

Lady Rosie waste rock landform design

I Taylor *Okane Consultants, Australia*

K Critchell *Westgold Resources, Australia*

S Hill *Practical Mining Consultants, Australia*

P Wheeler *Okane Consultants, Australia*

Abstract

The Lady Rosie waste rock landform, located at the Westgold Resources Ltd. Cuddingwarra Project in the Yilgarn, Western Australia, was designed to dispose of approximately 1.1 Mt of waste rock. The mine waste material is erodible, with limited competent rock available to encapsulate it. In response, a waste rock landform (WRL) was designed with geomorphic features to reduce erosion, negate the need for rock capping and balance multiple operational and environmental objectives.

The design was iteratively evaluated and refined using the SIBERIA landscape evolution model to develop a form capable of meeting the stability-related performance objectives. The model was parameterised from flume testing conducted on the mine materials, to best represent the surface stability when placed. The final design also integrated two sediment basins, as a secondary containment measure to arrest transported sediments and improve environmental performance.

The retrofit design received regulatory approval in Q2, 2020, incorporating geomorphic features and removing the previous requirement for rock capping associated with the previously approved conventional form. Westgold completed construction in Q1, 2021. Less waste rock was generated from the Lady Rosie pit than predicted but the flexible design still met the intended objectives. Subsequently, landform evolution modelling was updated based on the as-constructed geometry, confirming that forecast erosion performance remained acceptable.

By integrating geomorphic features into the design of the Lady Rosie WRL, Westgold was able to attain regulatory approval, reduce construction costs and achieve environmental objectives using available mining equipment. Early monitoring of the landform WRL indicates the design is performing in accord with the model's predictions for stability.

Keywords: *waste rock landform design, geomorphic, SIBERIA, landform evolution model*

1 Introduction

The Lady Rosie waste rock landform (WRL) is located at the Lady Rosie/South Victory mining area of Westgold Resources Limited's (Westgold) Cuddingwarra Project. Gold was discovered in the Cuddingwarra Region in 1888 and mining occurred between 1887 and 1939, predominantly via underground or small open pits. Large-scale mining occurred between 1999 and 2006 under multiple owners, ceasing operations in 2006. In 2020, Westgold recommenced mining, which included the development of the Lady Rosie open cut pit. All mining has now ceased at the Cuddingwarra Project.

The Cuddingwarra Project is located in the Murchison region of Western Australia, approximately 10 km northwest of Cue (Figure 1). The region experiences a hot desert climate with high evaporation and low annual rainfall. It lies within the Austin land system and is characterised by flat, saline stony plains and low rises (Curry et al. 1994). The waste rock generated comprises oxidised and transitional mafic, ultramafic and felsic units that are inherently erodible, as observed throughout Cuddingwarra operations. The red, shallow sandy duplex soils present are also erodible.

The WRL was designed and constructed in 2020 to provide the ultimate disposal of all waste rock produced from the Lady Rosie pit. Designed to contain approximately 1.1 Mt of material, the small WRL is a traditional/geomorphic hybrid form that strikes a balance of constructability, cost, erosion stability and environmental performance. The original design for the WRL was conventional, comprising regular, bench and berm geometry with a final rock cap. The design was modified to include geomorphic features shortly after construction had commenced to limit erosion and negate the requirement for the rock capping.

