with 0% groundcover were also considered as a way of assessing the impact of achievement of lower groundcover levels than commonly observed in ecosystems adjacent to the Project. Levels of 65% and 50% were chosen. The effect of 80%, 65%, 50%, and 0% groundcover was considered in two ways, the effect on surface detachment, and the effect on infiltration capacity.

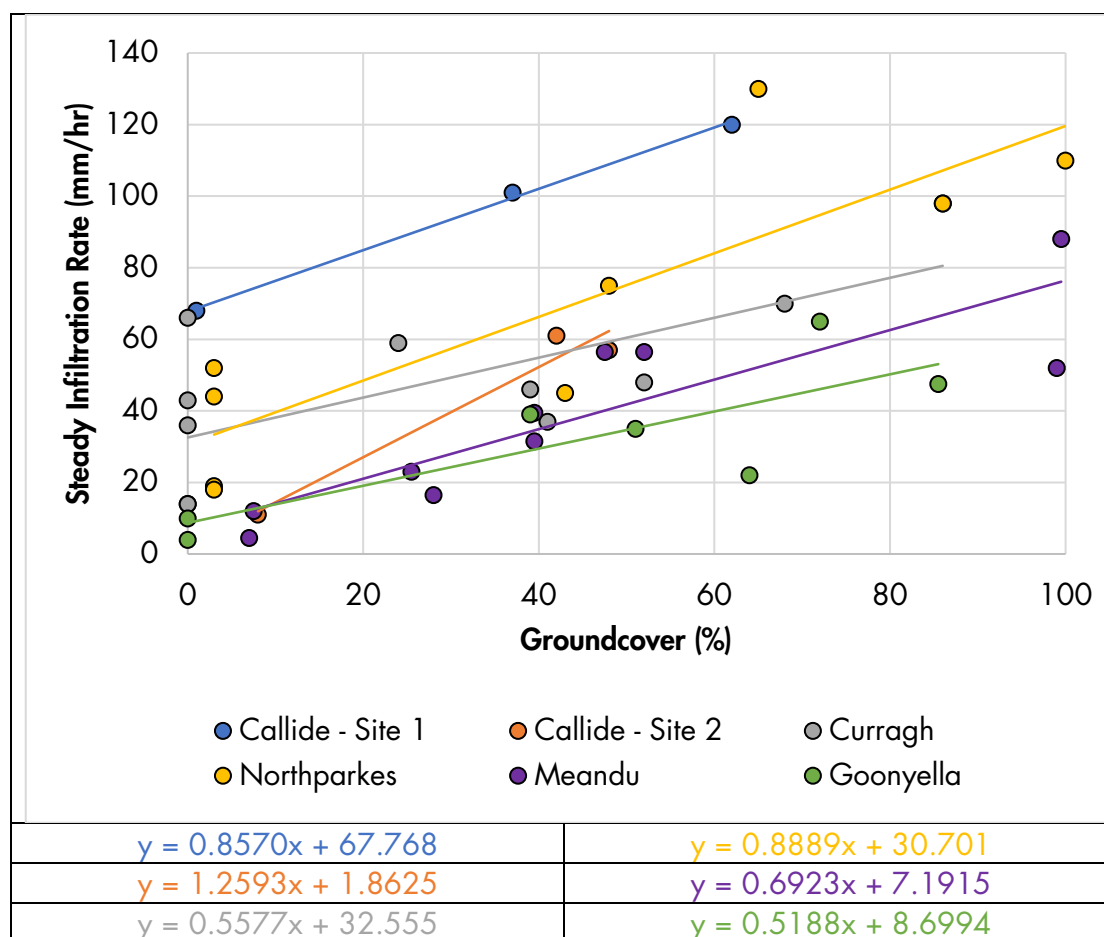
The effect on surface detachment was considered by applying a cover factor that reduces erosion predicted from an unvegetated surface to that of the vegetated surface. Cover factors were developed as part of early erosion prediction equations, the Revised Universal Soil Loss Equation (RUSLE) being one that is widely used in Australia (Renard

<sup>2</sup> <https://www.longpaddock.qld.gov.au/forage/about/>

*et al.* 1993). The cover factor was sourced from Rosewell (1993), after accounting for the fact that the surface being considered will not be freshly tilled. The cover factors used were:

- 80% groundcover – 0.029,
- 65% groundcover – 0.077,
- 50% groundcover – 0.158, and
- 0% groundcover – 1.000.

The effect of groundcover on infiltration capacity have been assessed by Landloch personnel on numerous Australian mine sites, including Callide (2 sites), Curragh, Goonyella, Meandu, and Northparkes (So *et al.* 1998; Loch 2000a; Loch 2000b)<sup>3</sup>. These studies showed that for every 10% increase in groundcover, there is a measured 5–13 mm/hr increase in steady infiltration rate (Figure 7).



**Figure 7:** Measured relationships between groundcover levels and steady infiltration rates for 6 locations on Australian mine site.

<sup>3</sup> Data for the two Callide sites are published in So *et al.* (1998). Data for Curragh and Goonyella were collected as part of the So *et al.* (1998) project but were not published. Data for Meandu is found in Loch (2000a). Data for Northparkes is found in Loch (2000b).

The average increase in steady infiltration is 8 mm/hr for every 10% increase in groundcover. The effect of groundcover on the soils from the Project was considered by increasing the measured steady infiltration rate by 8 mm/hr for every 10% increase in groundcover. Therefore, for 80% groundcover, an increase in steady infiltration rate of 64 mm/hr was applied. This was done in addition to the application of the cover factor to account for the effect on detachment capacity.

These factors were used to represent a consolidated soil surface supporting a vegetation system dominated by grasses with some scattered trees. It assumes that vegetation is randomly distributed at the stated average groundcover level across the entire area being modelled.

### *3.1.5 Accounting for effect of rock armour on erosion*

Addition of rock armour into a soil acts to reduce detachment potential. The rock fraction is considerably more resistant to detachment than the fine fraction due to the larger particle size.

The initiation of detachment in rills is governed by a material's critical shear. Therefore, the effect on surface detachment related to rock was considered by modifying the critical shear value of the soil and applying a RUSLE cover factor that reduces erosion predicted to account for the growth of vegetation.

Landloch has assessed the erodibility of more than 10 samples of fresh waste from Central Queensland coal mines, and has measured critical shear values ranging from 19–82 Pa (median 44 Pa). A critical shear of 32 Pa (the lowest quartile value) was adopted in this study to provide conservatism. In terms of vegetation growth, it was assumed that 30% vegetative groundcover is established, to reflect that lower levels of vegetation will likely establish on a rocky surface. Therefore, a cover factor for 30% cover (0.333) was applied along with a modification to the final infiltration rate to account for 30% groundcover (increase of 24 mm/hr).

### *3.1.6 Definition of 'acceptable' erosion*

Some degree of erosion will always occur from any land surface. The concept of 'acceptable' erosion is widely mentioned, but common definitions are not directly relevant to mine site rehabilitation. For example, Wischmeier and Smith (1978) defined acceptable erosion 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 threshold value of 4.5 t/ha/y was developed for erosion of rangeland soils and shallow cultivated soils by USA soil conservation agencies (Wight and Siddoway 1979) using similar criteria to those applied for crop land (i.e. maintenance of land productivity).

In contrast to only considering land productivity, Landloch's approach to landform design aims to create rehabilitated slopes on which the risk of rilling will be reduced. In the mining context, rilling:

- Is most likely to lead to further flow concentration and possibly drive the formation of gullies that in turn will greatly accelerate erosion rate over time;
- Generates significantly higher sediment concentrations than interrill erosion;

- Is more likely to increase the risk that the integrity of a dump capping layer is compromised, possibly exposing more erosive underlying wastes;
- Increases the mobilisation of materials from the surface that in turn negatively impacts on vegetation establishment and growth in areas affected by rills; and
- Is a more visible form of erosion than interrill erosion, and is often the focus of erosion concerns raised by stakeholders.

In Landloch's experience, long-term annual erosion rates that produce batters with a low tendency to rill are:

- Mean average annual erosion –  $\leq 5\text{t/ha/y}$ ; and
- Mean peak annual erosion –  $\leq 10\text{t/ha/y}$ .

These erosion rates are also commonly applied as rehabilitation milestone criteria in approved PRC Plans for coal mines in the Bowen Basin.

## 3.2 Landform evolution modelling

### 3.2.1 The SIBERIA model

The SIBERIA landform evolution model predicts the long-term, 3D development of erosion features and hillslopes (e.g. landform batters) in a catchment based on runoff, erosion, and deposition. SIBERIA solves for two variables:

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

Changes to the predicted erosion features are governed by an activation threshold that is dependent on the runoff discharge and gradient of the slope. When the activation threshold is exceeded, an erosion feature is predicted to develop. In this way, it is possible for a modelled surface to initially have no erosion features and for features to develop over time where the activation threshold is exceeded.

The rate at which rills and gullies develop is controlled by a channelisation function. SIBERIA does not directly input rainfall or material erodibility parameters. Rather, the SIBERIA input parameters define the channelisation function that is a function of both runoff and erosion (Willgoose *et al.* 1989). As a result, SIBERIA parameters are specific to both the climatic regime and the material being considered, and must be derived for each specific material located within each specific climatic regime.

SIBERIA has been successfully applied to explain aspects of the geomorphology of natural landforms (Willgoose 1994) and has been widely used to assess the evolution of constructed waste dumps on 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). It has also been subjected to numerous validation studies. In general, the validation studies indicate that SIBERIA's predictions of landform evolution are reasonable provided

the model is suitably parameterised (Hancock *et al.* 2000; Hancock *et al.* 2003). In one validation study (Hancock 2004) it was noted that erosion rates predicted by SIBERIA for a catchment in the Northern Territory compared favourably to erosion estimates derived using the caesium-137 method. As the two erosion assessment methods use independent input information, the reported agreement is particularly significant.

### 3.2.2 SIBERIA input parameters

SIBERIA predicts the long-term average change in elevation of a node (i.e. a point in the landscape) by predicting the volume of sediment lost from that node. The rate of sediment transport through a node ( $q_s$  in units of  $m^3/y$ ) is determined by the equation:

$$q_s = \beta_1 \times q^{m_1} \times S^{n_1} \quad 1)$$

where  $\beta_1$  is the sediment transport rate coefficient (unitless),  $q$  is discharge ( $m^3/y$ ),  $m_1$  is the discharge exponent (unitless),  $S$  is the slope ( $m/m$ ), and  $n_1$  is the slope exponent (unitless). SIBERIA does not directly model discharge, but uses sub-grid effective parameterisation which relates discharge to the area draining through a node as:

$$q = \beta_3 \times A^{m_3} \quad 2)$$

where  $\beta_3$  is the coefficient between discharge and area (unitless),  $A$  is area ( $m^2$ ), and  $m_3$  is the exponent of the area in discharge (unitless).

To run SIBERIA, the parameters  $\beta_1$ ,  $m_1$ ,  $n_1$ ,  $\beta_3$ , and  $m_3$  are needed. There is interaction between all 5 parameters, with the result that an almost infinite number of parameter sets will all show the same rate of erosion, though some aspects of the pattern of erosion that is predicted will vary. Fixed values for  $\beta_3$ ,  $n_1$ , and  $m_3$  are adopted where possible, reducing the difficulty of deriving parameter values. If the batter to be modelled is identical to the batter for which erosion data are available for calibration,  $m_3$  and  $\beta_3$  can be taken as 1.0, and for situations where slope gradient does not affect slope erodibility,  $n_1$  can be taken as 1.5 (Willgoose pers. comm.). This is consistent with Kirkby (1971) who suggests values ranging from 1.3–2.0 are reasonable for soils.

Therefore, two key parameters require fitting against runoff and erosion data:  $\beta_1$  and  $m_1$ . Effectively, the  $\beta_1$  parameter could be described as an erosion rate parameter, as it primarily controls the rate of sediment movement. The  $m_1$  parameter could be described as primarily controlling slope length responses of erosion.

### 3.2.3 Derivation of SIBERIA parameters

Input parameters for SIBERIA are typically derived by fitting the various model equations to time series data of runoff and erosion. To generate the necessary data, Landloch has developed a method that involves:

- a) Run the WEPP model to generate data sets of runoff and erosion for slopes consistent with the proposed landforms and for materials of interest using site specific climate data adjusted for climate change.
- b) Analyse the WEPP output to derive the required SIBERIA input parameters.



This approach ensures that SIBERIA parameters are effectively benchmarked to the WEPP output, and thereby, effectively based on measured erodibility parameters for site materials and on site climate adjusted for climate change.

It should be noted that the method of deriving parameters attempts to ensure that the  $m_1$  parameter is optimised so that SIBERIA simulations show a similar impact of slope length to that predicted by WEPP. However, because the two models use different methods to consider impacts of slope length, it is not reasonable to expect complete agreement between the two models over the full range of slope lengths considered.

### *3.2.4 Model settings*

The Digital Elevation Model (DEM) modelled by SIBERIA included the landform surface meshed into the surrounding landscape. A random roughness ( $\pm 10\text{cm}$ ) was added to the DEM prior to modelling. This was done to reduce triangulation gridding artefacts from the surface of the DEM and to provide a more realistic surface for modelling (landform surfaces are not perfectly smooth). The following SIBERIA outputs were produced for each landform modelled at years 50, 100, 200, and 300:

- Maximum depth of gullies at each output year with gullies defined as having a minimum depth of 0.3 m;
- Average erosion ( $\text{t/ha/y}$ );
- Cumulative erosion (mm) for each output year; and
- Visual outputs showing the evolved DEM over which is draped the predicted material movement (erosion and deposition).

### *3.2.5 SIBERIA modelling assumptions*

The following assumptions apply to the SIBERIA modelling:

- The DEM of the existing land surface and design file for the rehabilitation landform provided by Stanmore are assumed to be accurate.
- Vegetated soils are applied to surfaces with gradients  $\leq 15\%$  and vegetated rocky waste/soil mixtures are applied to surfaces with gradients  $> 15\%$ . The rocky waste is assumed to be fresh non-carbonaceous sandstone or carbonaceous sandstone (See Section 2.3 for more detail).

Modelling assumptions valid for 2D WEPP modelling also apply for 3D SIBERIA landform evolution modelling:

- In considering vegetation groundcover, this report specifically considers vegetation that is in contact with the land surface. Practically, this means a combination of grass cover and anchored (not readily moved) surface litter. Groundcover impacts do not consider rock.
- Soil management (including stripping, stockpiling, replacement, amendment, and fertilisation) will be carried out effectively to maximise rapid and persistent vegetation growth.
- Any cross-slope ripping will be carried out strictly on the contour.

### 3.3 Proposed final landform

The proposed final landform shape was developed by Stanmore. The design is shown in Figure 8. The design contains the following landforms:

- Main landform – Waste landform associated with the open cut pit comprising majority in-pit dumping, but with some out of pit dumping near the initial strips of mining, with the majority of runoff draining to the final void, and which is the largest Project waste landform.
- South-west (SW) landform – Small out of pit waste landform to the south-west of the final void, which is externally draining.
- East landform – small out of pit waste landform to the east of the final void, which is externally draining.

Representative cross sections of the final rehabilitation landform are given in Figure 9.

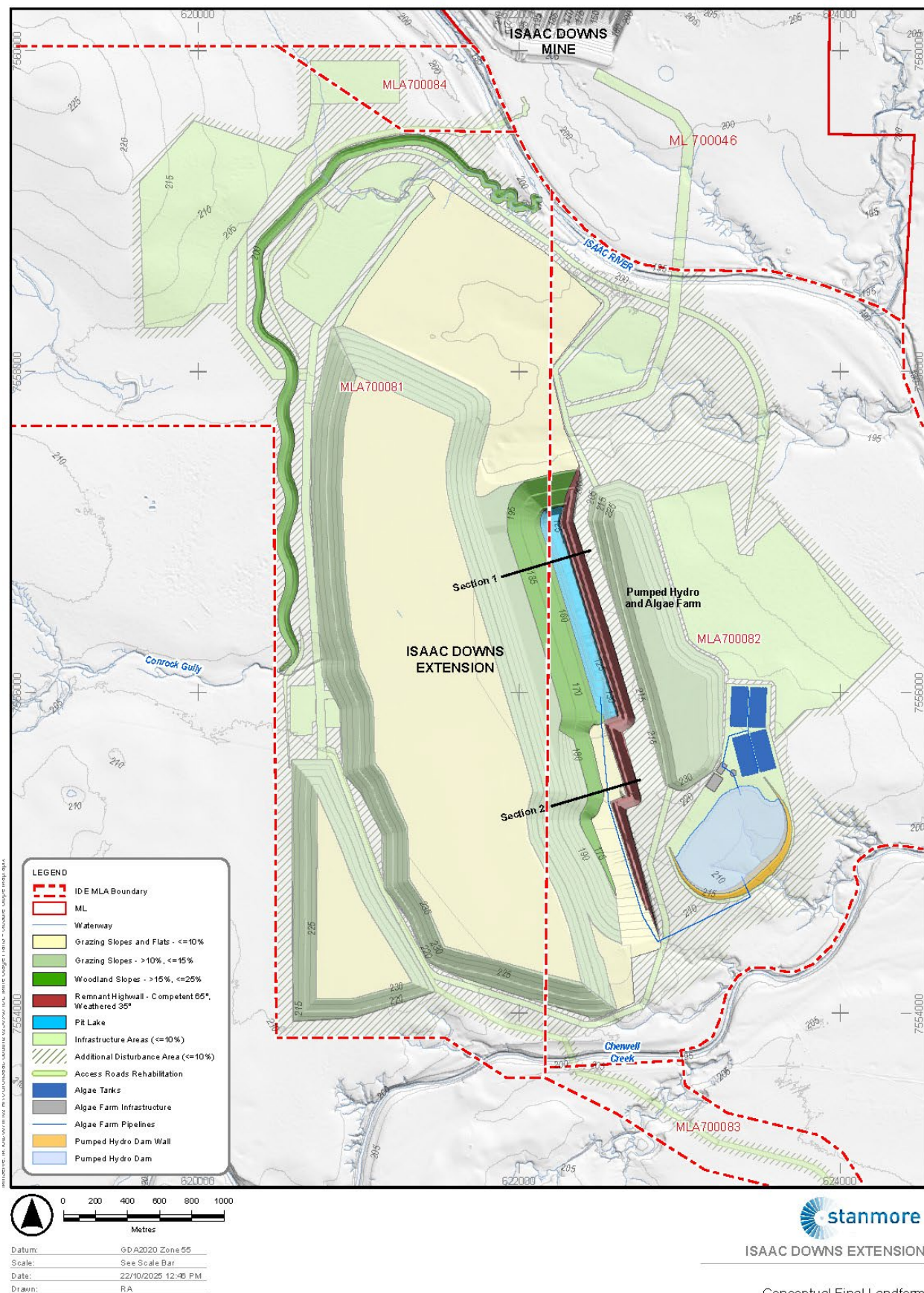
The majority of the in-pit dump slopes have gradients  $<15\%$ , with the gradient of the low wall slopes draining to the final void being between  $15\%$  and  $25\%$ . A portion of the low wall slope grading into the final void has a gradient of  $25\%$  and a maximum slope length of  $\sim 400$  m in the northern void area when the void is empty of water and  $\sim 300$  m when the void is filled with water (HydroBalance 2026b). The maximum slope length of the southern void area (backfilled to above the final water table) is  $\sim 200$  m. The slope of the main landform that is not internally draining to the final void has a maximum height on the north-eastern end of the landform. The maximum height is  $\sim 32$  m. It is comprised of 3 lifts, each with a gradient of  $15\%$  and slope length of  $\sim 75$  m.

The lifts are separated by narrow cross-slope berms that are  $\sim 10$  m wide. The average gradient of the entire height is  $\sim 14\%$  and the total slope length is  $\sim 230$  m. On the western and southern sides, much of the main landform is only slightly more than 2 lifts high. In those area, the overall height is  $\sim 22$ – $28$  m with overall slope lengths of  $\sim 200$  m.

The SW landform has a maximum height at the north of the landform of  $\sim 22$  m; the landform is lowest in the south-east with a height of  $\sim 13$  m. The landform consists of a maximum of 2 lifts each with a gradient of  $15\%$  and maximum slope length of  $\sim 80$  m. The lifts are separated by a narrow cross-slope berm that is  $\sim 10$  m wide. The average gradient of the entire height is  $\sim 14\%$  and the maximum total slope length is  $\sim 160$  m.

The east landform has a maximum height in the south-east of the landform of  $\sim 24$  m; the landform is lowest in the west (central section) with a height of  $\sim 5$  m. The landform consists of a maximum of 2 lifts each with a gradient of  $15\%$  and maximum slope length of  $\sim 80$  m. The lifts are separated by a narrow cross-slope berm that is  $\sim 10$  m wide. The average gradient of the entire height is  $\sim 14\%$  and the maximum total slope length is  $\sim 160$  m.

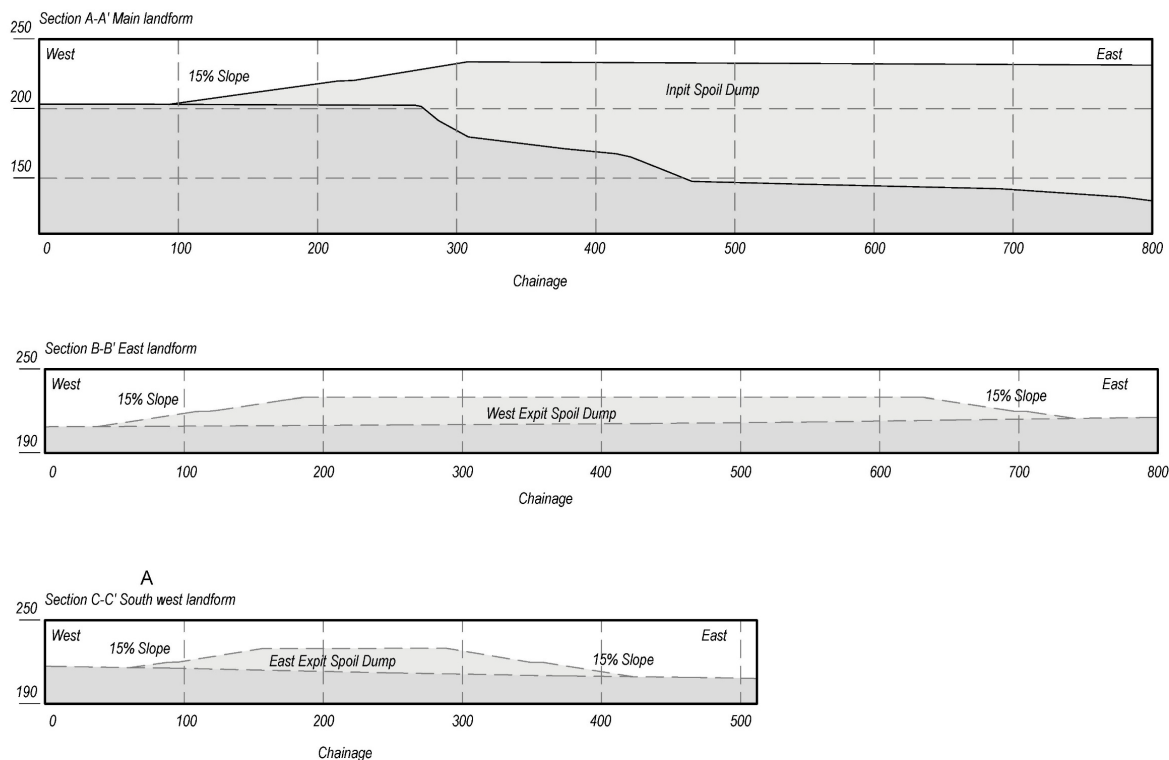
Figure 10 shows the gradients of the various landform batters.



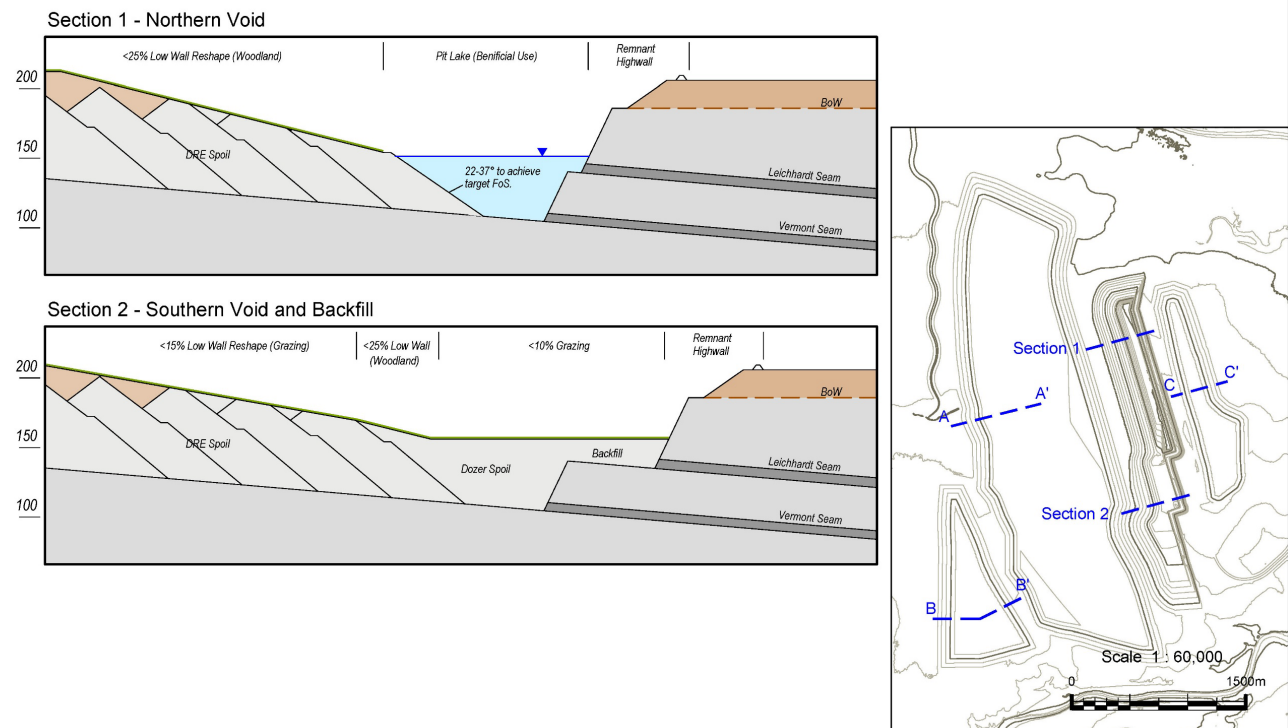
**Figure 8:** Proposed final landform design for the Project (Source: Stanmore).