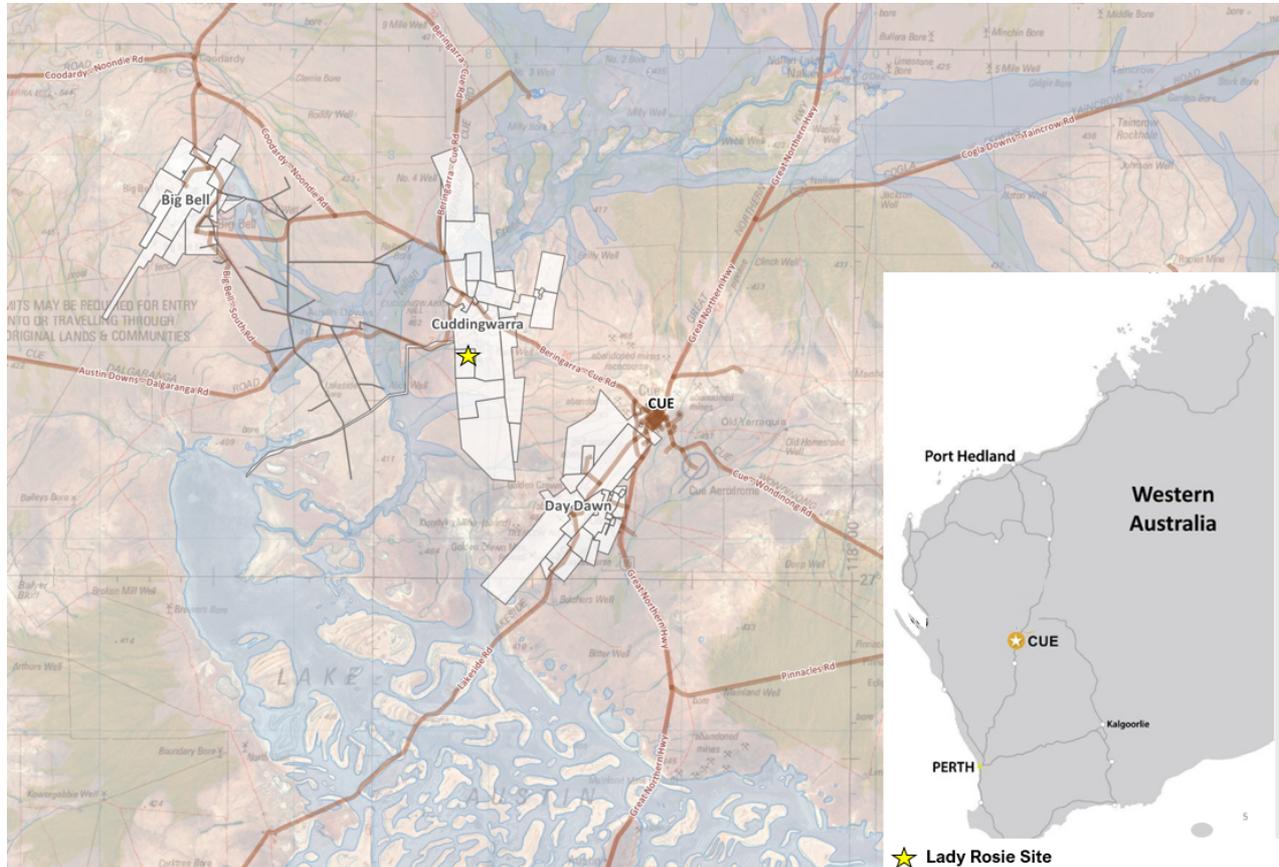


Figure 1 Site location

The land use and closure objectives for the Cuddingwarra Operations include the development of a self-sustaining ecosystem consistent with the surrounding pastoral lease (Westgold 2020). Specific objectives for the WRL were to 1) control water, 2) prevent excessive erosion, and 3) encourage vegetation to complement the surrounding habitat. The status quo approach to achieving stability was focused on strategies such as armouring slopes, revegetation and reducing face slope angles. Given the dry climate and the erodible nature of the materials, achieving WRL stability presented a range of logistical and economic challenges. The scarcity of rock, appreciable haulage distances and dry climate limited the viability of these approaches for constructing the WRL, and therefore an innovative solution was sought.

2 Methodology

2.1 General approach

Application of geomorphic methods replicates characteristics of mature natural landforms. In recent years, the adoption of geomorphic features in design has been recognised as an alternative approach to conventional WRL configurations (Hancock et al. 2003). Geomorphic designs are considered to provide a good guide for achieving stability, having evolved to this state, thus providing a geometrical form in equilibrium with erosive forces. However, it is not possible to replicate a perfect, steady-state condition (Toy & Chuse 2005). Blasting and handling of the mine materials degrades the material's physical, chemical,

and biological structure, often rendering it more erodible than in a natural state. Once placed, soils and soil structures can take decades to consolidate and regenerate (Toy & Chuse 2005). Therefore, one of the main challenges with a geomorphic approach is selecting an appropriate analogue as a blueprint for design.

For the Lady Rosie WRL, it was anticipated that the inclusion of geomorphic features could reduce erosion to acceptable levels and negate the requirement for rock capping. Short, efficient haulage and constructability needed to be maintained, constraining the design footprint and relief. Therefore, a balanced, hybrid design was adopted to simultaneously meet erosion objectives, minimise haulage and construction costs. Geomorphic features including concave slopes, sub-watershed catchment configurations and drainage characteristics consistent with the natural landscape were integrated into the design, while maintaining close proximity to the pit and support construction with available mining equipment and conventional tip head operation.