## SPOIL DUMP SECTIONS

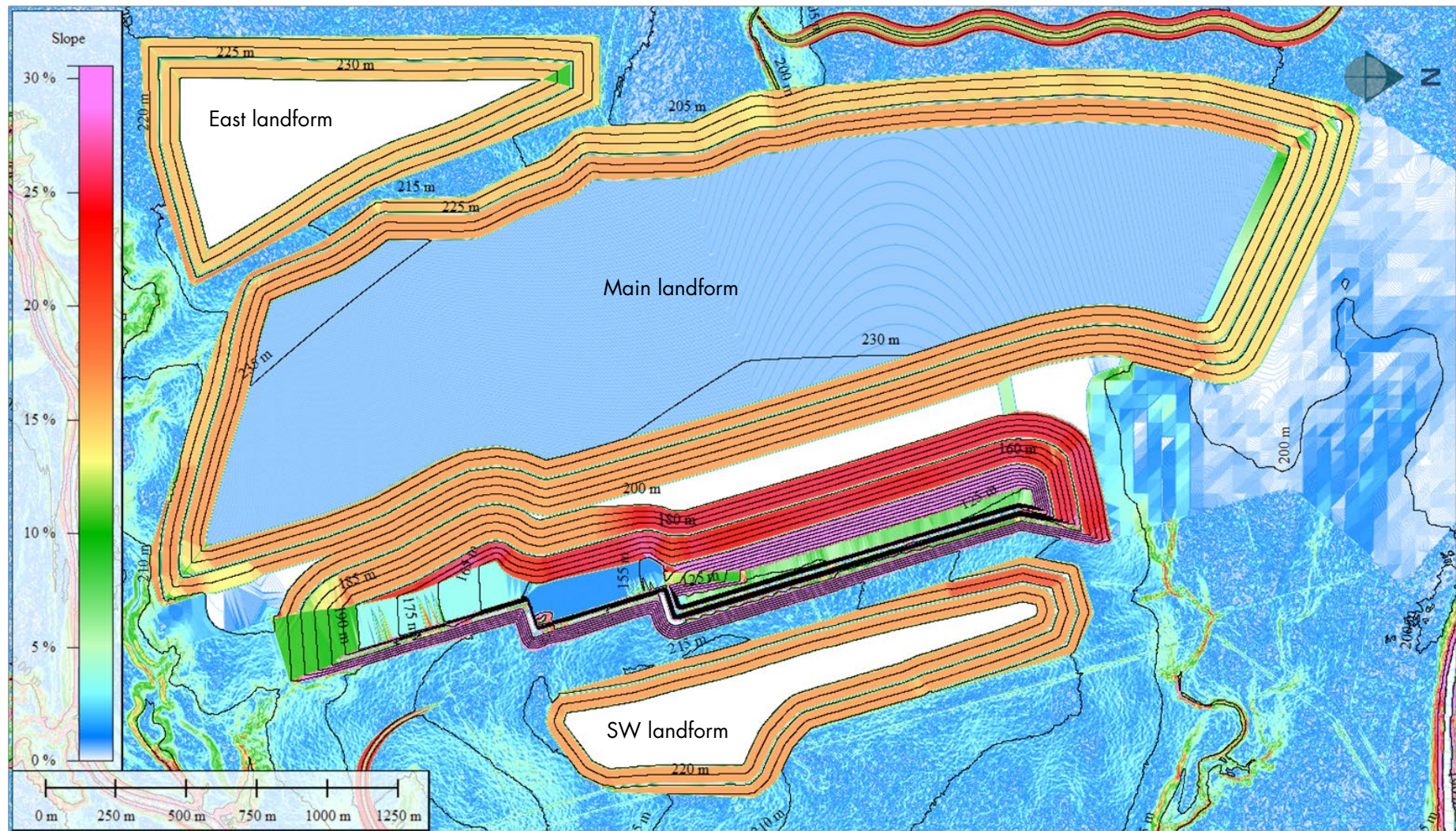


## VOID SECTIONS



**Figure 9:** Representative cross sections of the final landform. Final void water level is as per HydroBalance (2026b).





**Figure 10:** Gradient map of the final landform.



## 4 EROSION MODELLING RESULTS

### 4.1 Modelling completed

WEPP runoff/erosion modelling was undertaken to investigate a range of scenarios using 5 soils for which erodibility parameters were derived (Table 11): Taurus, Taurus-Teviot<sup>4</sup>, Krongie, Teviot, and Retro. The Taurus, Taurus-Teviot, and Krongie soil types are the most common soils within the proposed disturbance area (see Section 2.2.1) and the soils likely to be recovered for use in rehabilitation (see Section 2.2.4 and 2.2.5).

WEPP modelling was also completed for these same 5 soils but with the addition of a rock armour element, assumed to be fresh non-carbonaceous sandstone or fresh carbonaceous sandstone (excluding siltstone/mudstone).

WEPP simulations considered slope lengths up to 500 m to ensure that the modelling included the maximum slope length within the proposed final landform design (see Section 3.3). Slope gradients of 10% and 15% were modelled for soil-covered slopes, assuming groundcover levels of 0%, 50%, 65%, and 80%. 0% vegetation groundcover was modelled to show the erosion potential of the soils soon after rehabilitation when vegetation is absent. 80% groundcover was modelled to show the erosion potential that could be expected if vegetation groundcover levels consistent with the land in the vicinity of the Project are achieved. 50% vegetation groundcover was modelled to show the erosion potential of poorly performing rehabilitation on soil-covered slopes. 65% vegetation groundcover was modelled as the mid-point between 50% and 80% groundcover. Slope gradients >15% were not considered for soil-covered slopes as establishment of grasses on steeper slopes is considered more difficult to achieve as gradient increases.

Slope gradients of 10%, 15%, 20%, and 25% were modelled for slopes covered in soil incorporated into rock armour. A vegetation groundcover level of 30% was modelled, assuming that vegetation growth in rocky soils may be reduced.

### 4.2 Erosionally stable batter geometries

The results of modelling these different scenarios are given in Appendix C. Predicted maximum erosionally stable slope lengths for the 6 soils are given in Table 12.

#### 4.2.1 Unvegetated surface

Predicted long-term erosion rates of unvegetated soils are high. Except for the Krongie soil, the maximum slope length that can be achieved before erosion rates become unacceptably high are 30–35 m for a 10% gradient slope and 15–20 m for a 15% gradient slope. The Krongie soil is highly erodible and is predicted to erode at unacceptably high rates when unvegetated even on very short slope lengths (5 m).

<sup>4</sup> See Section 3.1.3.1 for more detail regarding the formation of the Taurus-Teviot sample.

**Table 12:** Predicted maximum erosionally stable slope lengths for a range of materials, uniform slope gradients and cover conditions.

| Surface Cover | Slope Gradient (%) | Maximum Erosionally Stable Slope Length (m)* |               |         |        |       |
|---------------|--------------------|----------------------------------------------|---------------|---------|--------|-------|
|               |                    | Taurus                                       | Taurus-Teviot | Krongie | Teviot | Retro |
| 0%            | 10                 | 35                                           | 30            | 5       | 30     | 30    |
| Groundcover   | 15                 | 20                                           | 20            | 5       | 15     | 15    |
| 50%           | 10                 | 500                                          | 140           | 100     | 500    | 500   |
| Groundcover   | 15                 | 500                                          | 60            | 60      | 500    | 185   |
| 65%           | 10                 | 500                                          | 500           | 270     | 500    | 500   |
| Groundcover   | 15                 | 500                                          | 335           | 150     | 500    | 500   |
| 80%           | 10                 | 500                                          | 500           | 500     | 500    | 500   |
| Groundcover   | 15                 | 500                                          | 500           | 500     | 500    | 500   |
| Rock Armour   | 10                 | 500                                          | 480           | 485     | 500    | 500   |
| +             | 15                 | 500                                          | 285           | 295     | 350    | 400   |
| 30%           | 20                 | 500                                          | 205           | 210     | 240    | 305   |
| Groundcover   | 25                 | 260                                          | 160           | 165     | 185    | 210   |

\*Based on a target mean average annual erosion rate of <5 t/ha/y and mean peak annual erosion rates <10 t/ha/y.

#### 4.2.2 Vegetated soils

Taurus and Teviot soils are predicted to erode at acceptable rates when groundcover levels are  $\geq 50\%$ . Taurus and Teviot soils are considered suitable for use on all the slopes of all three landforms except for the steep (25%) eastern low wall slope of the main landform that drains to the final void. This result also suggests that the narrow (~10 m) berms could be removed as part of progressive rehabilitation.

For Retro soils, the groundcover level needs to be  $\geq 65\%$  for 15% gradient slopes to be stable to 500 m. When the groundcover level is only 50%, the maximum stable slope length is predicted to be 185 m. Retro soils could be used on all three landforms except for the steep (25%) eastern slope of the main landform that drains to the final void.

For Taurus-Teviot soils, erosion rates are high when only 50% groundcover is achieved. However, when the groundcover level is  $\geq 65\%$  (considered achievable) the stable slope length is at least 335 m. Therefore, Taurus-Teviot soils could be used on all three landforms except for the steep (25%) eastern slope of the main landform that drains to the final void.

For the Krongie soil, erosion rates are higher than other soils and a groundcover of  $\geq 80\%$  is needed to achieve erosional stability. To reduce erosion risk, Krongie soil could be preferentially placed on low gradient portions of the final landform such as the landform tops or the backfill surface of the southern final void.

#### 4.2.3 Rock-armoured soils

The rock-armoured soils are all suitable for use on the gradients >15%.

For the southern section of the low wall dump slope of the main landform with 25% gradient slope (~200 m slope length), the rock-armoured Taurus and rock-armoured Retro soils (with 30% groundcover) are predicted to be acceptably stable.

For the northern section of the low wall dump slope of the main landform with 25% gradient slope (~300 m), the erosion rates are predicted to be within acceptable rates. Again, Taurus and Retro soils perform the best. Taurus soil is predicted to have an acceptable mean average annual rate (1.2 t/ha/y) and peak average annual rate (4.9 t/ha/y). Retro soil is predicted to have an acceptable mean average annual rate (1.4 t/ha/y) and peak average annual rate (5.4 t/ha/y).

## 5 LANDFORM EVOLUTION MODEL RESULTS

The proposed 3D final landform design was modelled using SIBERIA, assuming the following surface materials:

- Taurus with 65% groundcover on the slopes of the main landform except the low wall with 25% gradient which was modelled using rock-armoured Taurus soil with 30% groundcover;
- Taurus-Teviot with 65% groundcover on the outer slopes of the SW landform; and
- Retro with 65% groundcover on outer slopes of the east landform.

The soils were chosen for use on the slopes to reflect the range of soils available. They could be used interchangeably on any of the surfaces. For example, it is noted that Retro is in limited supply, but there is sufficient Taurus, Taurus-Teviot, and Teviot soils to use on this landform instead (see section 2.2.5).

On all landforms, the lower-gradient surfaces were covered with vegetated Krongie soil as a means of mitigating their higher erosion potential.

The landforms have been modelled using the SSP3-7.0 climate prediction.

Figures 11–13 shows the SIBERIA output after 300 years of simulation for the three landforms, which demonstrates that they are stable in the long term. All visualisations (50, 100, 200, and 300 years) are provided in Appendix D.

Statistics of the SIBERIA landform evolution modelling is summarised in Table 13. These statistics were derived from the steep-batter slope only (i.e. the low gradient landform top and base of the final void was excluded). Erosion of the highwall of the final void was not considered; the rates shown by SIBERIA are likely much higher than those that would occur in reality given that the highwall will remain unmined (undisturbed in-situ rock) and the model parameters are reflective on erosion from a mined (disturbed) waste material.

The three landforms are predicted to typically erode at acceptable erosion rates. The acceptable long-term mean average annual erosion rate was set at 5 t/ha/y for this study, being a rate at which the risk of rill erosion being initiated is low. The mean average annual erosion rate for the main landform is 3.7 t/ha/y after 50 years of simulation, increasing to 4.5 t/ha/y after 300 years of simulation. The mean annual average erosion for the SW landform is 2.9 t/ha/y after 50 years of simulation, increasing to 4.6 t/ha/y after 300 years of simulation. The mean average annual erosion for the east landform is 3.9 t/ha/y after 50 years of simulation, increasing to 5.4 t/ha/y after 300 years of simulation.





|                 |                                                                                                                   |                           |                      |                           |                                           |                    |
|-----------------|-------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|---------------------------|-------------------------------------------|--------------------|
| <b>Title:</b>   | Long-term erosion rates for SW landform at 300 years of simulation, using Taurus-Teviot soil with 65% groundcover |                           |                      | <div>N</div> <div>↑</div> | <b>Long-term Erosion Rate</b><br>(t/ha/y) |                    |
| <b>Project:</b> | Isaac Downs Extension<br>Rehabilitated Landform Study                                                             | <b>Coordinate System:</b> | MGA Zone 55<br>GDA94 | <div></div>               | <5                                        | <div></div> 7.5-10 |
|                 |                                                                                                                   | <b>Model:</b>             | SIBERIA              | <div></div>               | 5-7.5                                     | <div></div> >10    |

Figure 11: Long-term erosion rates at 300 years for the Project landform (SW landform).



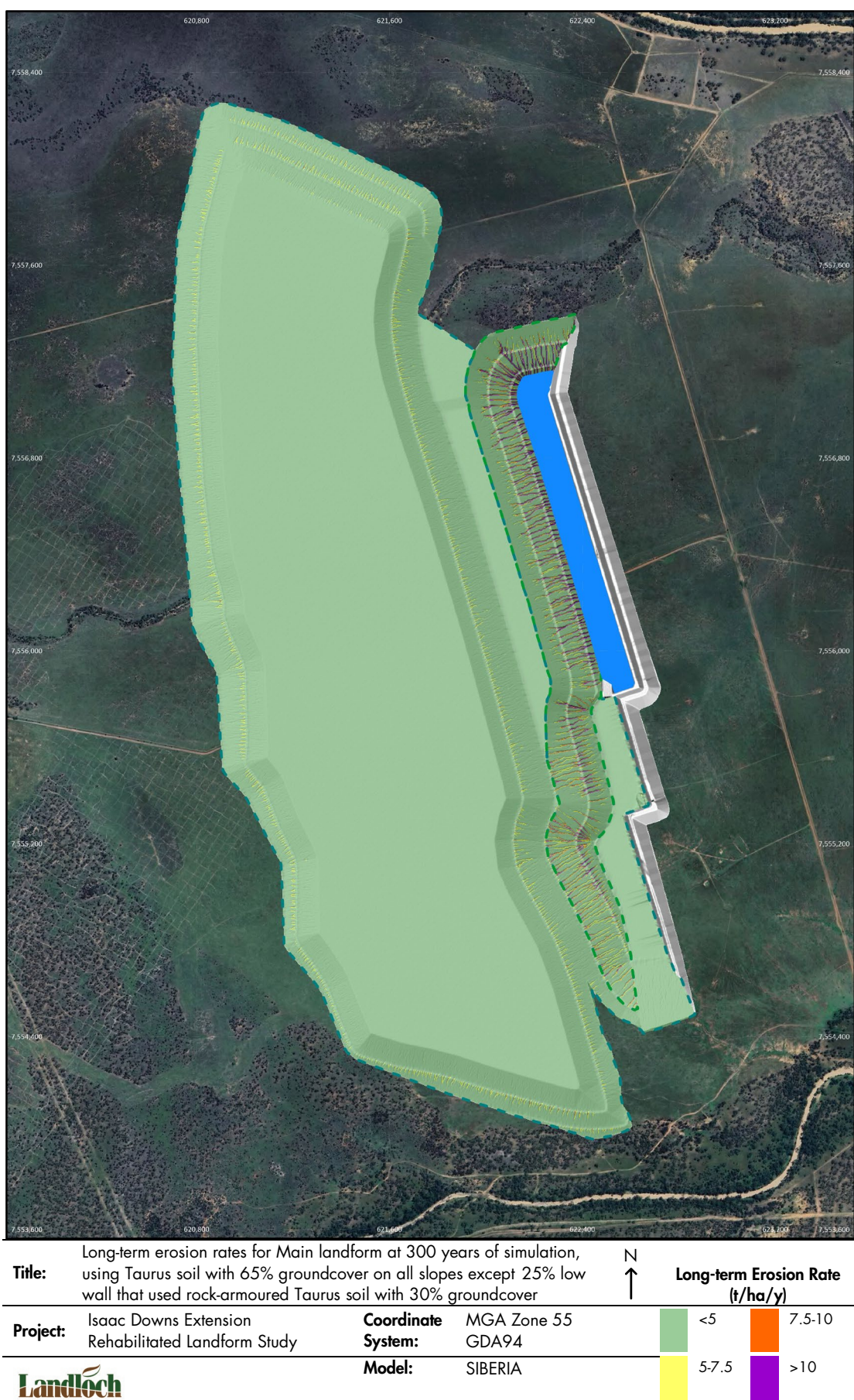


Figure 12: Long-term erosion rates at 300 years for the Project landform (main landform).





|                                                                                                                           |                                                |                    |       |                                            |        |
|---------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|--------------------|-------|--------------------------------------------|--------|
| <b>Title:</b> Long-term erosion rates for East landform at 300 years of simulation, using Retro soil with 65% groundcover |                                                | <div>N<br/>↑</div> |       | <b>Long-term Erosion Rate<br/>(t/ha/y)</b> |        |
| <b>Project:</b> Isaac Downs Extension<br>Rehabilitated Landform Study                                                     | <b>Coordinate System:</b> MGA Zone 55<br>GDA94 | <div></div>        | <5    | <div></div>                                | 7.5-10 |
|                                                                                                                           | <b>Model:</b> SIBERIA                          | <div></div>        | 5-7.5 | <div></div>                                | >10    |

Figure 13: Long-term erosion rates at 300 years for the Project landform (east landform).

**Table 13:** Predicted maximum gully depths, average erosion rates, and cumulative average erosion for the main landform, SW landform, and east landform.

| Simulation year                                 | Maximum gully depth (m) | Average annual erosion (t/ha/y) | Cumulative average erosion (mm) |
|-------------------------------------------------|-------------------------|---------------------------------|---------------------------------|
| Main landform – Taurus with 65% Groundcover     |                         |                                 |                                 |
| 50                                              | 0.3                     | 3.7                             | 12                              |
| 100                                             | 0.6                     | 4.2                             | 40                              |
| 200                                             | 0.8                     | 4.5                             | 100                             |
| 300                                             | 1.0                     | 4.5                             | 190                             |
| SW Landform– Taurus-Teviot with 65% Groundcover |                         |                                 |                                 |
| 50                                              | -                       | 2.9                             | 10                              |
| 100                                             | 0.4                     | 3.8                             | 35                              |
| 200                                             | 0.7                     | 4.4                             | 94                              |
| 300                                             | 0.9                     | 4.6                             | 185                             |
| East Landform– Retro with 65% Groundcover       |                         |                                 |                                 |
| 50                                              | 0.3                     | 3.9                             | 13                              |
| 100                                             | 0.5                     | 4.8                             | 45                              |
| 200                                             | 0.8                     | 5.3                             | 116                             |
| 300                                             | 1.0                     | 5.4                             | 223                             |

The increase in erosion in the longer term is a result of the modelled prediction of formation of gullies as runoff discharges from a lower gradient berm onto the steeper downslope batter. These berms are likely to be removed as a part of progressive rehabilitation and as a result, the landform is likely to be more erosional stable than the modelling indicates.

## 6 DISCUSSION

### 6.1 Topsoil selection and vegetation groundcover

The minimum groundcover levels of vegetated soils for the slope geometries found on the final landform are summarised in Table 14. The slopes considered include the main landform other than the low wall slope at 25% which will include rock armouring and vegetation cover, the SW landform, and the east landform.

**Table 14:** Summary of the minimum groundcover level for vegetated soils when placed on different rehabilitated landforms.

| Landform      | Slope Gradient (%) | Max. Slope Length (m) | Minimum Groundcover Level (%) for: |               |         |        |       |
|---------------|--------------------|-----------------------|------------------------------------|---------------|---------|--------|-------|
|               |                    |                       | Taurus                             | Taurus-Teviot | Krongie | Teviot | Retro |
| Main landform | 15                 | 230                   | 50                                 | 65            | 80      | 50     | 65    |
| SW landform   | 15                 | 160                   | 50                                 | 65            | 80      | 50     | 50    |
| East landform | 15                 | 160                   | 50                                 | 65            | 80      | 50     | 50    |

Taurus and Teviot soils are considered suitable for use all the slopes of all three landforms except for the steeper (25%) eastern slope of the main landform that drains to the final void. This assumes that  $\geq 50\%$  groundcover is sustained. This is considered achievable given that groundcover levels in the vicinity of the Project are  $\sim 80\%$ .

For Retro soils, the groundcover level needs to be  $\geq 65\%$  for 15% gradient slopes on the main landform and  $\geq 50\%$  on the SW landform and east landform. This is considered achievable given that groundcover levels in the vicinity of the Project are  $\sim 80\%$ .

For Taurus-Teviot soils, the groundcover levels needs to be  $\geq 65\%$  for 15% gradient slopes on all landforms. This is considered achievable given that groundcover levels in the vicinity of the Project are  $\sim 80\%$ . That said, to reduce erosion risk, this soil could be preferentially used on either of the SW landform or east landform that have shorter overall slope lengths.

The Krongie soils are the most erodible soil at the Project. It requires a groundcover level of  $\geq 80\%$  to achieve erosional stability. This is achievable, but gives no allowance for poorer than expected vegetation performance. To reduce the erosion risk posed by this soil, Krongie could be preferentially placed on low gradient portions of the final landform such as the landform tops or the backfill surface of the southern final void.

Sufficient volumes of good quality topsoil and marginal topsoil can be recovered such that recovery and use of the subsoils (that have properties less suited to being a growth medium) is not required.

## 6.2 Vegetation establishment

Establishment of vegetation, and in particular groundcover, is critical for long-term erosional stability of the Project landform. There is a period directly after seeding when the landform surface will be unconsolidated and have low vegetation groundcover levels. This period represents a risk to rehabilitation success. Rainfall that leads to significant runoff during this period is likely to lead to the development of rills and potentially gullies. Given the low infiltration capacity of some of the Project soils, it is likely that this will occur.

Consideration should be given to rapid establishment of vegetation groundcover. Seed mixes should include a significant proportion of grasses, preferentially stoloniferous grasses as they spread in contact with the soil surface and provide better erosion control than tussocky grasses.

Consideration should also be given to temporary soil stabilisation techniques such as the use of hydromulches, surface tackifiers, or compost blankets. These techniques are able to provide resistance to erosion for the initial 1–2 years as the groundcover develops. The specific techniques used should be trialled, with the results of the trial used to inform progressive rehabilitation plans for the site.

## 6.3 Sub-surface growth media (subsoil)

The wastes below the topsoils (and incorporated into the topsoil for rock-armoured slopes) should be gypsum treated to mitigate the risks posed by clay dispersion. This

applies to the 25% gradient low wall areas only. The rate of gypsum should be determined by an appropriately qualified person. This is most usefully be performed just prior to commencement of rehabilitation works when the surface materials that will actually be used are identified and available for sampling.

## **6.4 Rock armour materials**

Fresh non-carbonaceous sandstone and carbonaceous sandstone could be targeted for use as a rock armouring element in preference over fresh non-carbonaceous and carbonaceous siltstones/mudstones. Approximately half of the fresh waste is non-carbonaceous sandstone and carbonaceous sandstone.

When fresh non-carbonaceous sandstone and fresh carbonaceous sandstone is used as a rock armour element, the rock fraction must have good to marginal durability (or better). For the purpose of this assessment, the rock fraction can be considered particles greater than ~50 mm in diameter. Indicative quality indicators include rock particle density values  $>2.5 \text{ g/cm}^3$  and water absorption values  $<5.0\%$ . The rock fraction should have a mean particle size ( $D_{50}$ ) of at least 75 mm. The rock source should contain less than 40% fines ( $<2 \text{ mm}$  diameter).