The design also included two sedimentation basins as a further risk-reduction measure to attenuate surface water runoff from the WRL and minimise the possibility of sediment transport beyond the disturbance footprint. Surface water runoff from the WRL is directed to the sedimentation basins via drains constructed at the toe of the WRL. As dispersive sediments do not settle rapidly, the sediment basins were designed with a large capacity (100-year annual exceedance probability, 12-hour rainfall event). Under more frequent, rainfall conditions i.e. less than the design event, ponded surface water is attenuated and allowed to evaporate.

The landscape evolution model SIBERIA (Willgoose et al. 1991a, 1991b, 1991c) was used to develop and test the design. SIBERIA is the most widely tested and used landscape evolution model in the world (Hancock & Willgoose 2017). It is a physically based predictive model capable of simulating the geomorphic evolution of landforms subject to fluvial and diffusive erosion processes (Hancock et al. 2003). The model is particularly well suited for guiding geomorphic designs by rapidly processing, assessing and visualising a three-dimensional landform over time. For this project, SIBERIA was calibrated with parameters derived from flume experimentation conducted on the mined materials (Sheridan et al. 2000) and is therefore reflective of the mined waste.

2.2 Base case design

A base case design was established to provide a starting point for assessment and subsequent refinement. The base case design intended to simultaneously meet strategic operational needs as well as environmental performance (listed below). Early design planning workshops with mine planners and key environmental personnel identified these requirements, along with other inputs for the basis of design. The strategic operational requirements included:

- Provide a capacity for disposal of approximately 1.1 Mt of waste rock, with flexibility to accommodate more/less material.
- Minimise or avoid requirements for rock armour, which was scarce and costly to import.
- Rehabilitation to be conducted by the available mining fleet. Safe haulage was paramount, and rehandling of materials was to be minimised.
- Materials would be placed into the WRL using a conventional truck shovel tip head, with the final geometry achieved by dozing the material to the final shape.
- Short haul distances were preferred to improve haul efficiency, and the WRL would be located near the pit and outside the designated zone of instability.

Similarly, objectives were established for environmental performance, including:

- Low average erosion rates (defined as less than 10 t/ha/y for this study), over a 300-year assessment period.
- A consistent erosion profile across all surfaces of the WRL.

- Secondary containment for surface water runoff from the WRL. Sediment basins would be incorporated into the design to attenuate residual sediments and retained as long-term features until they inevitably fill with sediments.
- Construction staging of the WRL would support progressive rehabilitation activities.
- The WRL would not impede the natural hydrologic regime.

The materials and soils were expected to be erodible, as observed in other areas of the Cuddingwarra Project. Therefore, the base case was developed with geomorphic features, including concave slopes and an undulating ridge and swale topography.

The base case surface design was based on a nearby natural catchment (Figure 2), located approximately 2.5 km northwest of Cuddingwarra Operations. The analogue was selected due to its:

- Form, being proud of the surrounding landscape.
- Similar catchment area to the preferred WRL footprint.
- Natural state, with easily discernible dendritic flowpaths.
- Close proximity to the site.

The flowpath alignments and patterns observed on the analogue were mapped using aerial imagery and digitally draped onto the surface of the WRL. Design adjustments were made to include concave embankments, sufficiently high to accommodate the required capacity and footprint constraints. The gently sloping, wide flowpaths of the analogue, when fit to the WRL base case design, were identified as preferred haul routes for construction.



Figure 2 Analogue site, indicating natural flowpaths

2.3 Materials testing

As no waste was available from the Lady Rosie pit, mined rock material was collected for erosion testing from a nearby, previously mined area. A 200 L bulk sample was collected, which was consistent with the upper-mid saprolite zone at Cuddingwarra and was considered a good proxy for the material that would be used to construct the Lady Rosie WRL.

The materials were independently evaluated using an erosion flume to provide a measure of erodibility and derive key SIBERIA parameters. The erosion data, including measurements of surface water flow, slope gradient and sediment yield can then be used to determine the input parameters for the SIBERIA model (Hancock & Willgoose 2017; Sheridan et al. 2000).

Two tests were completed, under slope gradients of 5% and 20%, providing anticipated bookends for acceptable design gradients. The testing confirmed the material to be quite erodible, with some dispersive materials present. The input parameters needed to resolve SIBERIA's fluvial sediment transport algorithms (Willgoose 2012) and parameterise the SIBERIA model were derived from this data.

The SIBERIA input parameters used are listed in Table 1. These are applicable for the digital terrain model, which was gridded to a resolution of 1 m × 1 m. The test work program confirmed that the parameters derived for the SIBERIA model fit the empirical data well and provided a good representation of the materials assessed.