The degree to which a rocky waste can successfully mitigate risks associated with erosion is related not only to rock durability, but also to the size and abundance of rock, the geometry of the landforms being considered, and the climate in which the landform is situated. Therefore, the rock durability results provide a useful indication of potential rock armour materials, but more comprehensive particle size distribution and erodibility testing, and landform design modelling would improve the understanding of the limits of its use as a rock armour material.

## **6.5 Unsuitable wastes**

Tertiary sediments and weathered wastes are likely to be highly erodible and not suitable for use at or near the surface of rehabilitated surfaces. As such, fresh non-carbonaceous waste and/or fresh carbonaceous waste should be present below the growth media layer. A recommended thickness is 1.5 m. Tertiary sediments and weathered wastes can be present below this surface layer.

## **6.6 Slope design**

The results of the modelling show that the linear slopes present within the final landform design are predicted to erode at acceptable rates in the long-term when covered with the soils sourced during Project operations and when the required vegetation groundcover levels are achieved. Assuming the Krongie soil is used on very low gradient areas (landform tops or the backfill surface of the southern final void), vegetation groundcover levels  $\geq 50\%$  for Taurus and Teviot and  $\geq 65\%$  for Taurus-Teviot and Retro are required on slopes with  $\leq 15\%$  gradient. Groundcover levels of  $\geq 30\%$  are required on 25% gradient slopes that are also rock armoured.



## 6.7 Cross-slope berms

The current design includes narrow (~10 m wide) cross-slope berms that store and infiltrate water. They represent points of potential weakness in the design as they may unevenly fill with sediment and overtop. Berms should be monitored on a regular basis during rehabilitation (annually or after a large rainfall event) for signs of tunnel erosion or uneven settlement/filling. Where these are observed, remedial actions should be undertaken to ensure the continued function of the berms.

Refinement of the design to remove these berms should be considered as future developments allow. Given the erosion modelling results, this could be achieved by removing the berms as part of progressive rehabilitation. For example, the berms (in place to manage runoff and sediment from upslope sections during operations and the initial stages of rehabilitation) could be removed when the lower slopes are rehabilitated and suitably vegetated.

## 6.8 Landform tops

Krongie soils should preferentially be used on very low gradient landform tops or the backfill surface of the southern final void.

Uncontrolled runoff from the landform top is a common cause of gullying and landform failure. This risk could be mitigated by the installation of crest bunds around the perimeter of the landform tops. The bunds are to be thoroughly compacted and constructed of stable (non-dispersive) material. They are to have their outer faces continuous with the outer batter profile and have the same surface treatments applied to it (e.g. soils). They are to have a width across the top of the bund of at least 2 m and are to have their inner face sloping gradually inwards at a gradient of 1V:10H (10%). The gentle inward gradient ensures that any water that ponds will be ponded well away from the outer batter slope, thereby minimising the potential for any sinkhole that may form to reach the outer batter slope and create an "instant gully".

Alternatively, if the landform top is to be free draining and crest bunds are not able to be used, such as on the top of the main landform that drains to the final void, the landform top surface should be roughened to increase its depression storage and reduce the ability of surface water to move laterally across the top and reduce the likelihood that flows can concentrate and discharge at discrete locations onto the downslope slope sections. Roughening of the landform top could be achieved by deep ripping.

## 6.9 Surface ripping

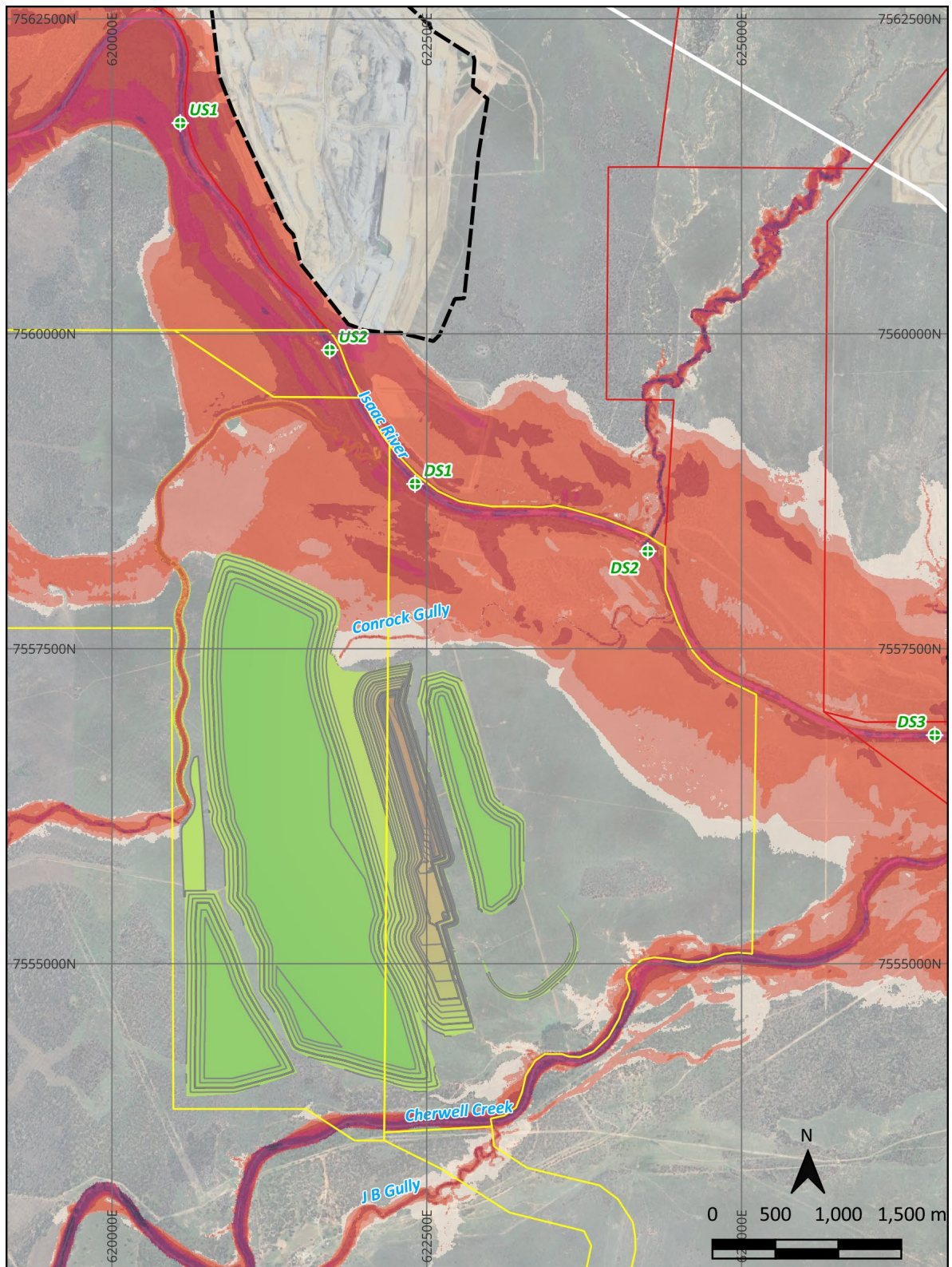
It is critical that flow concentration on the slopes is minimised. Concentration of runoff can be prevented by minimising the size of cross-slope rip lines. Rip lines should be no deeper than 300 mm from peak to trough of the rip line once settlement has occurred. To achieve this, an unconsolidated rip line ~500 mm deep is recommended. Ripping will be desirable to reduce machinery compaction, remove track marks that are not on contour, and incorporate amendments if required, as determined by an Appropriately Qualified Person (AQP) for the growth media available at the time that rehabilitation occurs encourage repaid vegetation growth.

For more precise results, equipment used for rehabilitation works should have guidance systems installed, and use operators that are highly skilled and experienced. Rehabilitation earthworks require greater levels of precision than mining earthworks, with adherence to the specified designs if successful rehabilitation is to be achieved.

## 6.10 Landform position and flood scour

The position of the landform within the landscape will play an important role in long-term erosional stability. The main landform is located within the 1% Annual Exceedance Probability (AEP) Isaac River (northern end), but not within the 1% AEP flood line for Cherwell Creek (Figure 14, Hydro Balance 2026). Maximum flow velocities adjacent the main landform are predicted to be 0.5–1.0 m/s. The SW landform and east landform are not positioned within the 1% AEP flood area for either the Isaac River or Cherwell Creek.

The velocities predicted for the northern end of the main landform are likely to lead to scour erosion when the soils are bare of vegetation (which is not the intention for rehabilitation of this area). The *Soil Conservation Guidelines for Queensland* recommend a maximum permissible velocity for easily eroded bare soils on low gradient land (1% is the lowest reported) of 0.5 m/s. When vegetated, the maximum permissible velocity increases. The guideline indicates that the maximum permissible velocity increases to 1.2 m/s (greater than the maximum predicted velocities of the 1% AEP event) for 50% vegetation groundcover and 1.5 m/s for 75% vegetation groundcover. Therefore, the proposed vegetation groundcover of the main landform would mitigate the risk of scour erosion.



**Title:** 1% AEP flood velocities  
Final landform

**Project:** Isaac Downs Extension  
Surface Water Assessment

**HydroBalance**

**Legend**

- MLA Boundary
- Surrounding MLs
- IDM final landform
- + Analysis point

**Velocity (m/s)**

- |  |           |  |           |
|--|-----------|--|-----------|
|  | <= 0.2    |  | 1.5 - 2.0 |
|  | 0.2 - 0.5 |  | 2.0 - 3.0 |
|  | 0.5 - 1.0 |  | 3.0 - 5.0 |
|  | 1.0 - 1.5 |  | > 5.0     |

**Figure 14:** 1% AEP flood velocities for the final landform (Source: Hydro Balance 2026).



## 7 CLOSING

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The results from the erosion and landform evolution modelling indicate that vegetated soil and vegetated rock-armoured soil surfaces can be used to create a rehabilitated landform that is erosionally stable in the long-term. The shape of the final landform proposed for the Project has been developed with consideration of the following:

- Erosion rates consistent with surfaces with a low tendency for rill erosion (soil erosion targets);
- Erodibility testing of the Project's soils and soil-fresh rock mixtures;
- Rainfall erosivity of the climate at the Project, adjusted for climate change;
- Suitability of the soils and fresh Permian waste as a primary growth media and the fresh wastes as secondary growth media (underlying the primary growth media layer);
- Ability of the required groundcover to be achieved; and
- Predicted long-term erosion rates for land surfaces found in the current final landform design for the Project.

The soils were assessed as being suitable for use as a primary growth medium (i.e. at the surface of the rehabilitated final landform). The fresh non-carbonaceous sandstone and fresh carbonaceous sandstone were also assessed as being suitable as a rock armour or secondary growth media once amended with gypsum (gypsum application applies to the 25% gradient low wall areas only). The rate of gypsum should be determined by an appropriately qualified person. This is most usefully performed just prior to commencement of rehabilitation works when the surface materials that will actually be used are identified and able to be sampled.

Tertiary and othered weathered wastes should not be placed within 2.0 m of the surface of the rehabilitated final landform.

Uncontrolled and concentrated runoff from the landform top could be mitigated by the installation of crest bunds around the perimeter of the landform tops. Alternatively, if the landform top is to be free draining and crest bunds are not able to be used, such as the top of the main landform that drains to the void, the landform top surface should be roughened to increase its depression storage and reduce the ability of surface water to move laterally across the top and reduce the likelihood that flows can concentrate and discharge at discrete locations onto the downslope sections. Roughening of the landform top could be achieved by deep ripping.

Consideration should be given to rapid establishment of groundcover. Seed mixes should include a significant proportion of grasses, preferentially stoloniferous grasses as they spread in contact with the soil surface and provide better erosion control than tussocky grasses. Surface stabilisation techniques such as the use of hydromulches, surface tackifiers, or compost blankets are recommended to be used in the initial phase of rehabilitation as vegetation establishes and reaches sufficient groundcover levels.



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## APPENDIX A: LABORATORY PHOTOS

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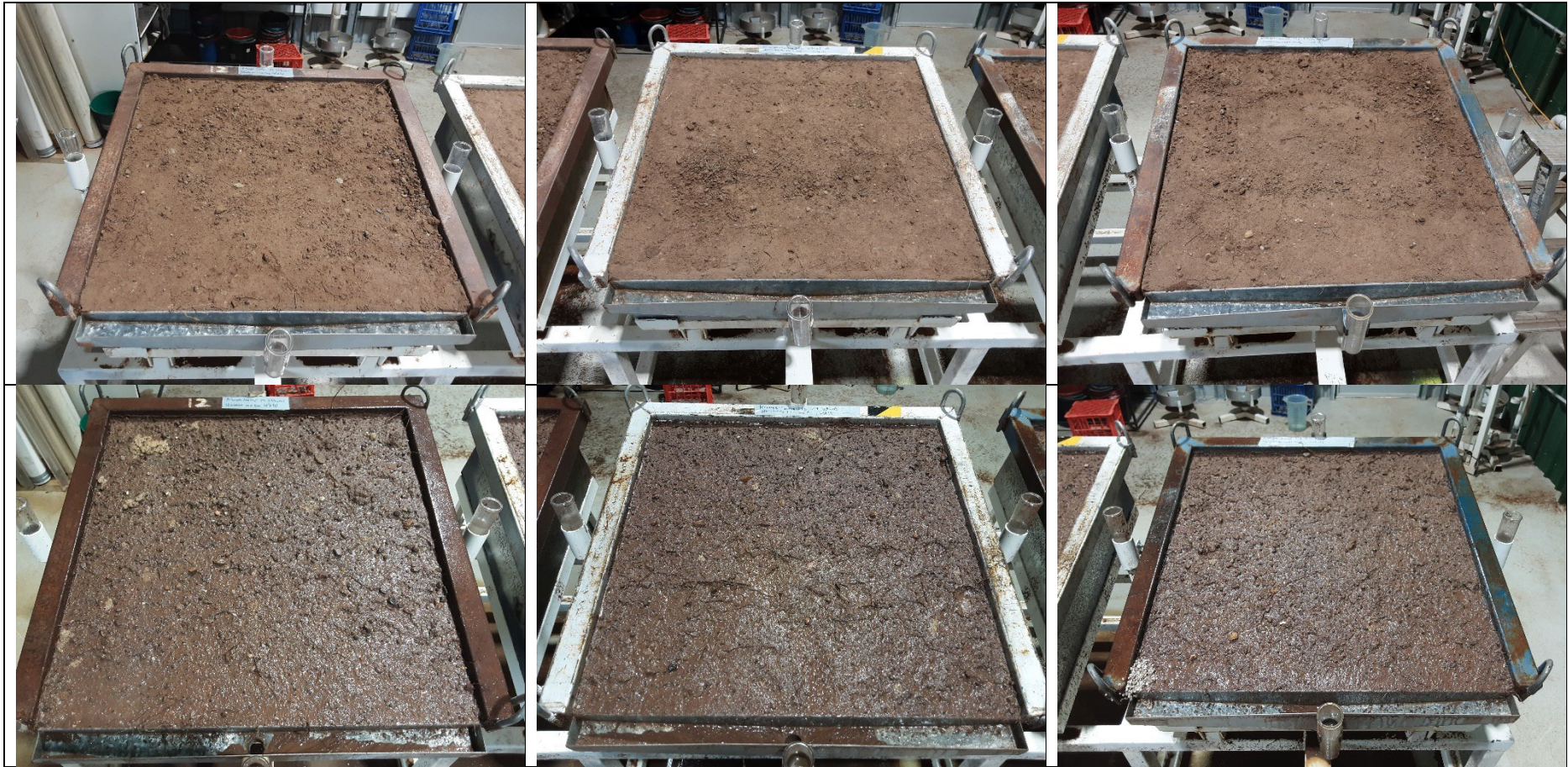
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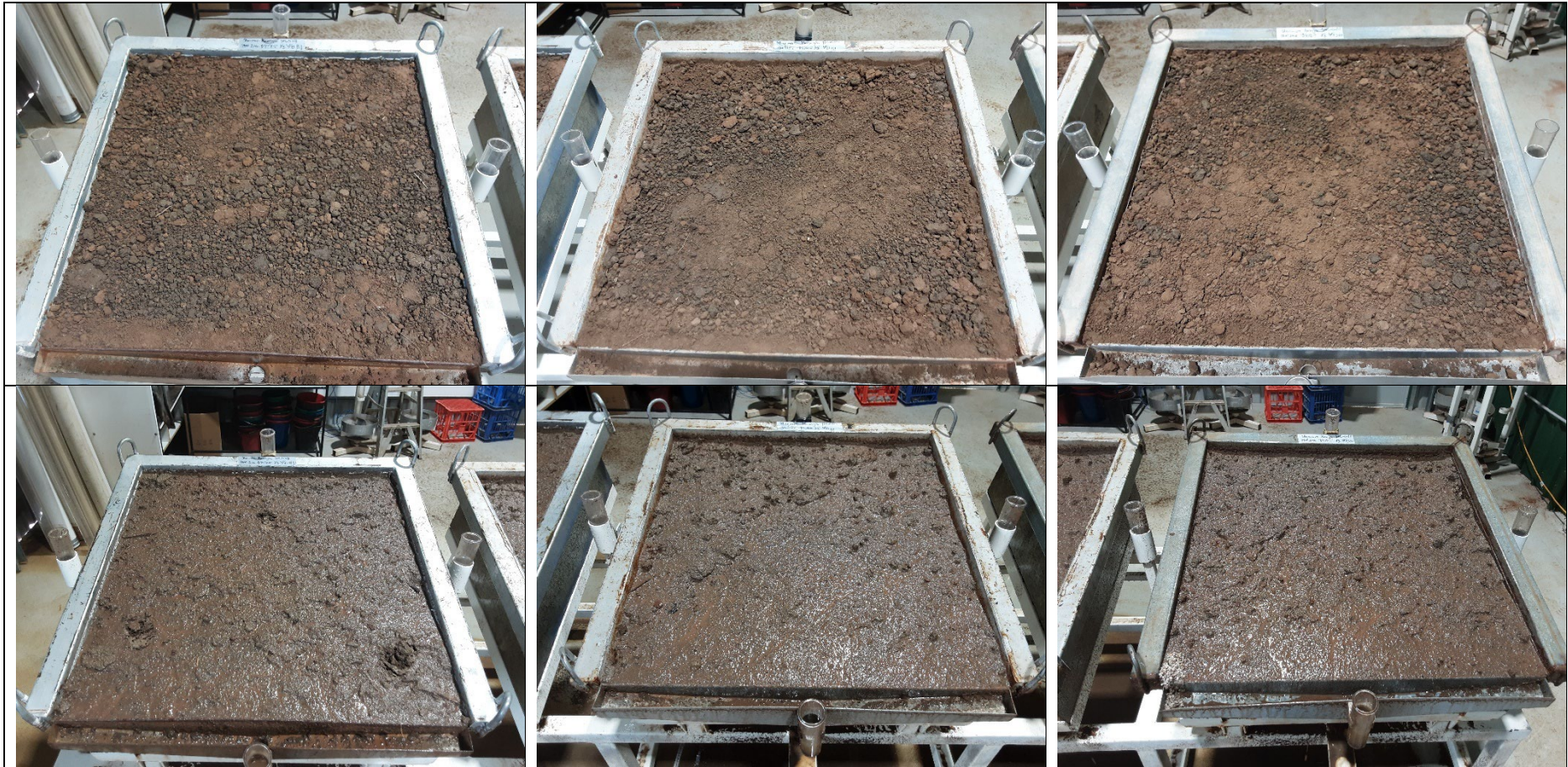
**Figure A-1:** Taurus rainfall simulation plots before application of simulated rain (top) and after application of simulated rain (bottom).





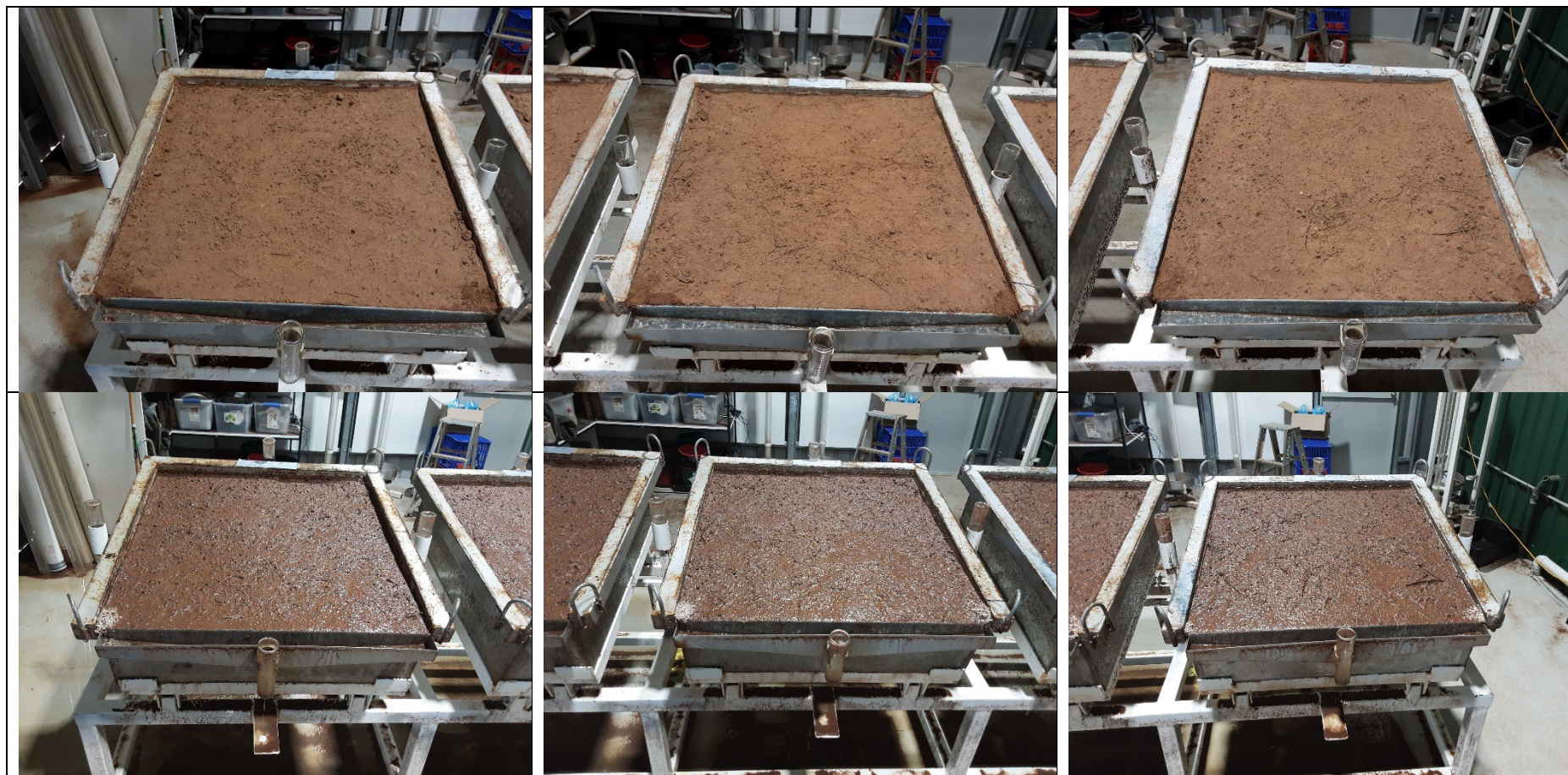
**Figure A-2:** Taurus-Teviot rainfall simulation plots before application of simulated rain (top) and after application of simulated rain (bottom).