Table 1 SIBERIA input values derived from flume testing

Parameter	Value	Parameter description
β_1	0.055	Coefficient of in the fluvial sediment transport term
m_1	1.25	Exponent on the discharge used in the fluvial sediment transport term
n_1	2.0	Exponent on the slope used in the fluvial sediment transport term
m_3	1	Exponent of the area in the discharge formula
β_3	1	Runoff rate constant in the discharge formula

3 Results

3.1 Final design

The final WRL (Figure 3) was designed to contain approximately 1.1 Mt of material with a footprint of approximately 9.3 ha. The footprint was located immediately east of the Lady Rosie pit and just outside the predicted zone of instability. The dendritic drainage pattern, applied to the upper surface was based on a nearby natural analogue. Broad, shallow swales were adopted; these were intended to reflect the area's natural wide, meandering flow paths. These swales produce subcritical flow conditions, minimising flow velocity, shear stresses and scour risk. Importantly, these wide corridors double as haul routes and adhere to the maximum grades required for safe operation.

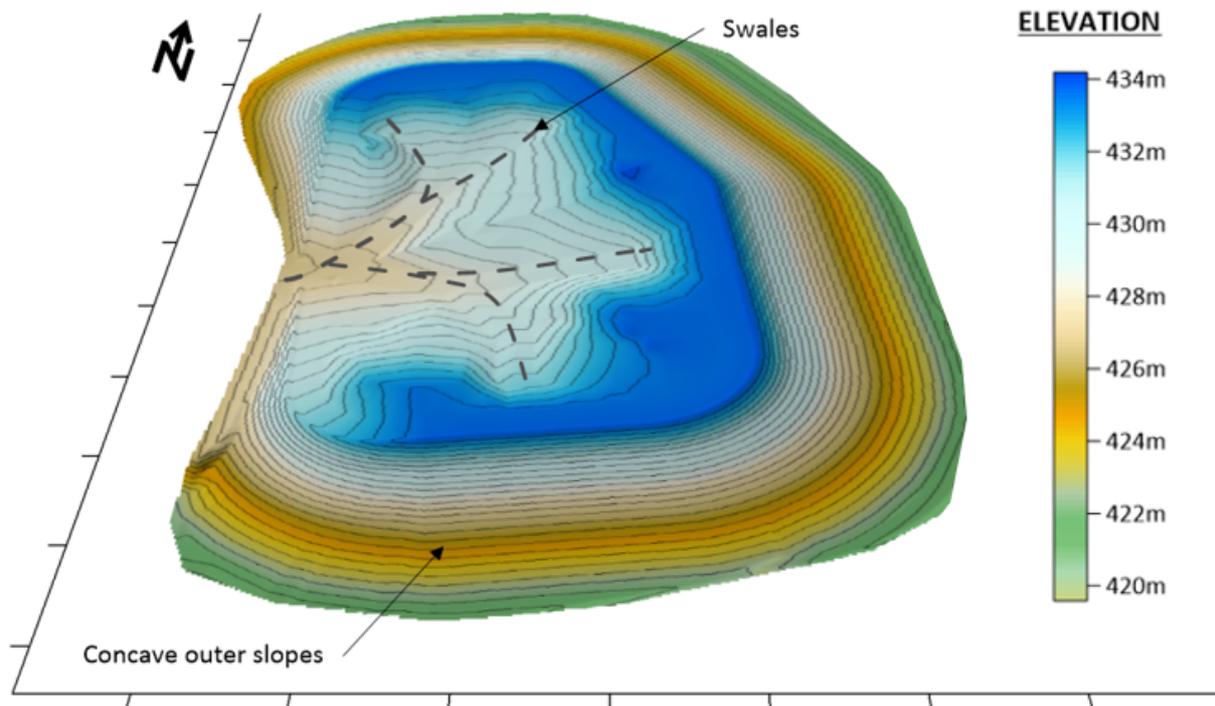


Figure 3 Design surface developed from SIBERIA landform evolution modelling

The outer slopes are concave (Figure 4), a geomorphic design feature intended to reduce erosion of the slopes. The WRL design concavity has been developed through iterative modelling in SIBERIA. Internally, the upper surfaces are shaped with mild gradients, typically less than 25%. Two sedimentation basins were included at the topographic low points at the eastern and southern toe of the WRL. The in-ground basins were fed by the swales on and around the WRL. The sediment basins were sized to accommodate runoff during large magnitude rainfall events, up to the 100-year ARI, 12-hour event.



Figure 4 Concave slope designs

3.2 Predicted erosion performance

Six iterations of modelling were conducted before the design was deemed acceptable. Low average erosion rates are predicted for the WRL, of <5 t/ha/y, satisfying the performance objectives for a low erosion rate over the 300-year assessment period modelled. The low erosion classification indicates that the WRL surface is stable with limited adverse environmental and stability effects. Sediment transport beyond the disturbance footprint is expected to be very low, given the inclusion of the two sedimentation basins included in the footprint of the WRL.

The positive results are attributed primarily to the low overall vertical relief, shallow slopes and the adoption of geomorphic principles in the design. The base case design (described in Section 2.2) was found to be sub-optimal, experiencing an inconsistent erosion across the surfaces of the WRL, in particular around the crest of the slopes. A comparison of the base case (non-conforming) versus final (conforming) erosion distribution is illustrated in Figures 5a and 5b, (areas of erosion are identified as red and deposition green).

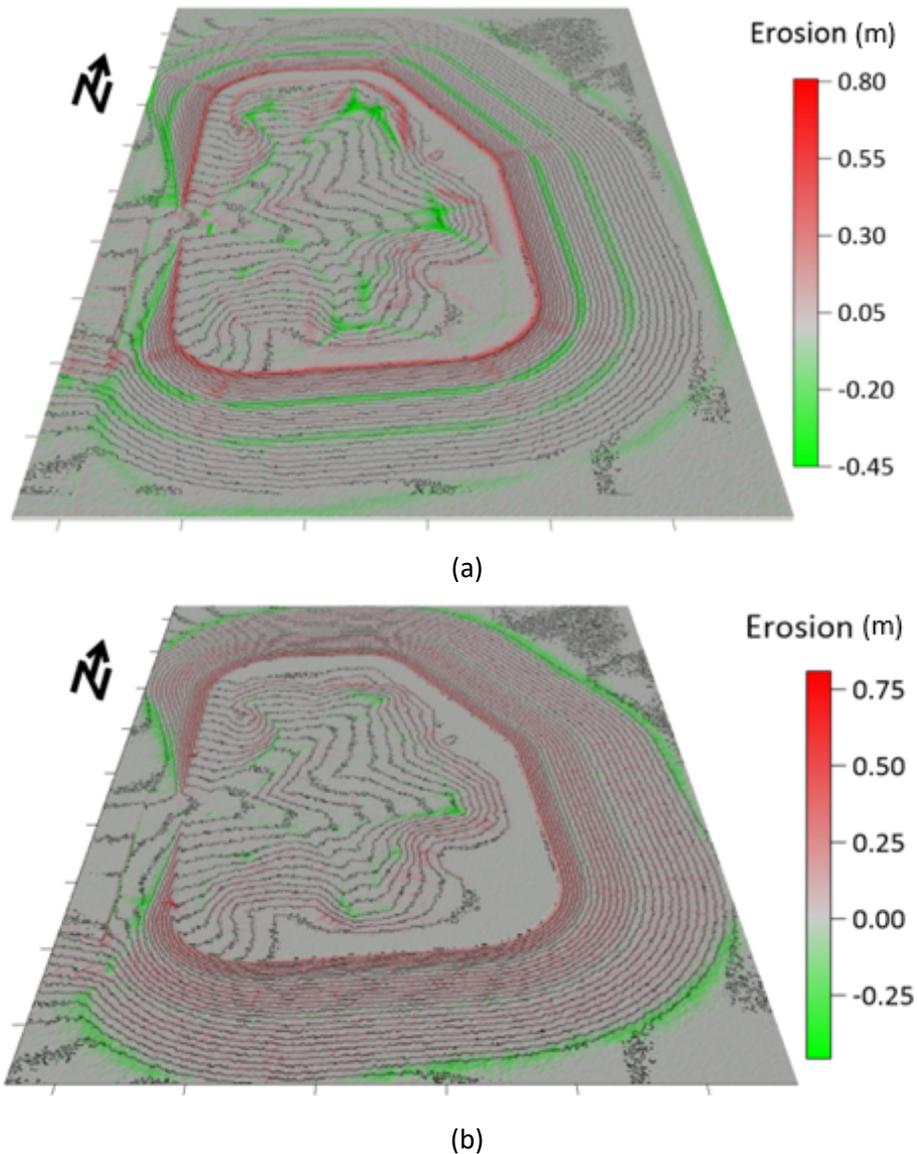


Figure 5 Spatial distribution of erosion depth. (a) Base case WRL; (b) Final design WRL

3.3 Staging considerations

Mining approval was granted in Q2, 2020, superseding prior approvals that required capping with rock. Construction had already commenced at that stage based on the prior approval. Geomorphic WRLs are inevitably more complex than traditional shapes, having non-linear slopes, undulating surfaces and meandering, non-linear drainage patterns. Despite construction having already commenced, the updated design was simple to retrofit as placement had not occurred outside the design envelope.