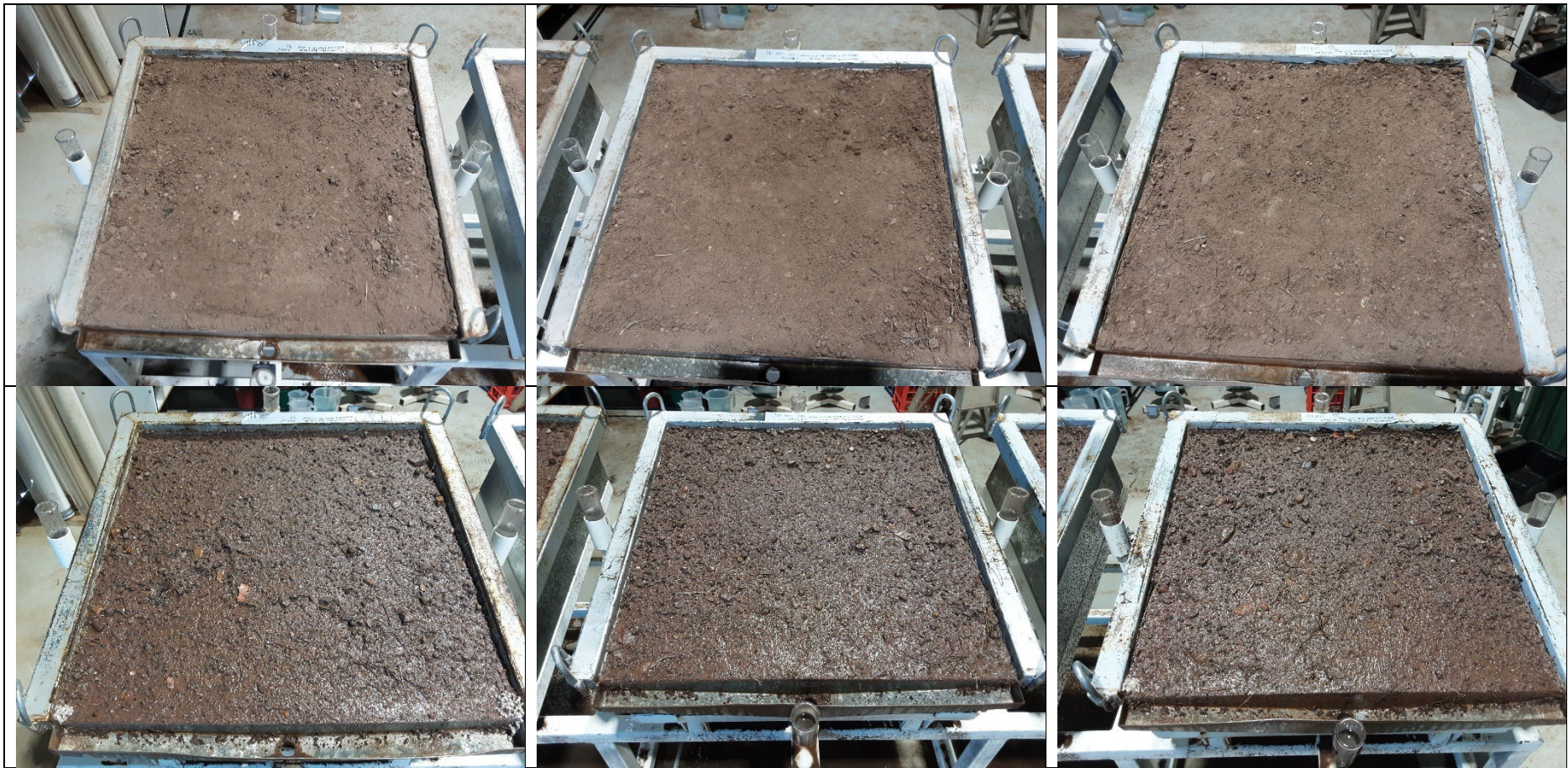
**Figure A-3:** Krongie rainfall simulation plots before application of simulated rain (top) and after application of simulated rain (bottom).





**Figure A-4:** Teviot rainfall simulation plots before application of simulated rain (top) and after application of simulated rain (bottom).





**Figure A-5:** Retro rainfall simulation plots before application of simulated rain (top) and after application of simulated rain (bottom).





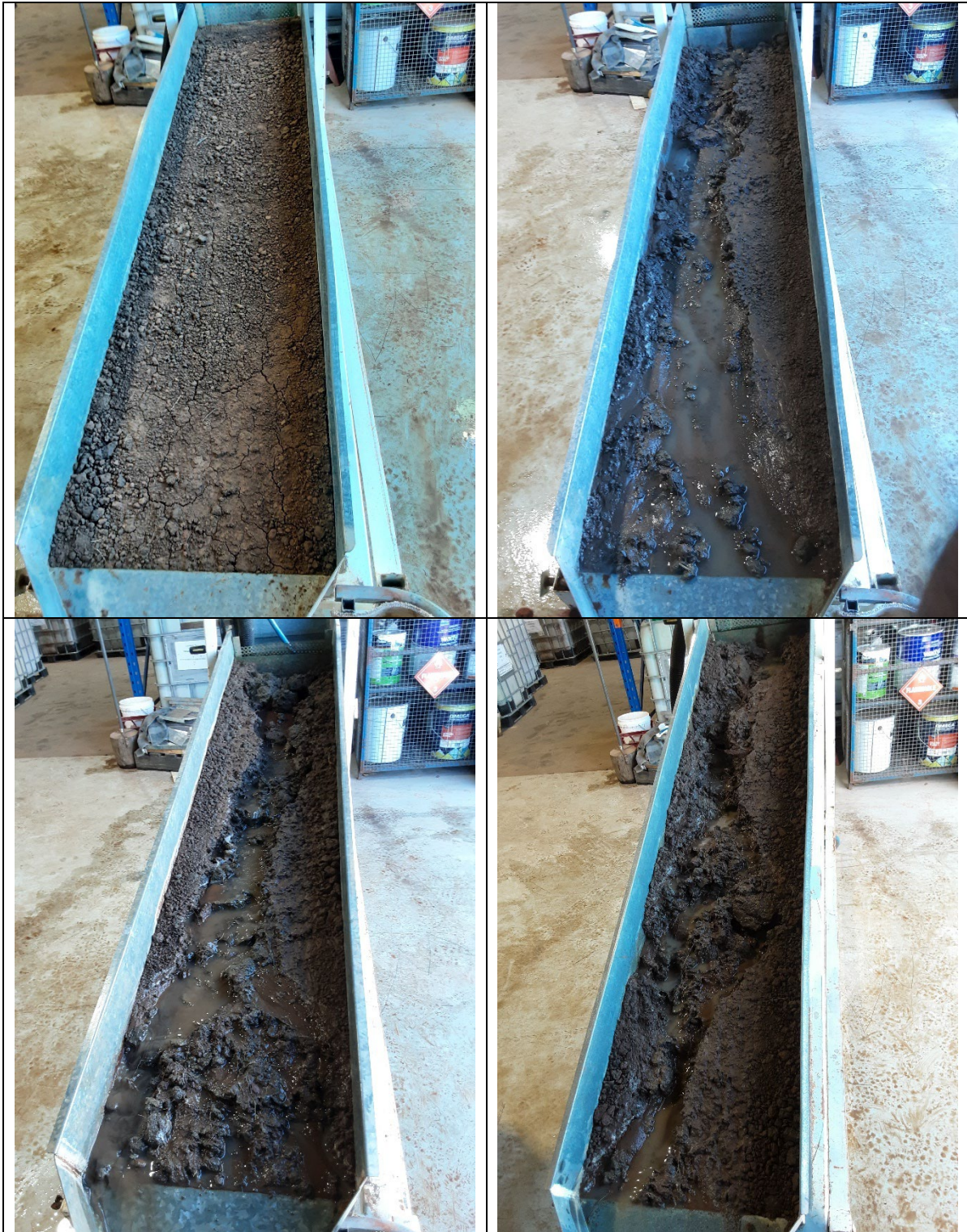
**Figure A-6:** Taurus overland flow studies before application of flow on 10% gradient flume (top left), and during application of flows on 10% gradient flume (top right), 20% gradient flume (bottom left), and 30% gradient flume (bottom right).





**Figure A-7:** Taurus-Teviot overland flow studies before application of flow on 10% gradient flume (top left), and during application of flows on 10% gradient flume (top right), 20% gradient flume (bottom left), and 30% gradient flume (bottom right).





**Figure A-8:** Krongie overland flow studies before application of flow on 10% gradient flume (top left), and during application of flows on 10% gradient flume (top right), 20% gradient flume (bottom left), and 30% gradient flume (bottom right).





**Figure A-9:** Teviot overland flow studies before application of flow on 5% gradient flume (top left), and during application of flows on 5% gradient flume (top right), 10% gradient flume (bottom left), and 20% gradient flume (bottom right).





**Figure A-10:** Retro overland flow studies before application of flow on 10% gradient flume (top left), and during application of flows on 10% gradient flume (top right), 20% gradient flume (bottom left), and 30% gradient flume (bottom right).

## APPENDIX B: LABORATORY RESULTS

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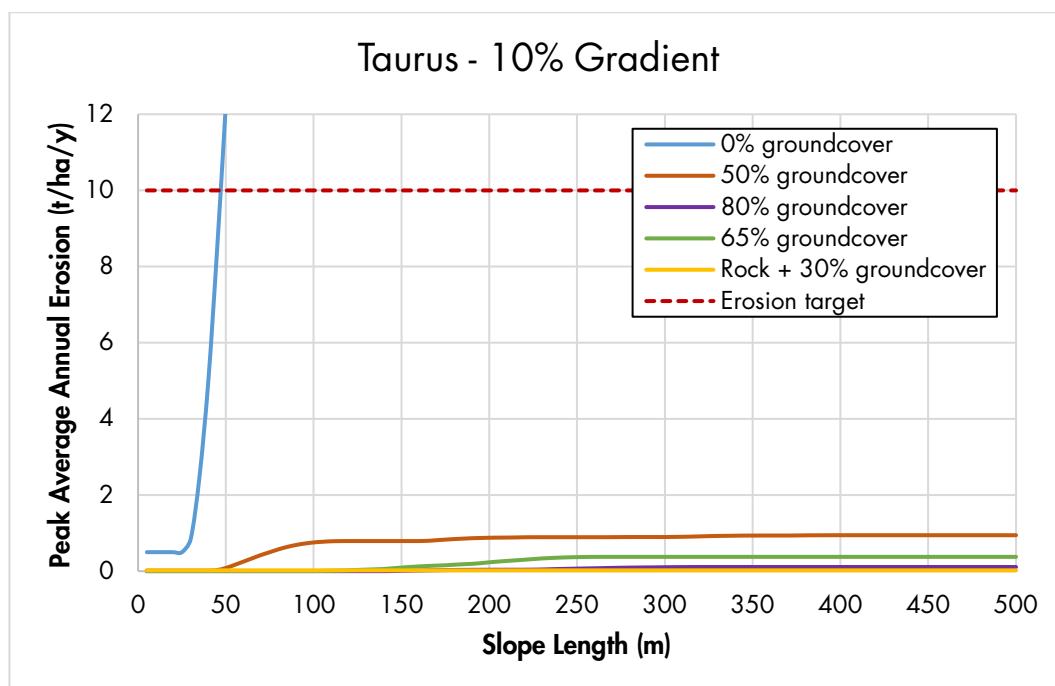
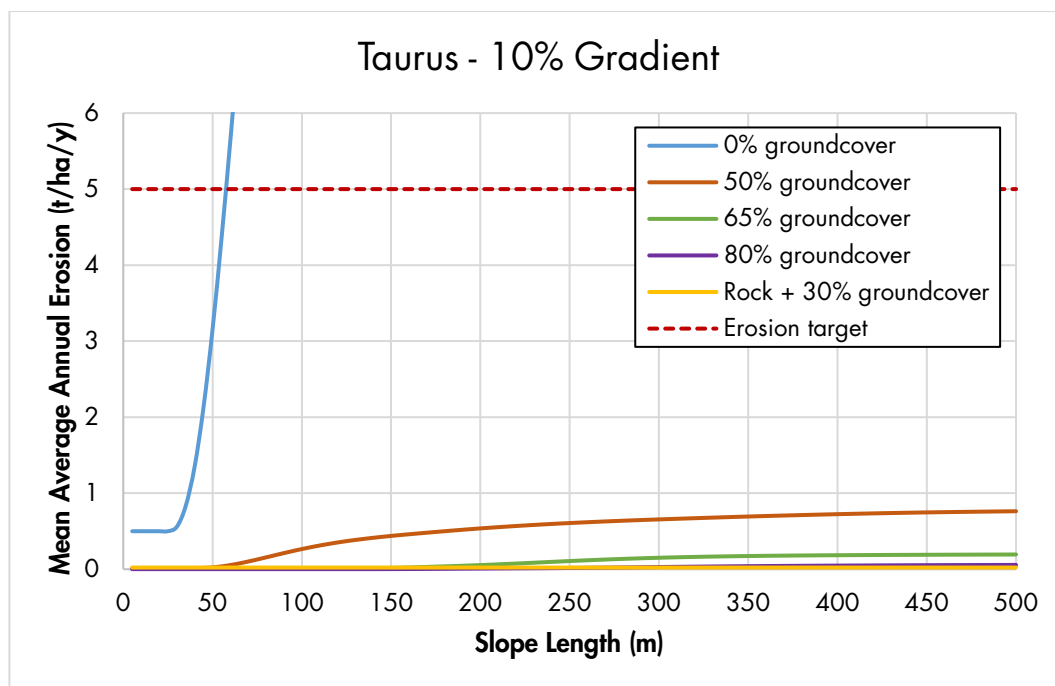
**Table B-1:** Baseline laboratory results.

| Analysis                                     |                      | Unit      | Ta1-A  | Ta1-B | Ta2  | Tv1-A  | Tv1-B | Tv2  | Kg1     | Kg2   | Rt1   | Rt2  |
|----------------------------------------------|----------------------|-----------|--------|-------|------|--------|-------|------|---------|-------|-------|------|
|                                              |                      |           | Taurus |       |      | Teviot |       |      | Krongie |       | Retro |      |
| pH - Water                                   |                      | pH units  | 6.06   | 5.85  | 7.13 | 6.72   | 7.47  | 7.08 | 7.35    | 8.14  | 7.80  | 6.58 |
| Electrical Conductivity (EC <sub>1:5</sub> ) |                      | dS/m      | 0.01   | 0.01  | 0.03 | 0.01   | 0.06  | 0.02 | 0.03    | 0.20  | 0.03  | 0.02 |
| Chloride                                     |                      | mg/kg     | 5.1    | 5.4   | 7.1  | 6.5    | 6.0   | 8.3  | 7.3     | 16.5  | 6.7   | 8.1  |
| Exchangeable Cations                         | Extraction Method    | -         | 15A1   | 15A1  | 15A1 | 15A1   | 15C1  | 15A1 | 15C1    | 15C1  | 15C1  | 15A1 |
|                                              | Effective CEC        | meq/100g  | 4.3    | 3.6   | 4.5  | 3.5    | 4.5   | 4.2  | 14.1    | 19.2  | 8.6   | 4.9  |
|                                              | Ex Sodium Percent    | %         | 4.2    | 4.1   | 5.6  | 3.6    | 1.7   | 2.9  | 3.7     | 4.0   | 2.2   | 3.0  |
|                                              | Ex Magnesium Percent | %         | 31.7   | 32.6  | 28.8 | 25.2   | 12.6  | 14.9 | 36.7    | 34.5  | 10.1  | 23.5 |
|                                              | Ex. Calcium          | meq/100g  | 2.45   | 1.91  | 2.59 | 2.15   | 3.55  | 3.01 | 7.97    | 11.44 | 7.39  | 3.04 |
|                                              | Ex. Magnesium        | meq/100g  | 1.35   | 1.17  | 1.29 | 0.88   | 0.57  | 0.63 | 5.18    | 6.60  | 0.87  | 1.15 |
|                                              | Ex. Potassium        | meq/100g  | 0.21   | 0.22  | 0.34 | 0.29   | 0.27  | 0.45 | 0.41    | 0.33  | 0.09  | 0.53 |
|                                              | Ex. Sodium           | meq/100g  | 0.18   | 0.15  | 0.25 | 0.12   | 0.08  | 0.12 | 0.53    | 0.76  | 0.19  | 0.15 |
|                                              | Ex. Aluminium        | meq/ 100g | 0.07   | 0.15  | 0.02 | 0.02   | 0.02  | 0.02 | 0.02    | 0.02  | 0.02  | 0.02 |
|                                              | Ca:Mg                | -         | 1.8    | 1.6   | 2.0  | 2.5    | 6.3   | 4.8  | 1.5     | 1.7   | 8.5   | 2.6  |
| Particle Size Distribution                   | C. Sand (0.2-2.0mm)  | %         | 33.8   | 33.2  | 35.1 | 26.3   | 26.1  | 30.6 | 8.1     | 8.0   | 41.4  | 42.7 |
|                                              | F. Sand (0.02—0.2mm) | %         | 35.3   | 36.3  | 43.0 | 49.9   | 45.6  | 44.1 | 28.2    | 28.5  | 30.3  | 33.6 |
|                                              | Silt (0.002-0.02mm)  | %         | 3.4    | 3.4   | 3.3  | 5.3    | 7.5   | 7.3  | 10.6    | 14.7  | 7.5   | 5.4  |
|                                              | Clay (<0.002mm)      | %         | 27.4   | 27.1  | 18.5 | 18.4   | 20.6  | 18.1 | 53.0    | 48.8  | 20.7  | 18.2 |

## APPENDIX C: WEPP MODEL OUTPUT

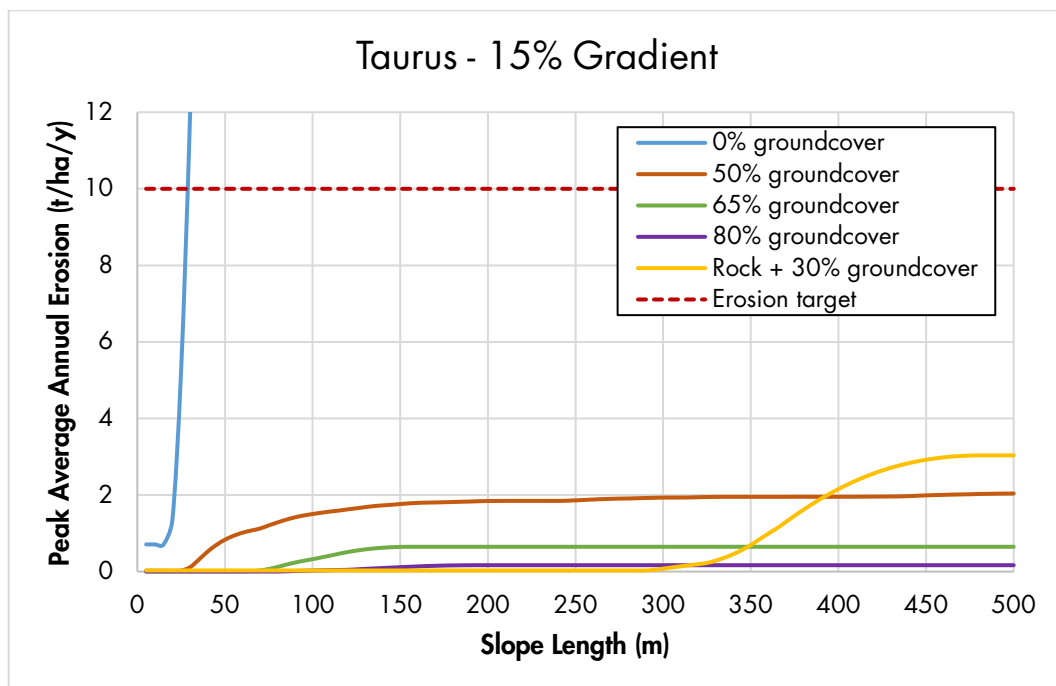
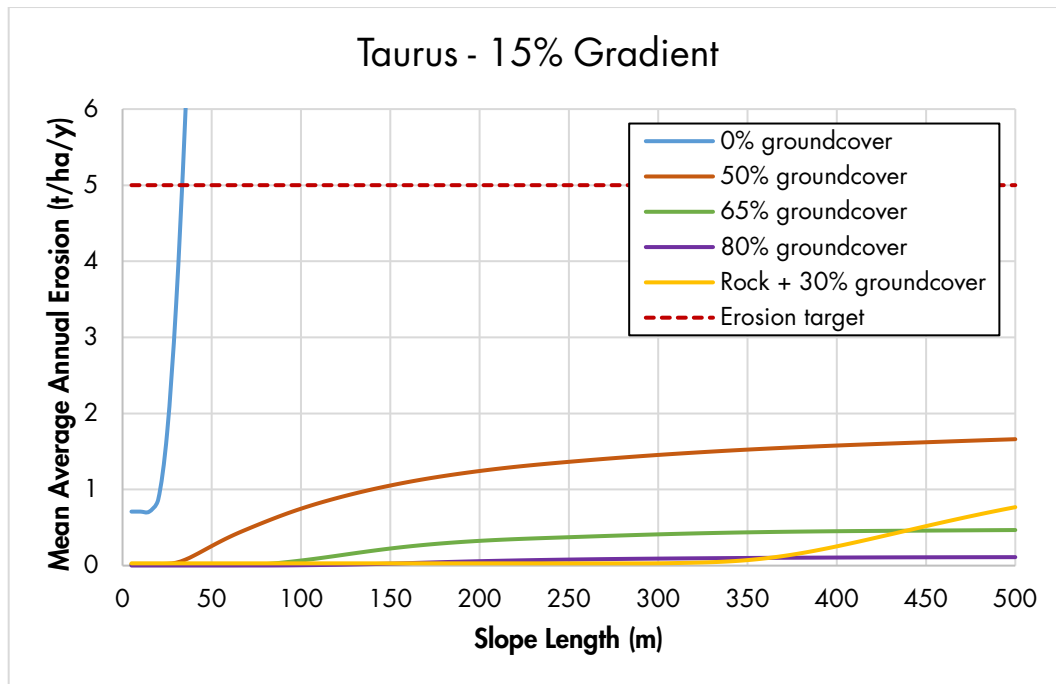
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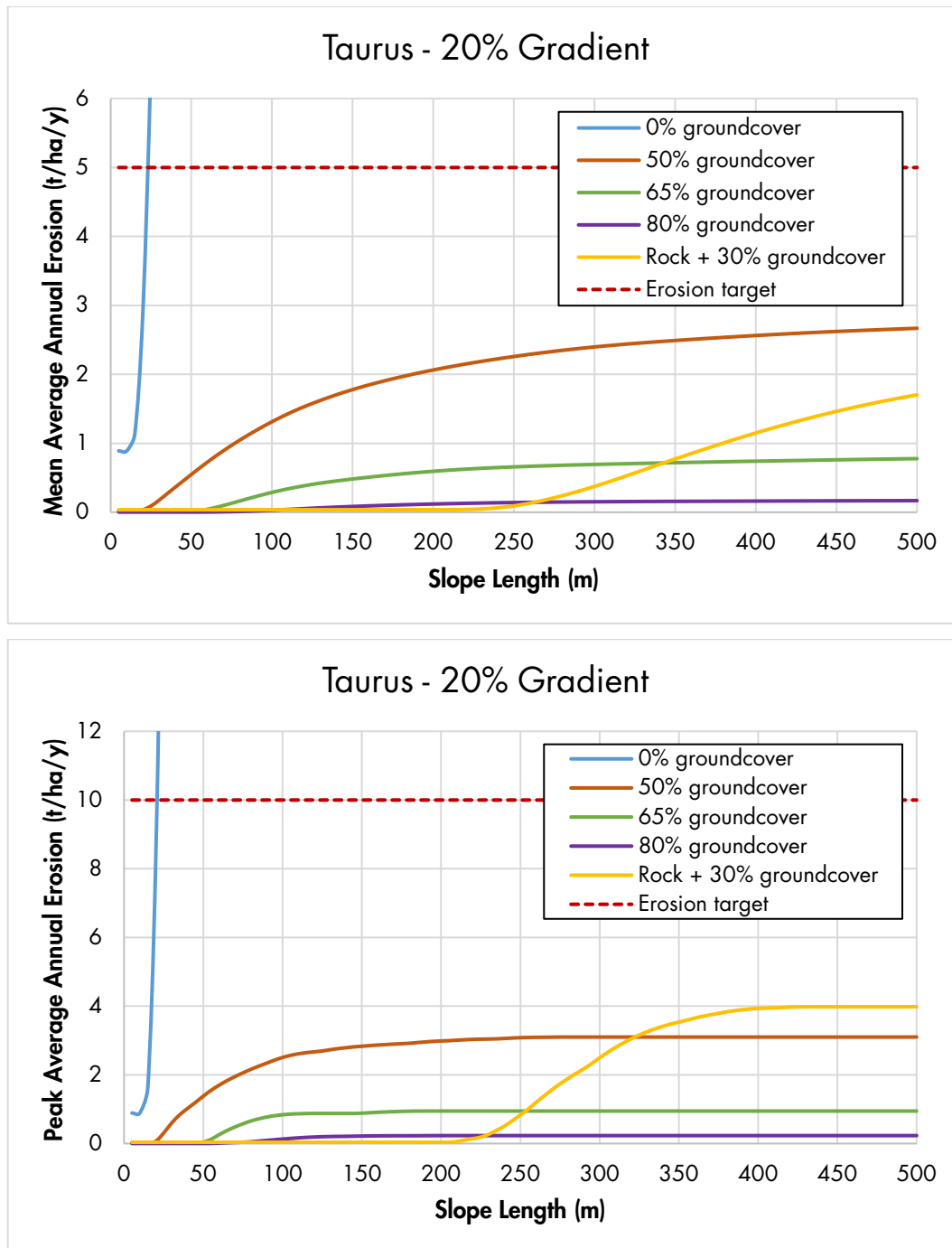


**Figure C-1:** Mean (top) and peak (bottom) average annual erosion for a 10% gradient, 500m long slope sheeted with Taurus soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