The 'as dumped' designs were completed to ensure that material was placed in the correct position using conventional tip head dumping (Figure 6a). This ensured that resloping push distances were minimised and mostly negated rehandling, minimising truck and dozer hours. Additionally, the final rehabilitated WRLs (Figure 6b) were developed in stages to facilitate operational flexibility and progressive rehabilitation. Initially Stage 1 was filled to the requisite height, then mining will progress into Stage 2 while final shaping occurs on Stage 1. This sequence will be repeated for Stages 2 and 3.

This staged approach to construction allowed final shaping activities to commence and progressive rehabilitation activities to begin sooner than would have been possible if construction were completed in lifts that spanned the entire footprint. The staged approach provided flexibility in allocating mining

equipment, allowing mine operations to use available equipment. The stage boundaries were established along the ramps to allow practical access to the uppermost lift of each stage.

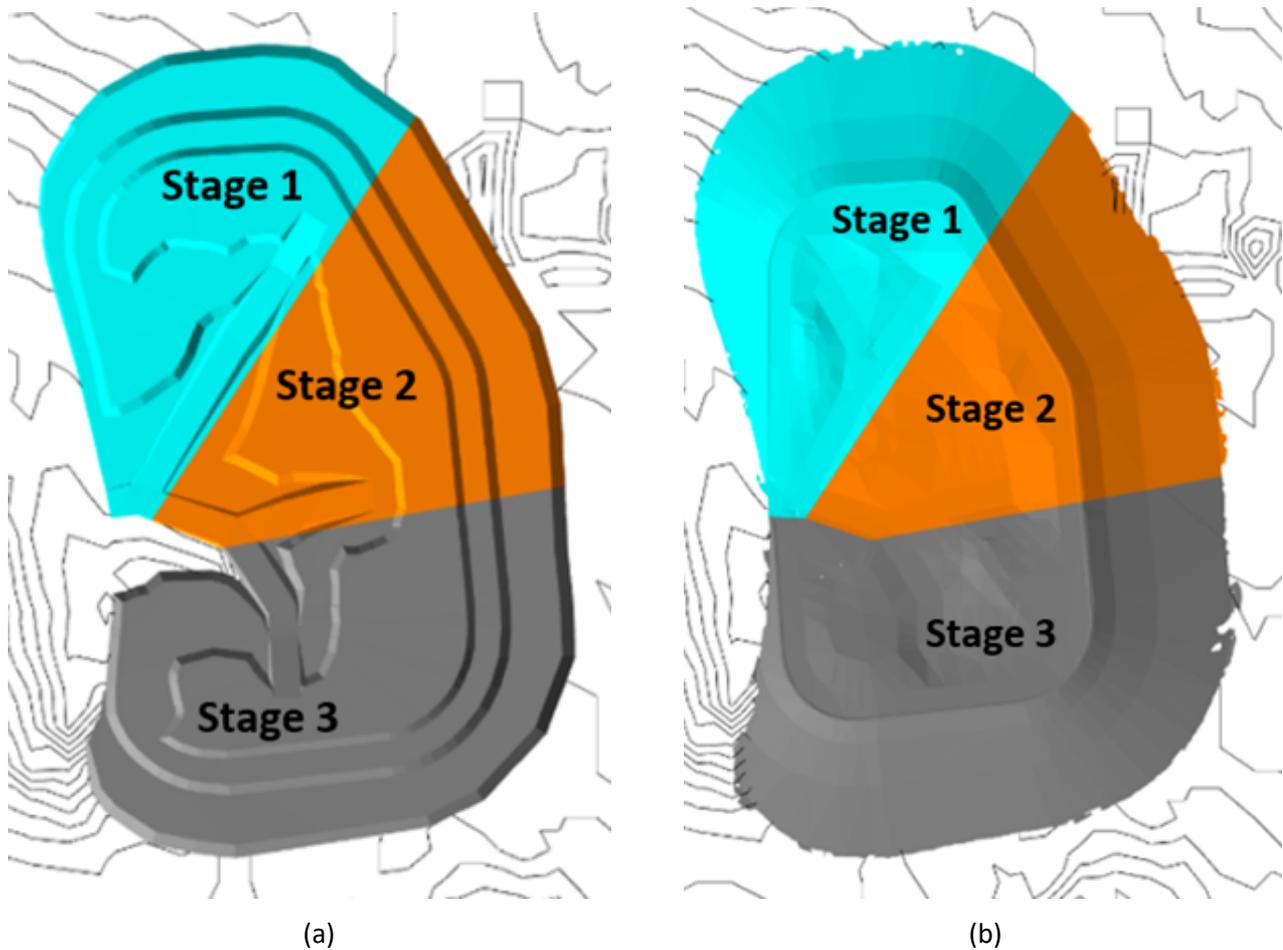


Figure 6 Construction staging. (a) Tip-to; (b) Final rehabilitated design

3.4 Construction

Construction was completed in Q1, 2021 (Figure 7). One of the Lady Rosie satellite pits was ultimately not developed, resulting in a volume of waste approximately 30% lower than originally anticipated. This led to a reduced WRL size and smaller footprint, though in accord with the basis of design (Figure 8). A comparison of the designed and constructed contours is illustrated in Figures 9a and 9b.



Figure 7 Lady Rosie WRL (2021)



Figure 8 Typical slope profile (2021)

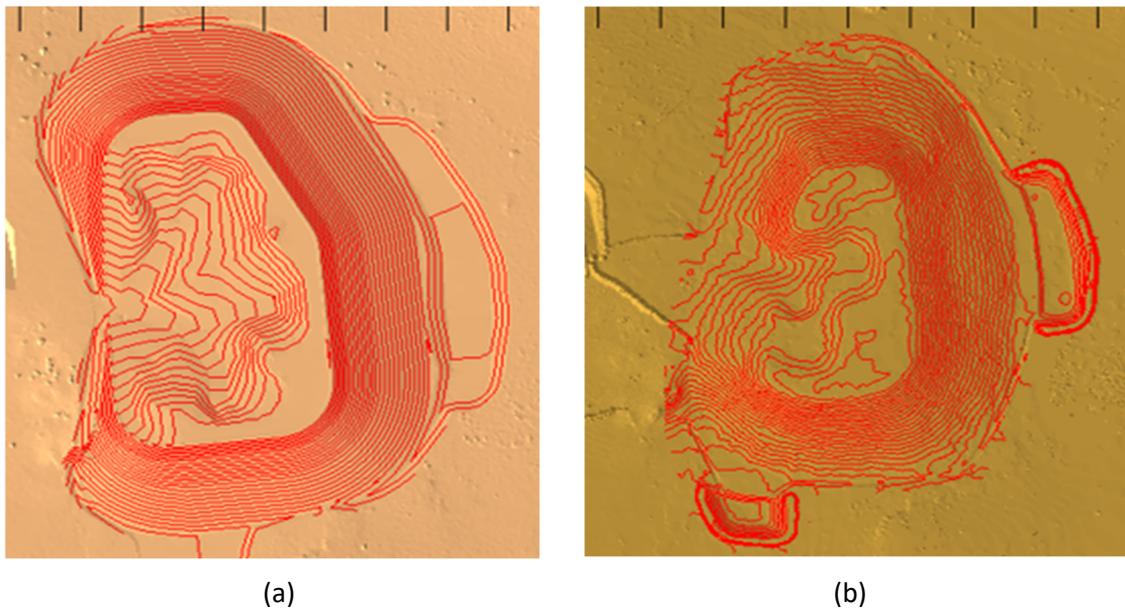


Figure 9 Comparison of contours (a) As designed; (b) As constructed

3.5 Validation of the constructed WRL

The as-constructed WRL was re-evaluated in SIBERIA to assess the efficacy and determine if the deviations to the original design were tolerable with respect to the design intent, in particular the ability to mitigate erosion risk. The results of the modelling are illustrated in Figure 10, showing the elevation of the WRL and Figure 11, presenting the predicted spatial distribution of erosion. Figures 10 and 11 indicate comparable results to those previously predicted in Figure 3. Low rates of erosion were predicted, with a consistent spatial distribution of erosion on the outer faces, confirming that the constructed landform was in accord with the design intent.