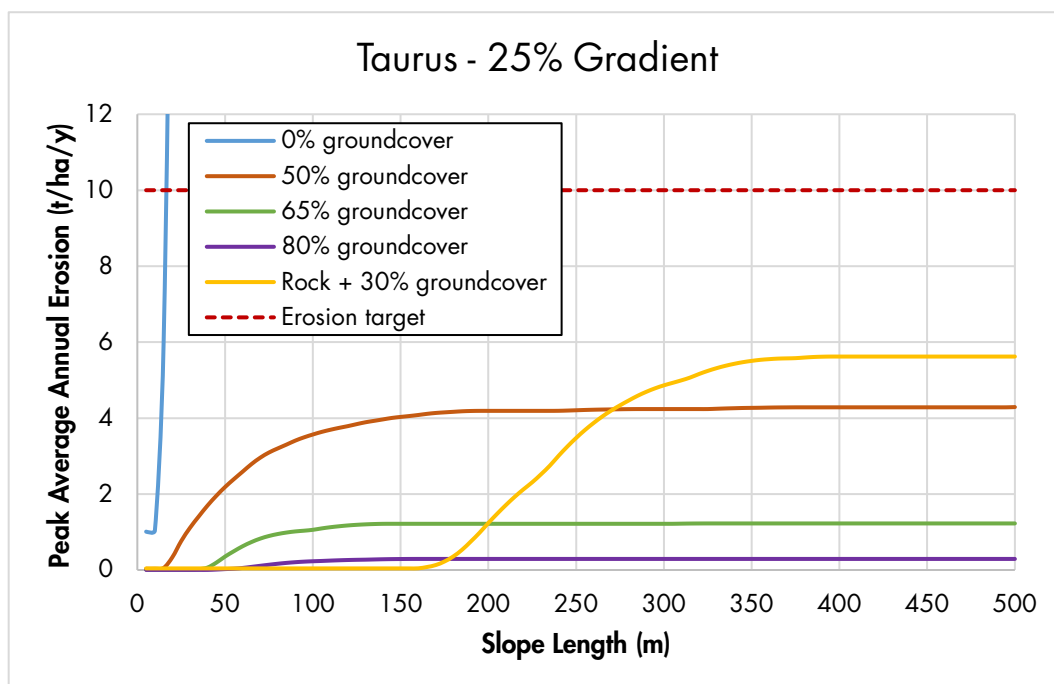
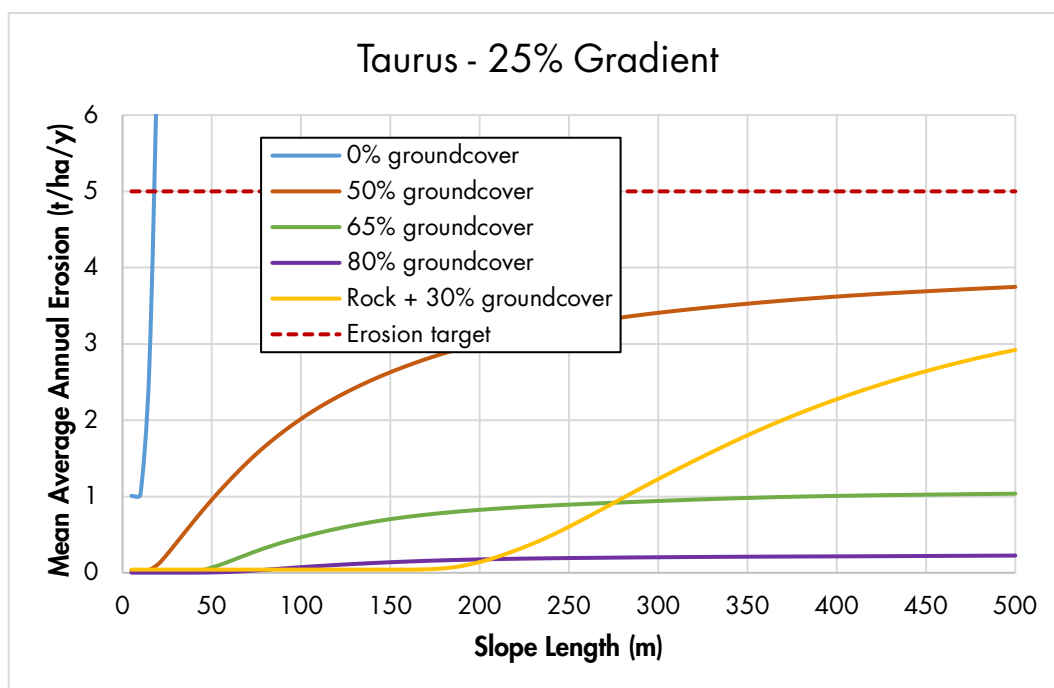




**Figure C-2:** Mean (top) and peak (bottom) average annual erosion for a 15% gradient, 500m long slope sheeted with Taurus soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

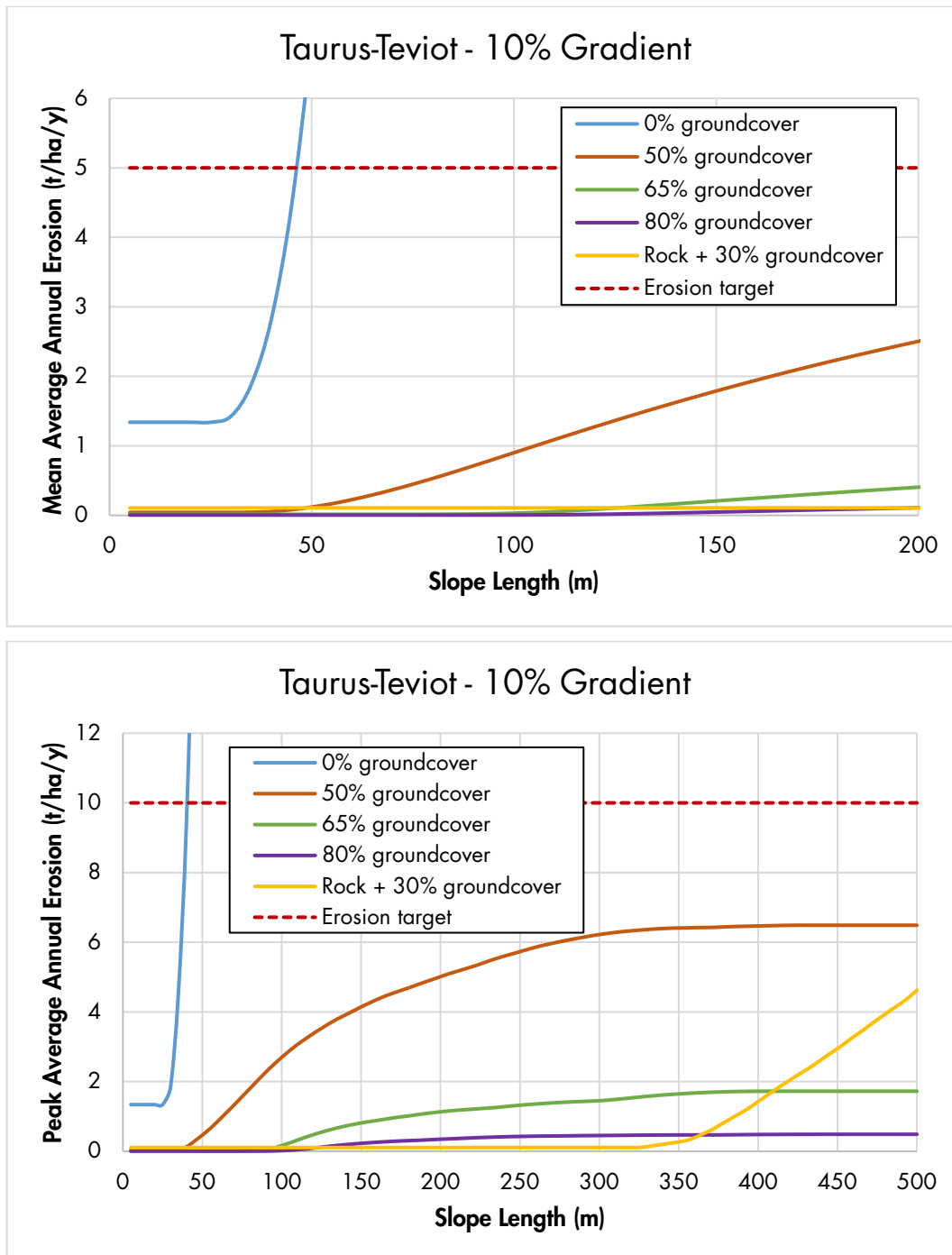


**Figure C-3:** Mean (top) and peak (bottom) average annual erosion for a 20% gradient, 500m long slope sheeted with Taurus soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

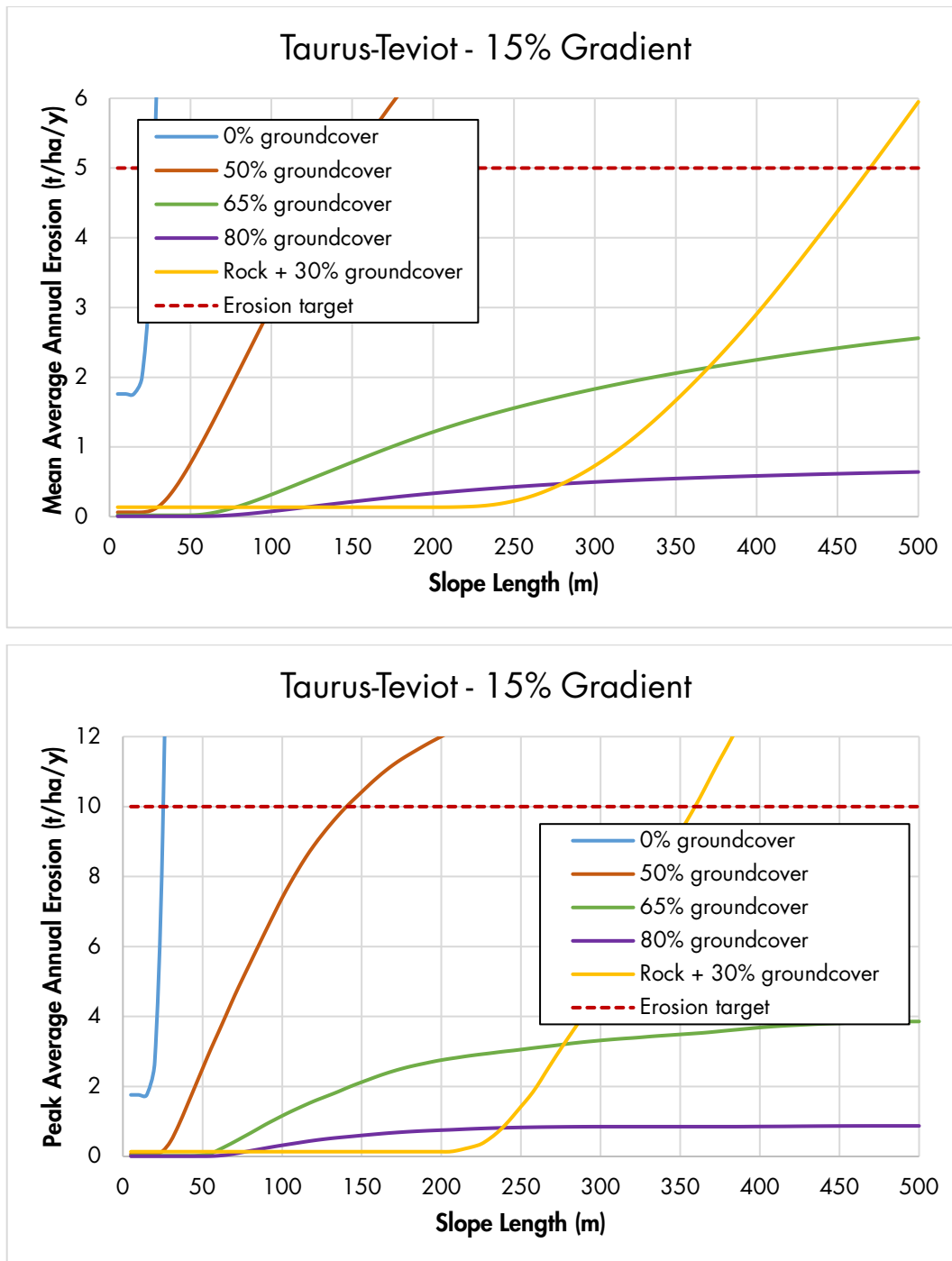


**Figure C-4:** Mean (top) and peak (bottom) average annual erosion for a 25% gradient, 500m long slope sheeted with Taurus soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

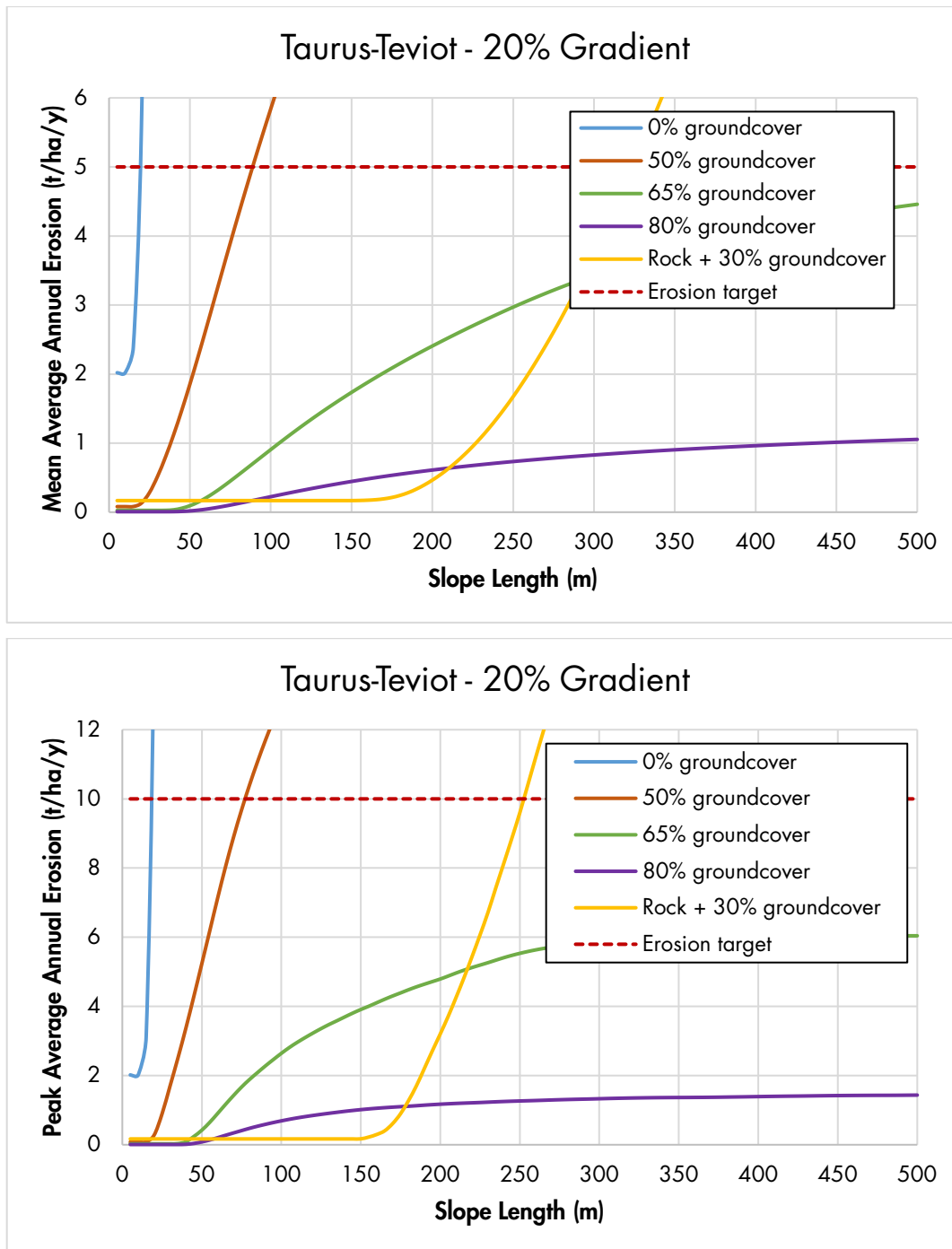




**Figure C-5:** Mean (top) and peak (bottom) average annual erosion for a 10% gradient, 500m long slope sheeted with Taurus-Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover. Represented by the Taurus-Krongie modelling results.

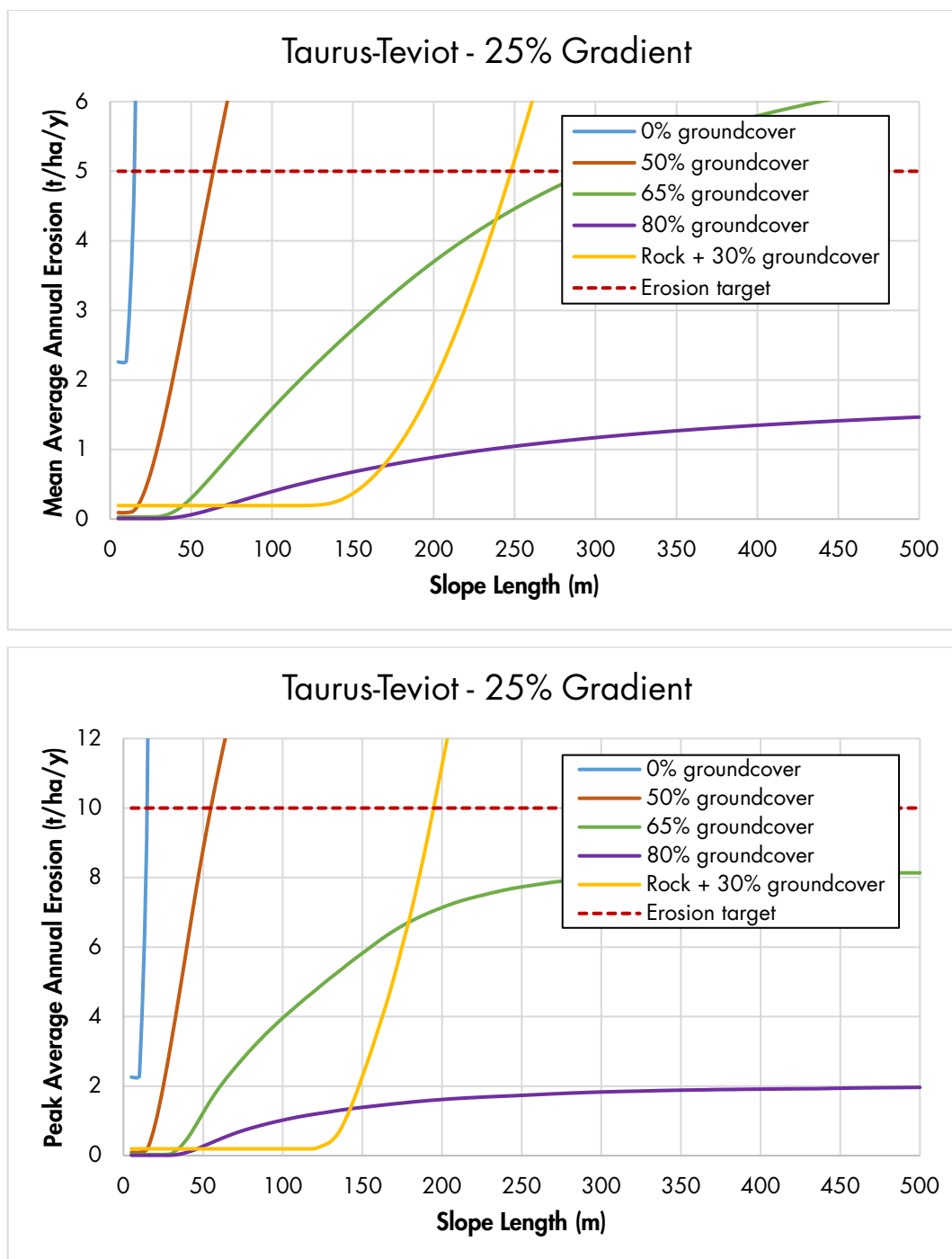


**Figure C-6:** Mean (top) and peak (bottom) average annual erosion for a 15% gradient, 500m long slope sheeted with Taurus-Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover. Represented by the Taurus-Krongie modelling results.

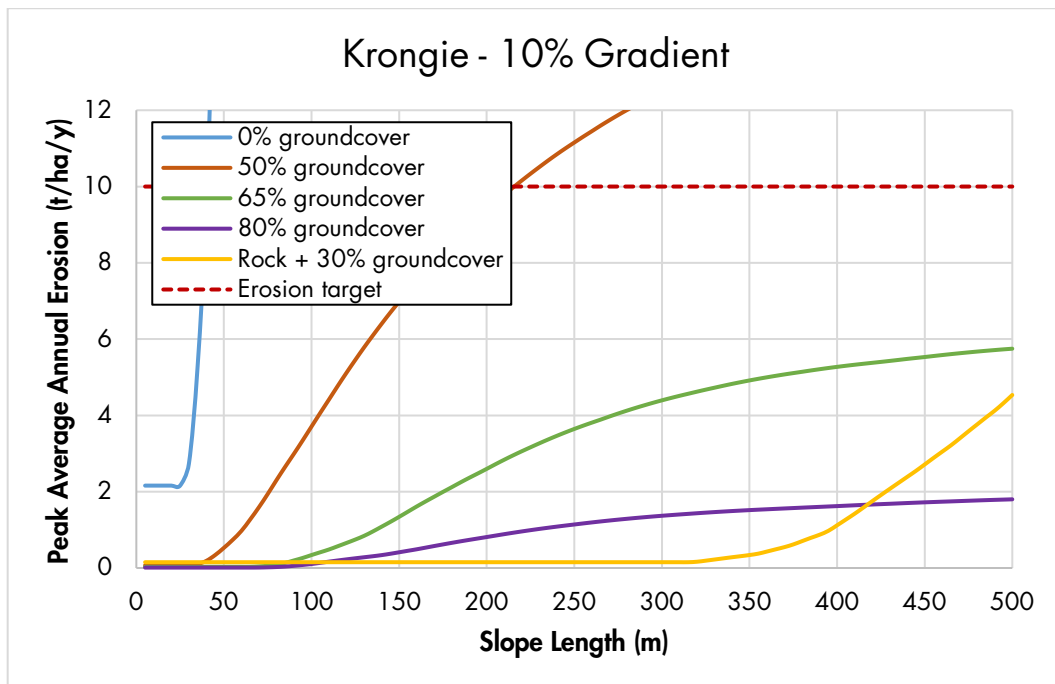
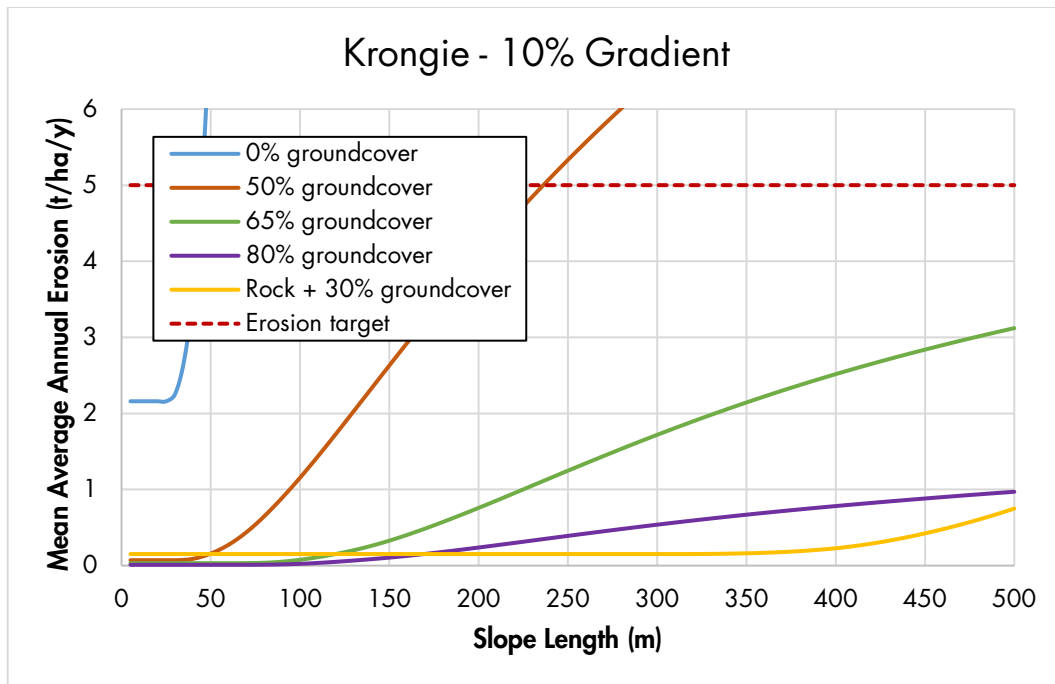


**Figure C-7:** Mean (top) and peak (bottom) average annual erosion for a 20% gradient, 500m long slope sheeted with Taurus-Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover. Represented by the Taurus-Krongie modelling results.

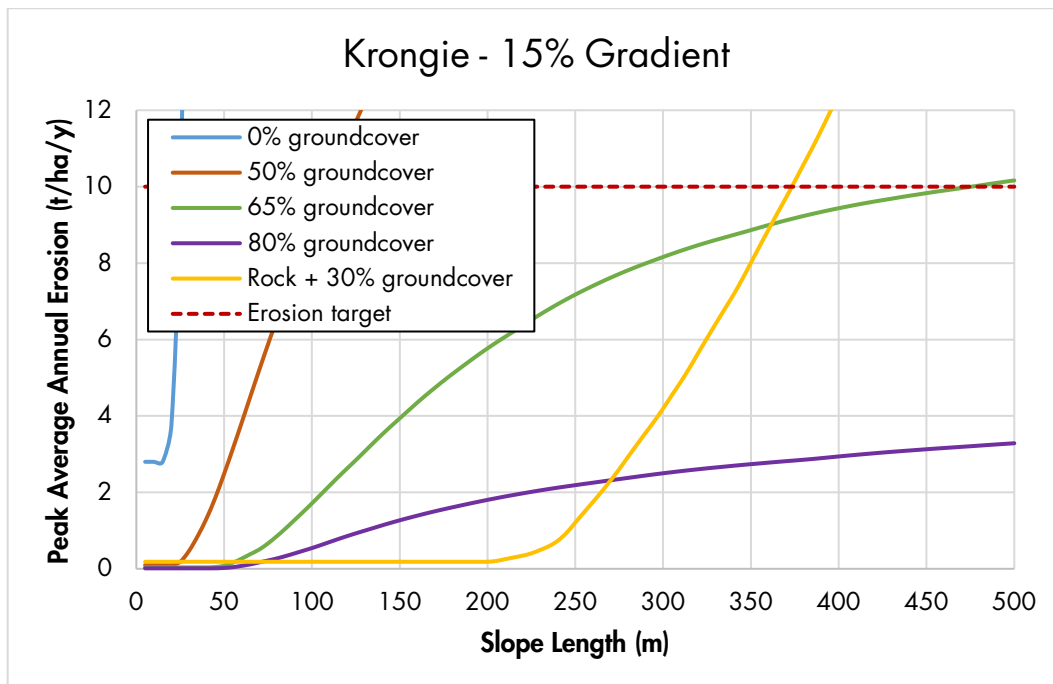
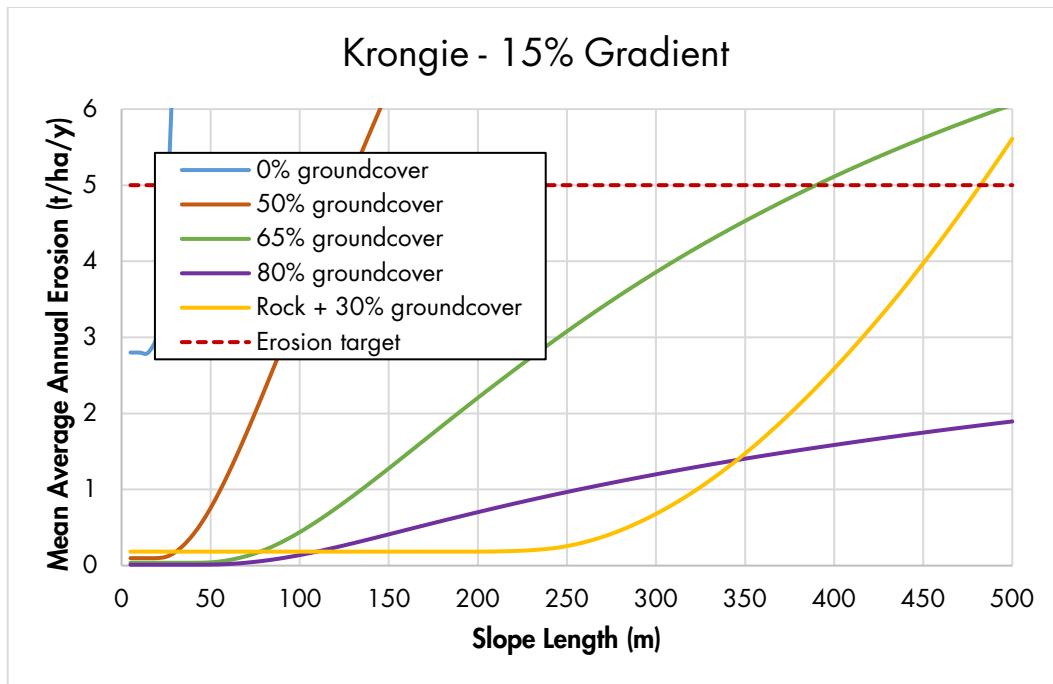




**Figure C-8:** Mean (top) and peak (bottom) average annual erosion for a 25% gradient, 500m long slope sheeted with Taurus-Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover. Represented by the Taurus-Krongie modelling results.

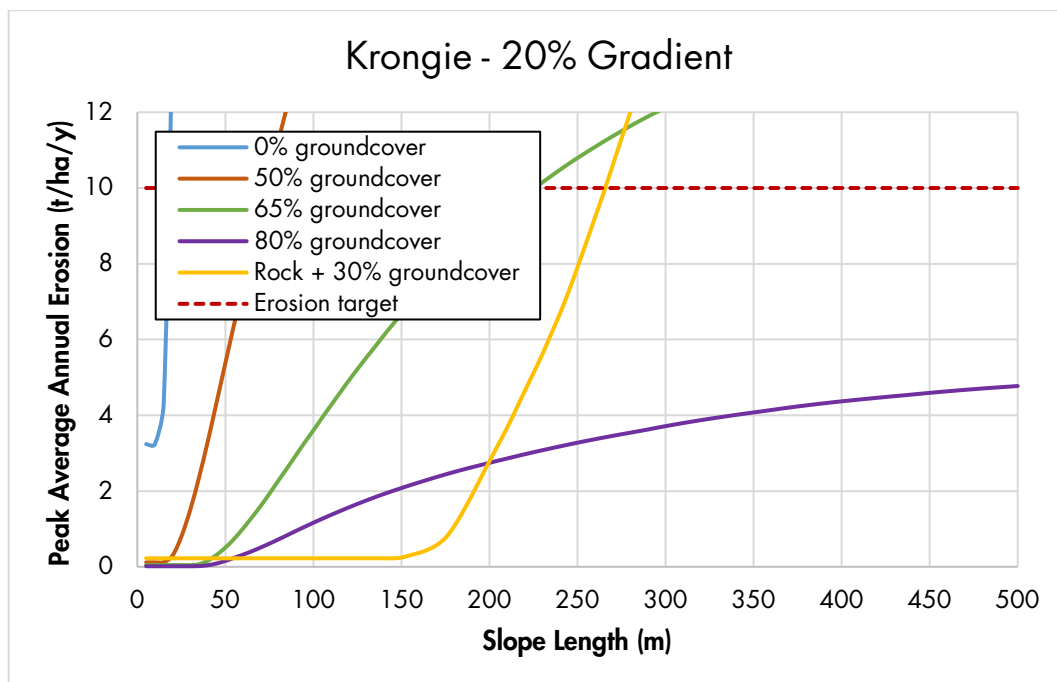
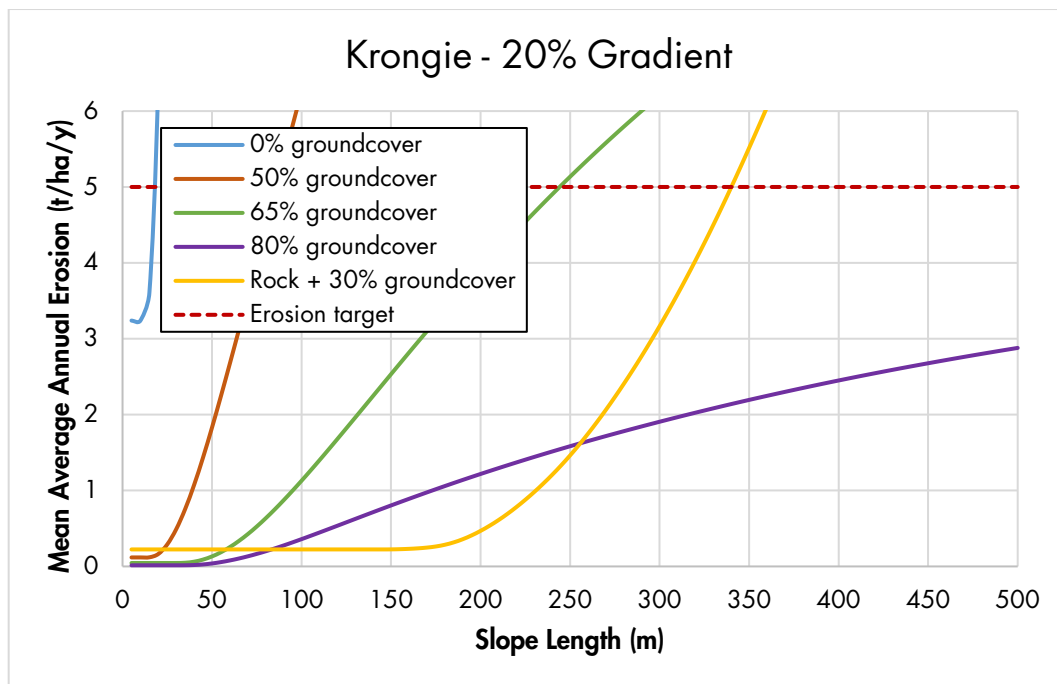


**Figure C-9:** Mean (top) and peak (bottom) average annual erosion for a 10% gradient, 500m long slope sheeted with Krongie soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

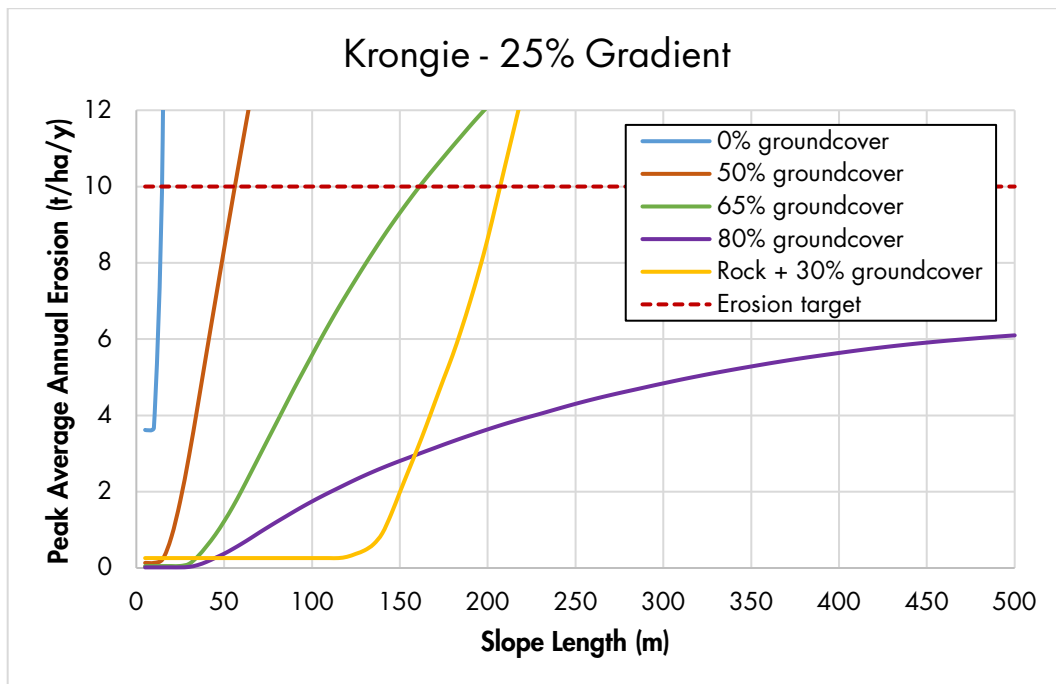
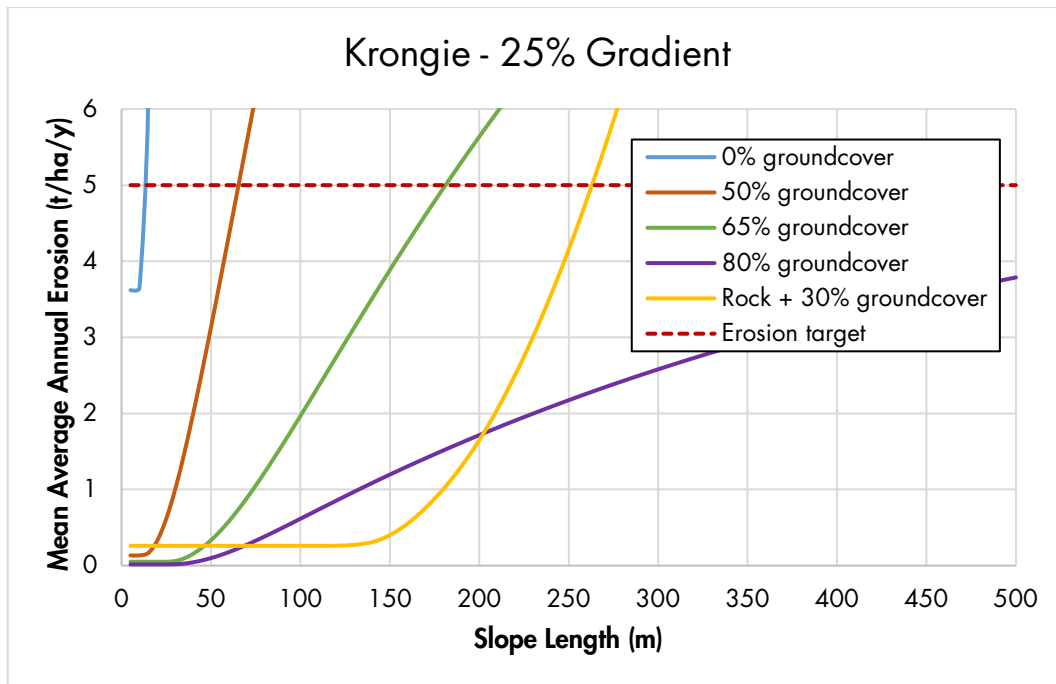


**Figure C-10:** Mean (top) and peak (bottom) average annual erosion for a 15% gradient, 500m long slope sheeted with Krongie soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

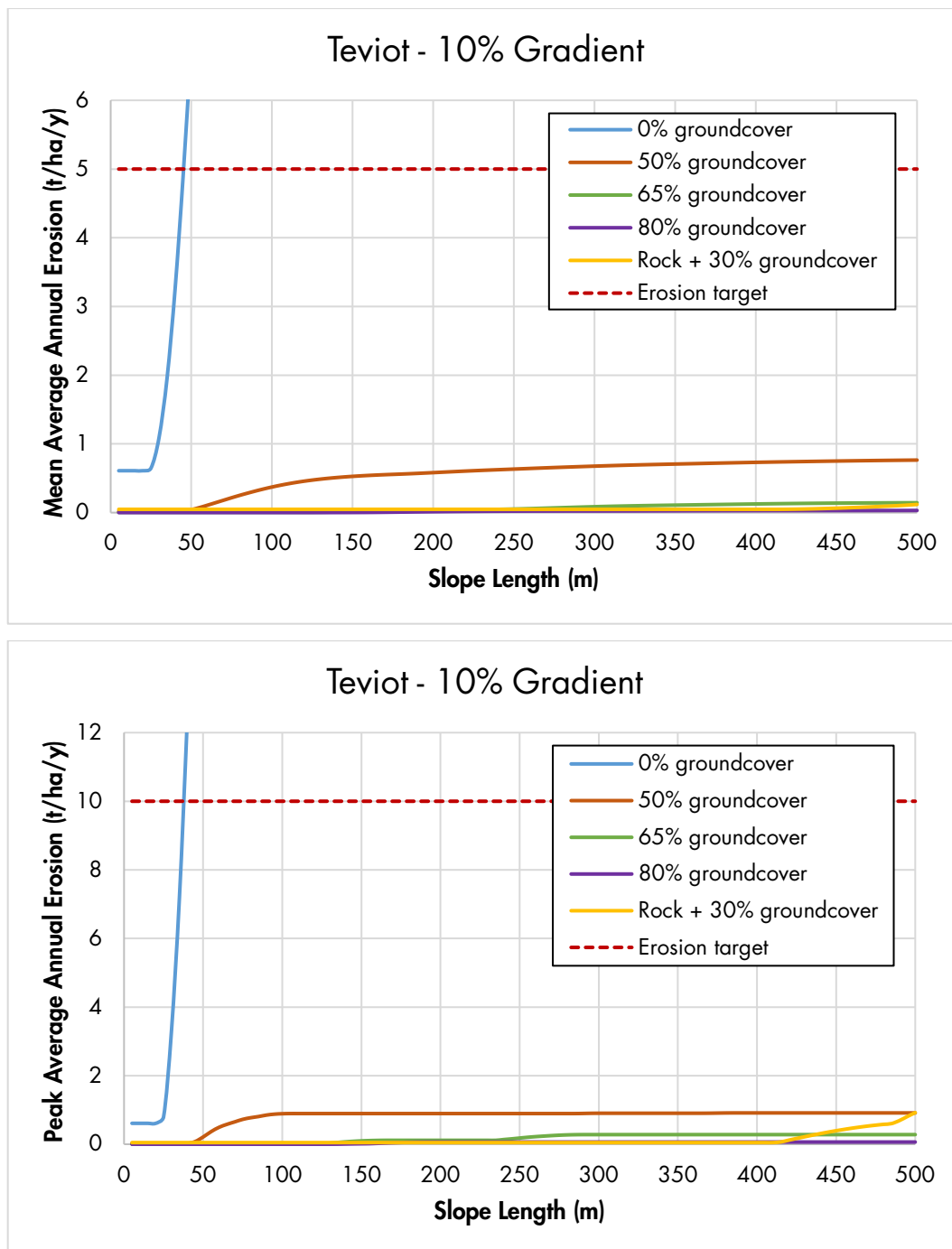




**Figure C-11:** Mean (top) and peak (bottom) average annual erosion for a 20% gradient, 500m long slope sheeted with Krongie soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

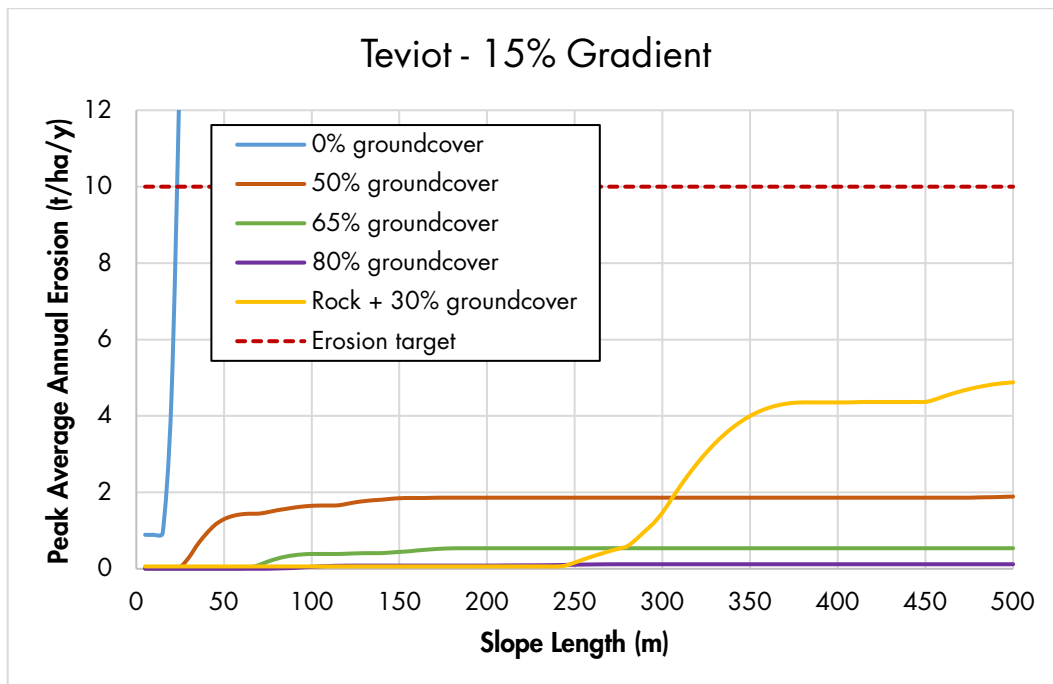
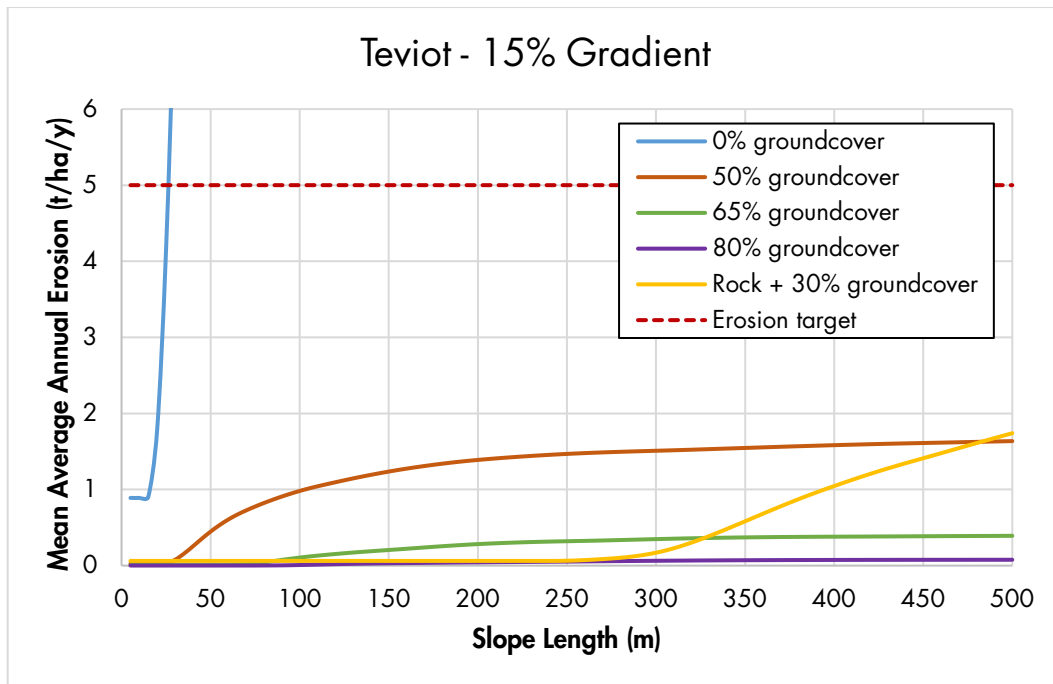


**Figure C-12:** Mean (top) and peak (bottom) average annual erosion for a 25% gradient, 500m long slope sheeted with Krongie soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

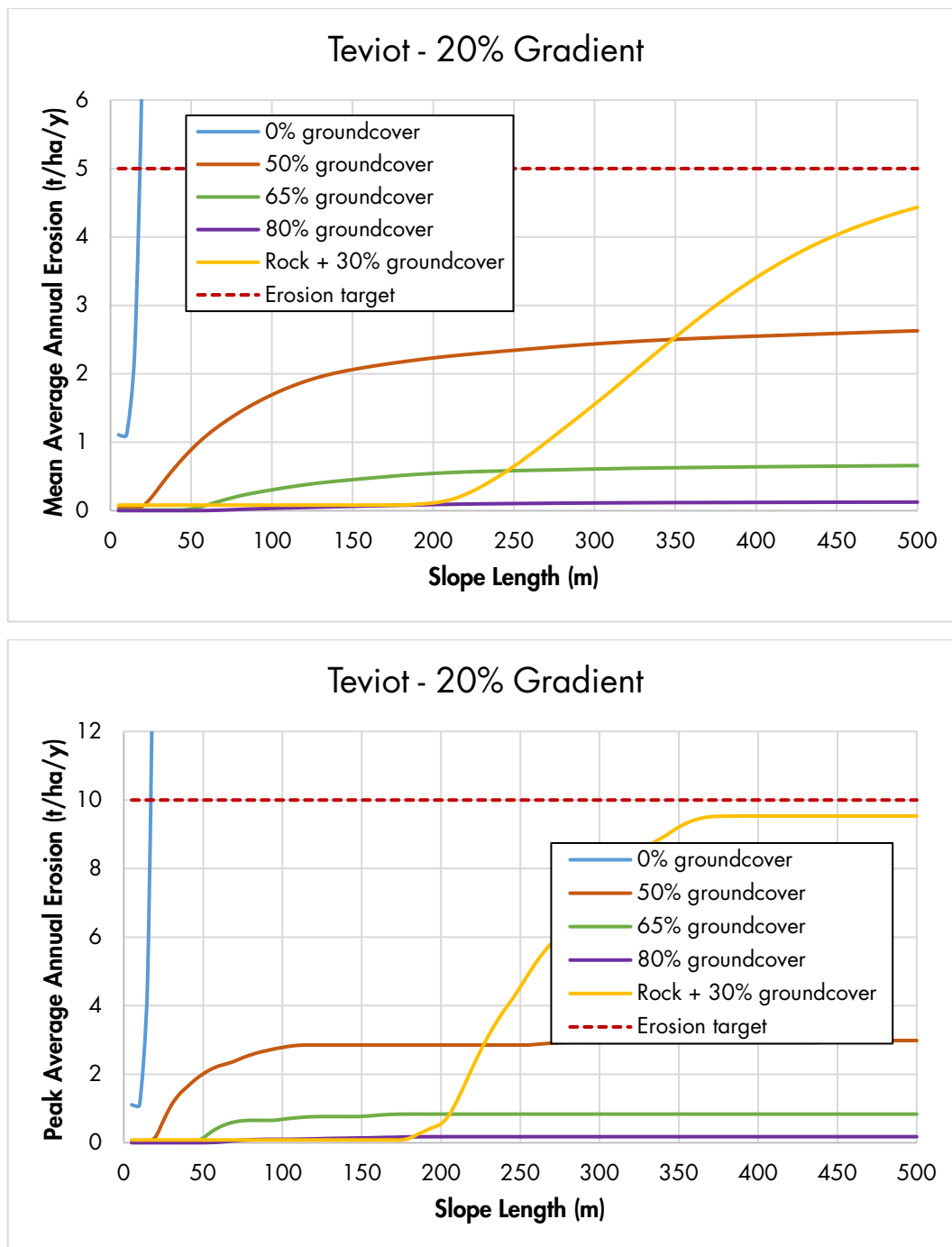


**Figure C-13:** Mean (top) and peak (bottom) average annual erosion for a 10% gradient, 500m long slope sheeted with Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

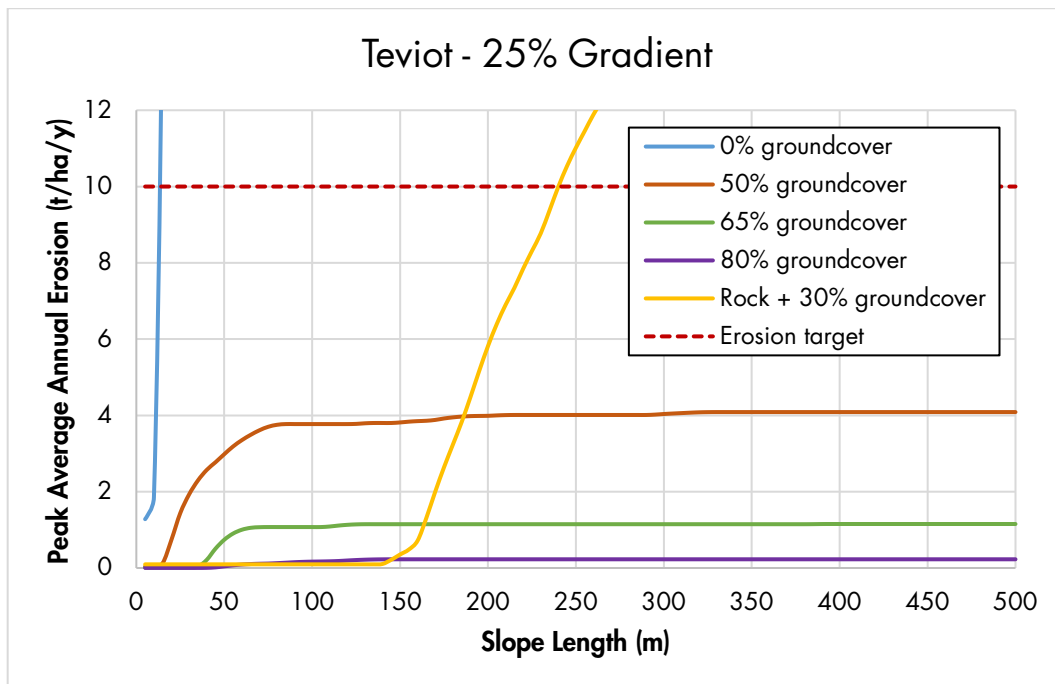
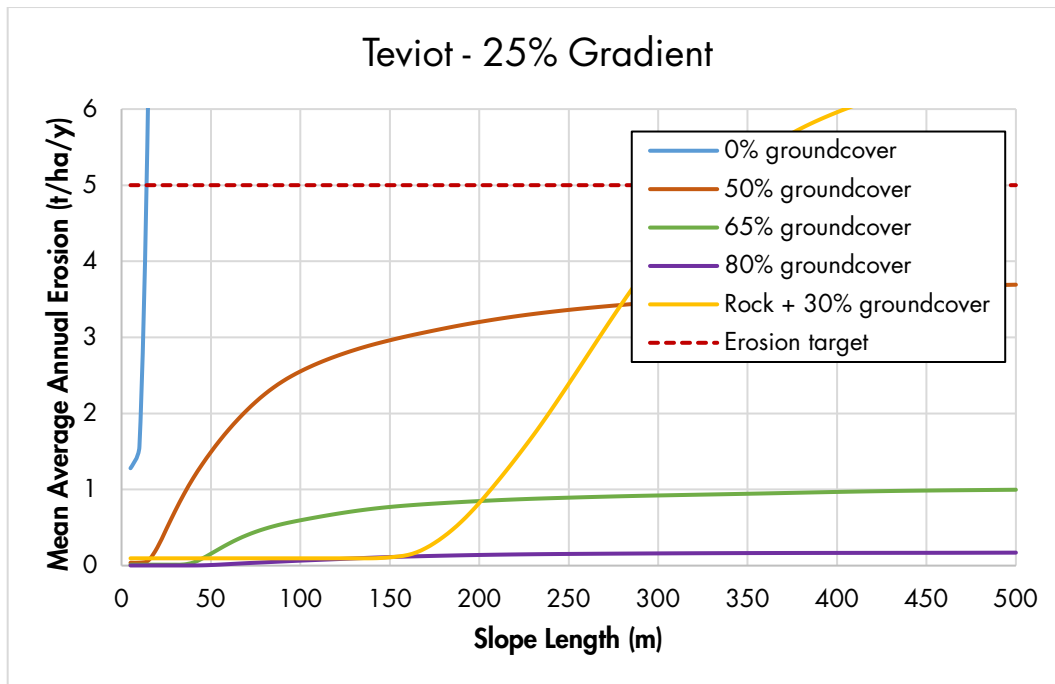




**Figure C-14:** Mean (top) and peak (bottom) average annual erosion for a 15% gradient, 500m long slope sheeted with Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

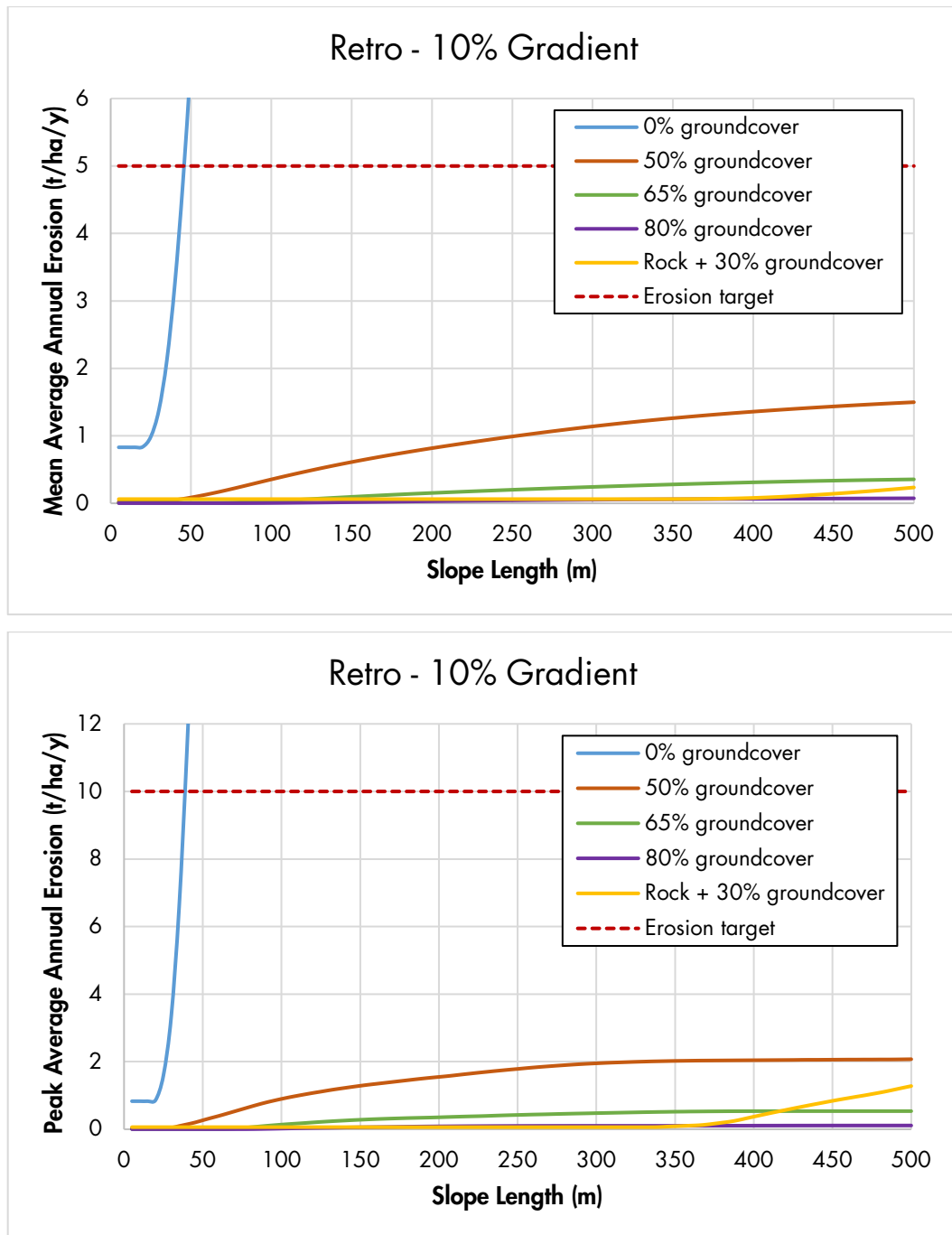


**Figure C-15:** Mean (top) and peak (bottom) average annual erosion for a 20% gradient, 500m long slope sheeted with Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

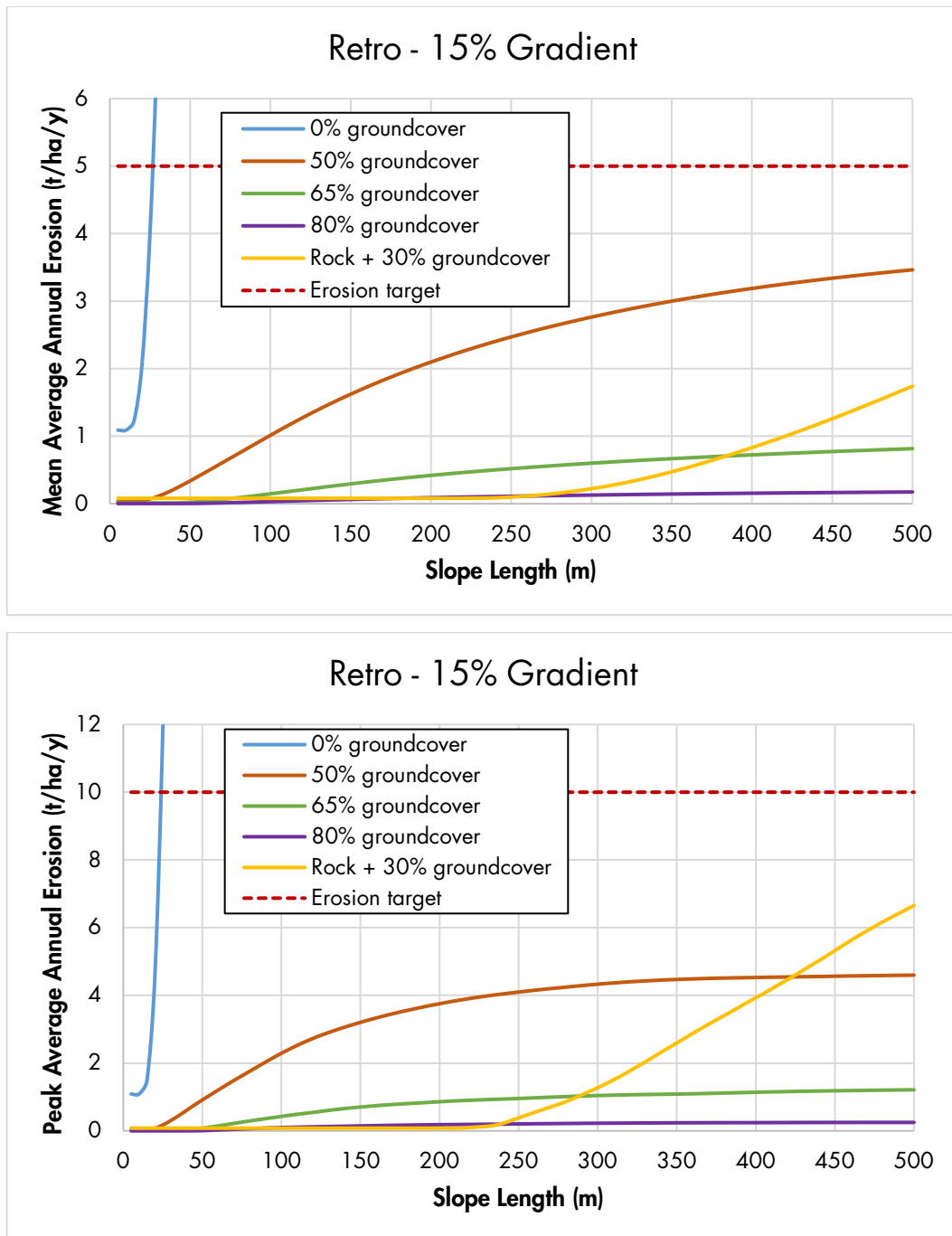


**Figure C-16:** Mean (top) and peak (bottom) average annual erosion for a 25% gradient, 500m long slope sheeted with Teviot soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.

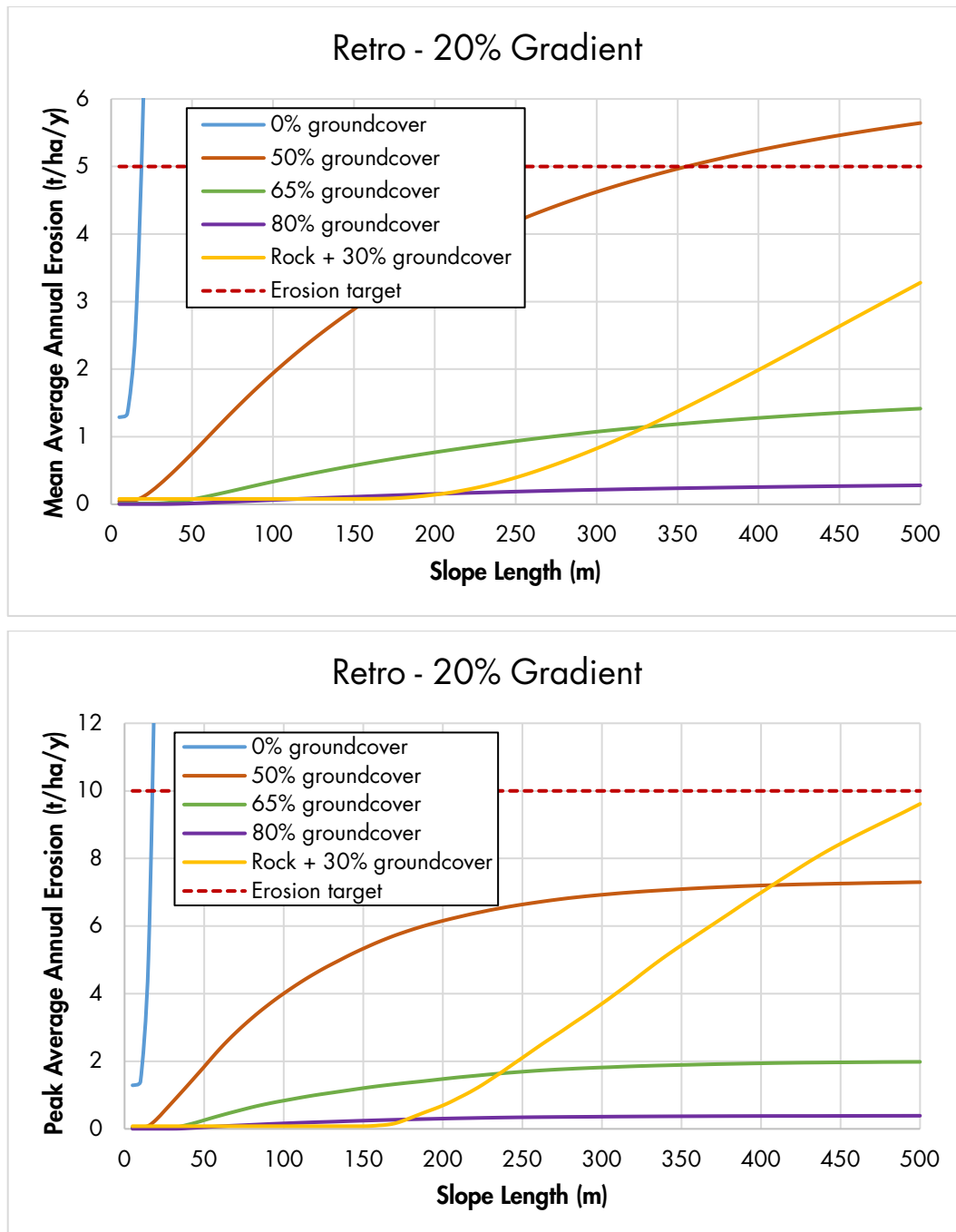




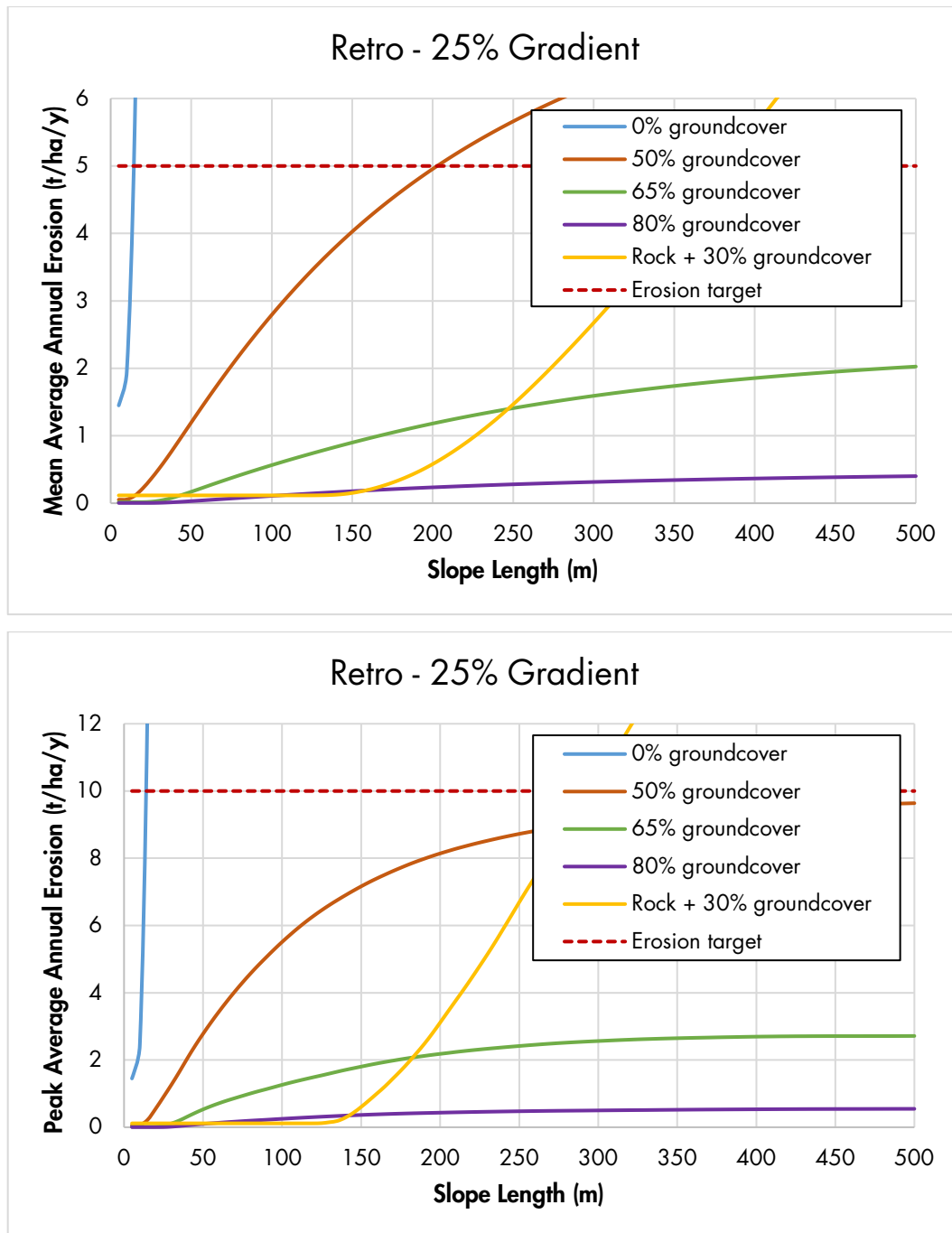
**Figure C-17:** Mean (top) and peak (bottom) average annual erosion for a 10% gradient, 500m long slope sheeted with Retro soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.



**Figure C-18:** Mean (top) and peak (bottom) average annual erosion for a 15% gradient, 500m long slope sheeted with Retro soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.



**Figure C-19:** Mean (top) and peak (bottom) average annual erosion for a 20% gradient, 500m long slope sheeted with Retro soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.



**Figure C-20:** Mean (top) and peak (bottom) average annual erosion for a 25% gradient, 500m long slope sheeted with Retro soil and supporting a 0%, 50%, 65% and 80% groundcover, and rock armour with 30% groundcover.



## APPENDIX D: SIBERIA VISUALISATIONS

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**Figure D-1:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 50 years of simulation – SW landform.





**Figure D-2:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 100 years of simulation – SW landform.





|                                                                                     |                                                                                                                       |                           |                      |                                     |                 |                              |                    |
|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|-------------------------------------|-----------------|------------------------------|--------------------|
| <b>Title:</b>                                                                       | Long-term material movement for SW landform at 200 years of simulation, using Taurus-Teviot soil with 65% groundcover |                           |                      | <div><div>N</div><div>↑</div></div> |                 | <b>Material Movement (m)</b> |                    |
| <b>Project:</b>                                                                     | Isaac Downs Extension<br>Rehabilitated Landform Study                                                                 | <b>Coordinate System:</b> | MGA Zone 55<br>GDA94 | <div><div></div></div>              | Erosion<br><0.3 | <div><div></div></div>       | Deposition<br>>0.3 |
|  |                                                                                                                       | <b>Model:</b>             | SIBERIA              | <div><div></div></div>              | ±0.3            | <div><div></div></div>       | Excluded           |

**Figure D-3:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 200 years of simulation – SW landform.





**Figure D-4:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 300 years of simulation – SW landform.





|                 |                                                                                                                                                                                                            |                           |                      |                                                                                       |                 |                                                                                                          |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|---------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------|
| <b>Title:</b>   | Long-term material movement for Main landform at 50 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                           |                      |                                                                                       | N<br>↑          | <b>Material Movement (m)</b>                                                                             |
| <b>Project:</b> | Isaac Downs Extension<br>Rehabilitated Landform Study                                                                                                                                                      | <b>Coordinate System:</b> | MGA Zone 55<br>GDA94 |  | Erosion<br><0.3 |  Deposition<br>>0.3 |
|                 |                                                                                                                                                                                                            | <b>Model:</b>             | SIBERIA              |  | ±0.3            |  Excluded           |



**Figure D-5:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 50 years of simulation – main landform.





|                 |                                                                                                                                                                                                             |                           |                      |                                           |                                              |                              |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|-------------------------------------------|----------------------------------------------|------------------------------|
| <b>Title:</b>   | Long-term material movement for Main landform at 100 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                           |                      |                                           | <div>N<br/>↑</div>                           | <b>Material Movement (m)</b> |
| <b>Project:</b> | Isaac Downs Extension<br>Rehabilitated Landform Study                                                                                                                                                       | <b>Coordinate System:</b> | MGA Zone 55<br>GDA94 | <div><div></div>Erosion<br/>&lt;0.3</div> | <div><div></div>Deposition<br/>&gt;0.3</div> |                              |
|                 |                                                                                                                                                                                                             | <b>Model:</b>             | SIBERIA              | <div><div></div>±0.3</div>                | <div><div></div>Excluded</div>               |                              |



**Figure D-6:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 100 years of simulation – main landform.





|                                                                                                                                                                                                                           |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |  |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Title:</b> Long-term material movement for Main landform at 200 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |  | <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> <b>Coordinate System:</b> MGA Zone 55 GDA94<br/><b>Model:</b> SIBERIA </div> <div style="display: flex; flex-direction: column; align-items: center;"> <div style="margin-bottom: 5px;">N<br/>↑</div> <div style="display: flex; gap: 5px;"> <div style="width: 15px; height: 15px; background-color: red; border: 1px solid black;"></div> Erosion &lt;0.3<br/>±0.3 </div> <div style="display: flex; gap: 5px;"> <div style="width: 15px; height: 15px; background-color: blue; border: 1px solid black;"></div> Deposition &gt;0.3<br/>Excluded </div> </div> </div> |  |
| <b>Project:</b> Isaac Downs Extension Rehabilitated Landform Study                                                                                                                                                        |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |  |

**Figure D-7:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 200 years of simulation – main landform.





|                 |                                                                                                                                                                                                             |                           |                      |                                                                                       |                 |                                                                                                          |
|-----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|---------------------------------------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------------------------|
| <b>Title:</b>   | Long-term material movement for Main landform at 300 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                           |                      |                                                                                       | N<br>↑          | <b>Material Movement (m)</b>                                                                             |
| <b>Project:</b> | Isaac Downs Extension<br>Rehabilitated Landform Study                                                                                                                                                       | <b>Coordinate System:</b> | MGA Zone 55<br>GDA94 |  | Erosion<br><0.3 |  Deposition<br>>0.3 |
|                 |                                                                                                                                                                                                             | <b>Model:</b>             | SIBERIA              |  | ±0.3            |  Excluded           |



**Figure D-8:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 300 years of simulation – main landform.





|                 |                                                                                                                |                           |                      |                                     |                 |                              |                    |
|-----------------|----------------------------------------------------------------------------------------------------------------|---------------------------|----------------------|-------------------------------------|-----------------|------------------------------|--------------------|
| <b>Title:</b>   | Long-term material movement for East landform at 50 years of simulation, using Retro soil with 65% groundcover |                           |                      | <div><div>N</div><div>↑</div></div> |                 | <b>Material Movement (m)</b> |                    |
| <b>Project:</b> | Isaac Downs Extension<br>Rehabilitated Landform Study                                                          | <b>Coordinate System:</b> | MGA Zone 55<br>GDA94 | <div><div></div></div>              | Erosion<br><0.3 | <div><div></div></div>       | Deposition<br>>0.3 |
|                 |                                                                                                                | <b>Model:</b>             | SIBERIA              | <div><div></div></div>              | ±0.3            | <div><div></div></div>       | Excluded           |

**Figure D-9:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 50 years of simulation – East landform.



|                 |                                                                                                                 |                           |        |                              |                      |
|-----------------|-----------------------------------------------------------------------------------------------------------------|---------------------------|--------|------------------------------|----------------------|
| <b>Title:</b>   | Long-term material movement for East landform at 100 years of simulation, using Retro soil with 65% groundcover |                           | N<br>↑ | <b>Material Movement (m)</b> |                      |
| <b>Project:</b> | Isaac Downs Extension Rehabilitated Landform Study                                                              | <b>Coordinate System:</b> |        | Red <0.3 Erosion             | Blue >0.3 Deposition |
| <b>Model:</b>   | SIBERIA                                                                                                         |                           |        | Green ±0.3                   | Grey Excluded        |

**Figure D-10:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 100 years of simulation – East landform.





**Figure D-11:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 200 years of simulation – East landform.





|                                                                                                                               |                           |                              |                 |
|-------------------------------------------------------------------------------------------------------------------------------|---------------------------|------------------------------|-----------------|
| <b>Title:</b> Long-term material movement for East landform at 300 years of simulation, using Retro soil with 65% groundcover |                           | <b>Material Movement (m)</b> |                 |
| <b>Project:</b> Isaac Downs Extension Rehabilitated Landform Study                                                            | <b>Coordinate System:</b> | MGA Zone 55                  | Erosion <0.3    |
|                                                                                                                               |                           | GDA94                        | Deposition >0.3 |
|                                                                                                                               | <b>Model:</b>             | SIBERIA                      | ±0.3            |
|                                                                                                                               |                           |                              | Excluded        |

**Figure D-12:** Predicted material movement for the proposed Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 300 years of simulation – East landform.





|                                                                                                                                |                                                                      |                                                                                                                                                                 |  |
|--------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|--|
| <b>Title:</b> Long-term erosion rates for SW landform at 50 years of simulation, using Taurus-Teviot soil with 65% groundcover |                                                                      | <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;">N<br/>↑</div> <div> <b>Long-term Erosion Rate</b><br/>(t/ha/y) </div> </div> |  |
| <b>Project:</b> Isaac Downs Extension Rehabilitated Landform Study                                                             | <b>Coordinate System:</b> MGA Zone 55 GDA94<br><b>Model:</b> SIBERIA |                                                                                                                                                                 |  |
|                                                                                                                                |                                                                      |                                                                                                                                                                 |  |

**Figure D-13:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 50 years of simulation – SW landform.





|                                                                                     |                                                                                                                   |                           |                                                                                       |                                                                                             |                                                                                              |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| <b>Title:</b>                                                                       | Long-term erosion rates for SW landform at 100 years of simulation, using Taurus-Teviot soil with 65% groundcover |                           |  | <b>Long-term Erosion Rate (t/ha/y)</b>                                                      |                                                                                              |
| <b>Project:</b>                                                                     | Isaac Downs Extension Rehabilitated Landform Study                                                                | <b>Coordinate System:</b> | MGA Zone 55 GDA94                                                                     |  <5    |  7.5-10 |
|  |                                                                                                                   | <b>Model:</b>             | SIBERIA                                                                               |  5-7.5 |  >10    |

**Figure D-14:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 100 years of simulation – SW landform.





|                                                                                     |                                                                                                                   |                           |                                                                                       |                                                                                             |                                                                                              |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| <b>Title:</b>                                                                       | Long-term erosion rates for SW landform at 200 years of simulation, using Taurus-Teviot soil with 65% groundcover |                           |  | <b>Long-term Erosion Rate (t/ha/y)</b>                                                      |                                                                                              |
| <b>Project:</b>                                                                     | Isaac Downs Extension Rehabilitated Landform Study                                                                | <b>Coordinate System:</b> | MGA Zone 55 GDA94                                                                     |  <5    |  7.5-10 |
|  |                                                                                                                   | <b>Model:</b>             | SIBERIA                                                                               |  5-7.5 |  >10    |

**Figure D-15:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 200 years of simulation – SW landform.





|                                                                                     |                                                                                                                   |                           |                                                                                       |                                                                                             |                                                                                              |
|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|
| <b>Title:</b>                                                                       | Long-term erosion rates for SW landform at 300 years of simulation, using Taurus-Teviot soil with 65% groundcover |                           |  | <b>Long-term Erosion Rate (t/ha/y)</b>                                                      |                                                                                              |
| <b>Project:</b>                                                                     | Isaac Downs Extension Rehabilitated Landform Study                                                                | <b>Coordinate System:</b> | MGA Zone 55 GDA94                                                                     |  <5    |  7.5-10 |
|  |                                                                                                                   | <b>Model:</b>             | SIBERIA                                                                               |  5-7.5 |  >10    |

**Figure D-16:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus-Teviot) supporting 65% groundcover after 300 years of simulation – SW landform.





|                                                                                                                                                                                                                      |                                             |        |                                        |        |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|--------|----------------------------------------|--------|
| <b>Title:</b> Long-term erosion rates for Main landform at 50 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                                             | N<br>↑ | <b>Long-term Erosion Rate (t/ha/y)</b> |        |
| <b>Project:</b> Isaac Downs Extension Rehabilitated Landform Study                                                                                                                                                   | <b>Coordinate System:</b> MGA Zone 55 GDA94 |        | <5                                     | 7.5-10 |
|                                                                                                                                                                                                                      | <b>Model:</b> SIBERIA                       |        | 5-7.5                                  | >10    |

**Figure D-17:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 50 years of simulation – Main landform.





|                                                                                                                                                                                                                       |                                             |                                                |                                        |        |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|------------------------------------------------|----------------------------------------|--------|
| <b>Title:</b> Long-term erosion rates for Main landform at 100 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                                             | <div style="text-align: center;">N<br/>↑</div> | <b>Long-term Erosion Rate (t/ha/y)</b> |        |
| <b>Project:</b> Isaac Downs Extension Rehabilitated Landform Study                                                                                                                                                    | <b>Coordinate System:</b> MGA Zone 55 GDA94 |                                                |                                        | <5     |
|                                                                                                                                                                                                                       | <b>Model:</b> SIBERIA                       |                                                |                                        | 5-7.5  |
|                                                                                                                                                                                                                       |                                             |                                                |                                        | 7.5-10 |
|                                                                                                                                                                                                                       |                                             |                                                |                                        | >10    |

**Figure D-18:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 100 years of simulation – Main landform.





|                                                                                                                                                                                                                       |                                             |        |                                        |        |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------|--------|----------------------------------------|--------|
| <b>Title:</b> Long-term erosion rates for Main landform at 200 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                                             | N<br>↑ | <b>Long-term Erosion Rate (t/ha/y)</b> |        |
| <b>Project:</b> Isaac Downs Extension Rehabilitated Landform Study                                                                                                                                                    | <b>Coordinate System:</b> MGA Zone 55 GDA94 |        | <5                                     | 7.5-10 |
|                                                                                                                                                                                                                       | <b>Model:</b> SIBERIA                       |        | 5-7.5                                  | >10    |

**Figure D-19:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 200 years of simulation – Main landform.





|                 |                                                                                                                                                                                                         |                           |                   |                                                                                                                                                                                                                                                                                                                                                                                                                               |
|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Title:</b>   | Long-term erosion rates for Main landform at 300 years of simulation, using Taurus soil with 65% groundcover on all slopes except 25% low wall that used rock-armoured Taurus soil with 30% groundcover |                           | N<br>↑            | <b>Long-term Erosion Rate (t/ha/y)</b>                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Project:</b> | Isaac Downs Extension Rehabilitated Landform Study                                                                                                                                                      | <b>Coordinate System:</b> | MGA Zone 55 GDA94 | <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <div style="width: 20px; height: 20px; background-color: #90EE90; border: 1px solid black; margin: 0 auto;"></div> <div>&lt;5</div> </div> <div style="text-align: center;"> <div style="width: 20px; height: 20px; background-color: #FFA500; border: 1px solid black; margin: 0 auto;"></div> <div>7.5-10</div> </div> </div> |
|                 |                                                                                                                                                                                                         | <b>Model:</b>             | SIBERIA           | <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <div style="width: 20px; height: 20px; background-color: #FFFF00; border: 1px solid black; margin: 0 auto;"></div> <div>5-7.5</div> </div> <div style="text-align: center;"> <div style="width: 20px; height: 20px; background-color: #800080; border: 1px solid black; margin: 0 auto;"></div> <div>&gt;10</div> </div> </div> |

**Figure D-20:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Taurus) supporting 65% groundcover after 300 years of simulation – Main landform.





**Figure D-21:** Predicted average annual erosion for the proposed Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 50 years of simulation – East landform.





**Figure D-22:** Predicted average annual erosion for the proposed The Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 100 years of simulation – East landform.





**Figure D-23:** Predicted average annual erosion for the proposed The Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 200 years of simulation – East landform.





**Figure D-24:** Predicted average annual erosion for the proposed The Project rehabilitation landform when sheeted with topsoil (Retro) supporting 65% groundcover after 300 years of simulation – East landform.

## APPENDIX E: SOIL BALANCE

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**Table E-1: Soil balance for the Project.**

| Isaac Dams Extension Topsoil Balance |                                           |                        |                     |                   |                    |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      |         |         |     |     |   |
|--------------------------------------|-------------------------------------------|------------------------|---------------------|-------------------|--------------------|-------------------|-----------------------------------|--------------------|-----------------------|----------|---------|---------------------|----------|---------|----------------------|----------|---------|---------------------|----------|---------|---------------------|----------|---------|----------------------|----------|---------|-----------------------------|----------|---------|----------------------|----------|---------|----------------------------|----------------------------------|-----------------------|----------------------|---------|---------|-----|-----|---|
| Polygon ID                           | Description                               | Total Planar Area (ha) | Area - Arcurus (ha) | Area - Davey (ha) | Area - Kronge (ha) | Area - Loxor (ha) | Area - Taurus-Teviot (ha) Complex | Area - Teviot (ha) | Volume - Arcurus (m³) |          |         | Volume - Davey (m³) |          |         | Volume - Kronge (m³) |          |         | Volume - Loxor (m³) |          |         | Volume - Retro (m³) |          |         | Volume - Taurus (m³) |          |         | Volume - Taurus-Teviot (m³) |          |         | Volume - Teviot (m³) |          |         | Total SD Surface Area (ha) | Rehab Soil Applied Flag (Yes/No) | Topsoil Thickness (m) | Volume Required (m³) |         |         |     |     |   |
|                                      | Thickness (m)                             |                        |                     |                   |                    |                   |                                   |                    | Good Quality          | Marginal | Subsoil | Good Quality        | Marginal | Subsoil | Good Quality         | Marginal | Subsoil | Good Quality        | Marginal | Subsoil | Good Quality        | Marginal | Subsoil | Good Quality         | Marginal | Subsoil | Good Quality                | Marginal | Subsoil | Good Quality         | Marginal | Subsoil |                            |                                  |                       |                      |         |         |     |     |   |
| RA101                                | Cornock Gully Diversion (Grazing)         | 34.6                   |                     | 4.4               | 9.3                |                   | 4.5                               | 0.2                |                       |          |         | 18.2                |          |         |                      |          |         | 27,927              | 32,582   | 32,582  |                     |          |         | 6,756                | 4,504    | 47,292  | 875                         | 875      |         |                      | 32,336   | 64,672  | 64,672                     | 35.0                             | 0                     | 0.5                  | 0       |         |     |     |   |
| RA102                                | Waste Rock Dump (Grazing)                 | 26.0                   |                     |                   |                    |                   | 20.0                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 181,100               |                      | 0.5     | 0       |     |     |   |
| RA103                                | Waste Rock Dump (Grazing)                 | 29.3                   |                     |                   |                    |                   | 18.7                              | 11.6               |                       |          |         |                     |          |         |                      |          |         |                     | 50,075   | 50,075  |                     |          |         |                      |          |         | 34,797                      | 34,797   |         |                      | 28.4     | 0.5     | 0.5                        | 141,800                          |                       | 0.5                  | 0       |         |     |     |   |
| RA104                                | Waste Rock Dump (Grazing)                 | 38.4                   |                     |                   |                    |                   | 28.5                              | 4.7                |                       |          |         |                     |          |         |                      |          |         |                     | 84,555   | 84,555  |                     |          |         |                      |          |         | 16,497                      | 16,497   |         |                      | 9,384    | 18,768  | 18,768                     | 38.8                             | 1                     | 0.5                  | 193,985 |         | 0.5 | 0   |   |
| RA104                                | Waste Rock Dump (Grazing)                 | 114.8                  |                     |                   | 112.2              |                   | 2.2                               | 0.0                | 0.3                   |          |         |                     |          |         |                      |          |         |                     | 336,660  | 392,770 | 392,770             |          |         |                      | 3,320    | 2,220   | 23,310                      | 0        | 0       |                      |          | 568     | 1,336                      | 1,336                            | 114.8                 | 1                    | 0.5     | 574,000 |     | 0.5 | 0 |
| RA105                                | Waste Rock Dump (Grazing)                 | 24.8                   |                     |                   |                    |                   | 24.8                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 125,350               |                      | 0.5     | 0       |     |     |   |
| RA106                                | Waste Rock Dump (Grazing)                 | 24.8                   |                     |                   |                    |                   | 19.0                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 125,350               |                      | 0.5     | 0       |     |     |   |
| RA107                                | Waste Rock Dump (Grazing)                 | 121.8                  |                     |                   | 20.4               |                   | 49.3                              | 38.1               | 14.1                  |          |         |                     |          |         |                      |          |         |                     | 61,263   | 71,474  | 71,474              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 609,200               |                      | 0.5     | 0       |     |     |   |
| RA108                                | Waste Rock Dump (Grazing)                 | 14.7                   |                     |                   |                    |                   |                                   |                    | 14.7                  |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 73,650               |         | 0.5     | 0   |     |   |
| RA109                                | Waste Rock Dump (Grazing)                 | 13.3                   |                     |                   |                    |                   | 9.8                               | 2.7                | 0.8                   |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 68,548                |                      | 0.5     | 0       |     |     |   |
| RA110                                | Waste Rock Dump (Grazing)                 | 38.1                   |                     |                   |                    |                   | 25.0                              | 11.6               | 1.4                   |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 190,390               |                      | 0.5     | 0       |     |     |   |
| RA111                                | Waste Rock Dump (Grazing)                 | 39.4                   |                     | 0.4               |                    |                   | 48.5                              | 50.4               |                       |          |         |                     |          |         |                      |          |         |                     | 1,227    | 1,432   | 1,432               |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 501,742               |                      | 0.5     | 0       |     |     |   |
| RA112                                | Waste Rock Dump (Grazing)                 | 19.0                   |                     |                   |                    |                   | 0.9                               | 18.1               |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 95,000               |         | 0.5     | 0   |     |   |
| RA113                                | Waste Rock Dump (Grazing)                 | 14.8                   |                     |                   |                    |                   | 18.6                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 84,050               |         | 0.5     | 0   |     |   |
| RA114                                | Waste Rock Dump (Grazing)                 | 13.0                   |                     |                   |                    |                   | 13.0                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 65,700               |         | 0.5     | 0   |     |   |
| RA115                                | Waste Rock Dump (Grazing)                 | 19.3                   |                     |                   | 1.1                |                   | 18.3                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         | 4,272                       | 4,272    |         |                      |          |         |                            |                                  |                       | 97,650               |         | 0.5     | 0   |     |   |
| RA116                                | Waste Rock Dump (Grazing)                 | 4.8                    |                     |                   |                    |                   | 4.8                               |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 23,790               |         | 0.5     | 0   |     |   |
| RA117                                | Waste Rock Dump (Grazing)                 | 7.1                    |                     |                   |                    |                   | 7.1                               |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 35,380               |         | 0.5     | 0   |     |   |
| RA118                                | Waste Rock Dump (Grazing)                 | 4.9                    |                     |                   | 3.1                |                   | 1.8                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 9,234    | 10,773  | 10,773              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 49                    | 0.5                  | 0.5     | 24,435  |     | 0.5 | 0 |
| RA119                                | Waste Rock Dump (Grazing)                 | 29.5                   |                     |                   | 6.7                |                   | 22.8                              |                    |                       |          |         |                     |          |         |                      |          |         |                     | 20,064   | 23,408  | 23,408              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 147,600              |         | 0.5     | 0   |     |   |
| RA120                                | Waste Rock Dump (Grazing)                 | 12.7                   |                     |                   |                    |                   | 12.7                              |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 64,150               |         | 0.5     | 0   |     |   |
| RA121                                | Waste Rock Dump (Grazing)                 | 21.1                   |                     |                   | 13.2               |                   | 6.3                               |                    | 17.8                  |          |         |                     |          |         |                      |          |         |                     | 39,606   | 48,312  | 48,312              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 156,850              |         | 0.5     | 0   |     |   |
| RA122                                | Waste Rock Dump (Grazing)                 | 29.4                   |                     |                   |                    |                   | 14.7                              |                    |                       |          |         |                     |          |         |                      |          |         |                     | 44,067   | 51,412  | 51,412              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 147,000              |         | 0.5     | 0   |     |   |
| RA123                                | Waste Rock Dump (Grazing)                 | 24.3                   |                     |                   |                    |                   | 7.9                               | 16.4               |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 122,900              |         | 0.5     | 0   |     |   |
| RA124                                | Waste Rock Dump (Grazing)                 | 9.0                    |                     |                   |                    |                   | 1.1                               | 8.9                |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 45,150               |         | 0.5     | 0   |     |   |
| RA125                                | Waste Rock Dump (Grazing)                 | 15.2                   |                     |                   |                    |                   | 43.7                              | 18.2               | 0.3                   |          |         |                     |          |         |                      |          |         |                     | 311,100  | 331,100 | 331,100             |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 1,114,000            |         | 0.5     | 0   |     |   |
| RA126                                | Highwall Dump                             | 22.6                   |                     | 2.4               | 3.7                |                   | 16.4                              |                    |                       |          |         |                     |          |         |                      |          |         |                     | 36,330   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 112,950              |         | 0.5     | 0   |     |   |
| RA127                                | Waste Rock Dump (Grazing)                 | 9.5                    |                     |                   |                    |                   | 9.4                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 1,545    |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 48,166                |                      | 0.5     | 0       |     |     |   |
| RA128                                | Waste Rock Dump (Grazing)                 | 6.5                    |                     |                   |                    |                   |                                   |                    | 6.5                   |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 32,800               |         | 0.5     | 0   |     |   |
| RA129                                | Waste Rock Dump (Grazing)                 | 9.5                    |                     | 0.0               |                    |                   |                                   |                    | 9.5                   |          |         |                     |          |         |                      |          |         |                     | 33       | 39      | 39                  |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 42,860                |                      | 0.5     | 0       |     |     |   |
| RA130                                | Waste Rock Dump (Open Woodland / Grazing) | 36.9                   |                     |                   |                    |                   | 19.8                              | 17.1               |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 189,800              |         | 0.5     | 0   |     |   |
| RA131                                | Haul Road                                 | 0.4                    |                     | 0.2               | 0.1                |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     | 3,444    |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 1,789                |         | 0.5     | 0   |     |   |
| RA132                                | Boutot Spoil Dump                         | 4.4                    |                     |                   | 3.4                |                   | 0.9                               |                    | 0.1                   |          |         |                     |          |         |                      |          |         |                     | 10,173   | 11,869  | 11,869              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 21,870               |         | 0.5     | 0   |     |   |
| RA133                                | Boutot Spoil Dump                         | 2.0                    |                     |                   |                    |                   | 2.0                               |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 9,786                |         | 0.5     | 0   |     |   |
| RA134                                | MW Dam                                    | 2.8                    |                     | 2.1               |                    |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      | 14,075  |         | 0.5 | 0   |   |
| RA135                                | MW Dam                                    | 6.1                    |                     | 4.1               | 0.3                |                   | 1.7                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 61,835   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 30,650               |         | 0.5     | 0   |     |   |
| RA136                                | Haul Road                                 | 3.6                    |                     |                   | 2.0                | 1.6               |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     | 29,970   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 22,600               |         | 0.5     | 0   |     |   |
| RA137                                | Levee Stage 1                             | 1.5                    |                     |                   |                    |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      | 7,715   |         | 0.5 | 0   |   |
| RA138                                | Haul Road                                 | 5.3                    |                     | 0.8               |                    | 1.0               | 1.4                               |                    |                       |          |         | 2.1                 | 759      | 1,500   | 3,009                |          |         |                     | 2,880    | 3,360   | 3,360               |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 32,556                |                      | 0.5     | 0       |     |     |   |
| RA139                                | Drainage Walkway                          | 8.5                    |                     | 1.9               | 3.9                |                   | 2.7                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 28,230   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 42,300               |         | 0.5     | 0   |     |   |
| RA140                                | Haul Road                                 | 2.6                    |                     |                   |                    |                   |                                   | 2.6                |                       |          |         |                     |          |         |                      |          |         |                     | 11,568   | 13,496  | 13,496              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 12,860                |                      | 0.5     | 0       |     |     |   |
| RA141                                | Haul Road                                 | 15.5                   |                     |                   | 1.0                |                   |                                   | 12.8               | 1.9                   |          |         |                     |          |         |                      |          |         |                     | 15,390   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 77,205               |         | 0.5     | 0   |     |   |
| RA142                                | Haul Road                                 | 0.5                    |                     |                   |                    |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      | 2,635   |         | 0.5 | 0   |   |
| RA143                                | Haul Road                                 | 5.3                    |                     |                   | 0.3                | 2.9               |                                   | 2.1                |                       |          |         |                     |          |         |                      |          |         |                     | 4,263    | 10,210  | 10,210              |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 26,375               |         | 0.5     | 0   |     |   |
| RA144                                | RA1                                       | 35.0                   |                     |                   | 0.1                | 31.0              |                                   | 3.9                | 1.6                   | 0.0      |         |                     |          |         |                      |          |         |                     | 1,671    |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 175,000              |         | 0.5     | 0   |     |   |
| RA145                                | ROM Pad                                   | 1.6                    |                     |                   |                    |                   | 1.6                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 82,943   | 108,434 | 108,434             |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 218,100              |         | 0.5     | 0   |     |   |
| RA146                                | ROM Pad                                   | 4.7                    |                     |                   |                    |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      | 23,685  |         | 0.5 | 0   |   |
| RA147                                | Haul Road                                 | 11.7                   |                     |                   |                    |                   | 3.8                               |                    | 7.9                   |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 58,300               |         | 0.5     | 0   |     |   |
| RA148                                | MW Dam                                    | 6.1                    |                     |                   | 4.1                | 0.3               |                                   | 1.6                | 0.1                   | 0.2      |         |                     |          |         |                      |          |         |                     | 61,935   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 30,350               |         | 0.5     | 0   |     |   |
| RA149                                | Highwall Dump                             | 0.3                    |                     |                   |                    |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      | 1,490   |         | 0.5 | 0   |   |
| RA150                                | Levee Stage 1                             | 1.1                    |                     |                   | 0.8                |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     | 11,715   |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 5,655                |         | 0.5     | 0   |     |   |
| RA151                                | Sed Dam                                   | 1.4                    |                     |                   |                    |                   | 1.3                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 1,509    |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 6,785                |         | 0.5     | 0   |     |   |
| RA152                                | Sed Dam                                   | 0.4                    |                     |                   |                    |                   | 0.4                               |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 1,889                |         | 0.5     | 0   |     |   |
| RA153                                | Sed Dam                                   | 0.5                    |                     |                   | 0.2                |                   |                                   |                    |                       |          |         |                     |          |         |                      |          |         |                     | 3,255    |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       | 1,450                |         | 0.5     | 0   |     |   |
| RA154                                | MW Water                                  | 0.3                    |                     |                   |                    |                   | 0.3                               |                    |                       |          |         |                     |          |         |                      |          |         |                     | 1,035    | 1,035   |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  | 1,728                 |                      | 0.5     | 0       |     |     |   |
| RA155                                | Sed Dam                                   | 1.0                    |                     |                   |                    |                   | 1.0                               |                    |                       |          |         |                     |          |         |                      |          |         |                     |          |         |                     |          |         |                      |          |         |                             |          |         |                      |          |         |                            |                                  |                       |                      |         |         |     |     |   |