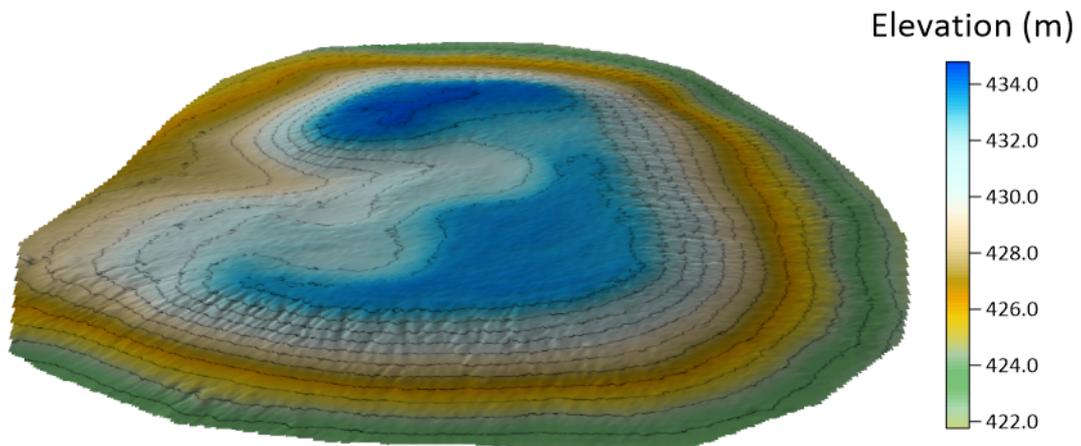


Figure 10 300-year predicted surface of the as-constructed WRL

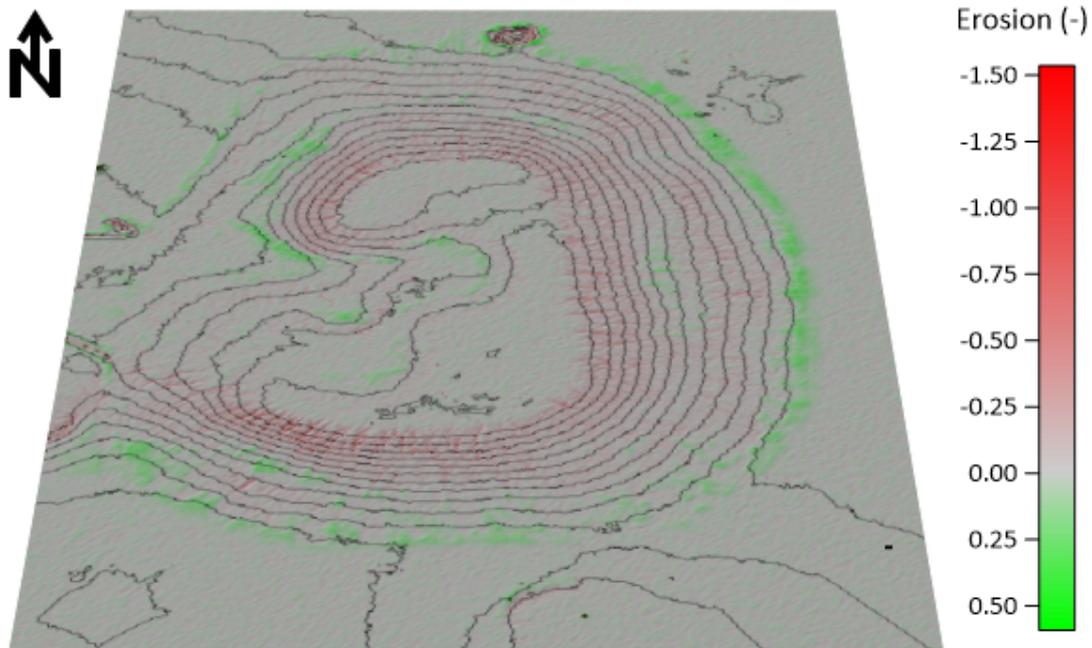


Figure 11 Erosion modelling conducted for the constructed WRL

4 Conclusion and discussion

4.1 Project outcomes

The WRL design presented a balanced approach that incorporated operational objectives, including cost and constructability, with environmental objectives, such as erosion stability and sediment transport. These are often considered competing positions, though this project demonstrates value in a balanced approach. The Lady Rosie WRL design has:

- Achieved regulatory support.
- Allowed for a reduction in construction cost by negating the need for rock capping.
- Enabled stability objectives to be achieved, despite the inherent erodibility of the waste.
- Enabled rehabilitation works to progress with available equipment.
- Demonstrated flexibility and construction ease, despite a retrofit design and changes to the mine schedule during construction.

Flume testing has enabled the key relationships for the mined materials to be determined and the development of stable forms appropriate for this material. SIBERIA is compatible with the flume testing and well suited to the iterative design approach, providing the platform to integrate the main factors affecting fluvial and diffusive erosion, including the geometry, rainfall runoff conditions and timeframe (Sheridan et al. 2000).

The design developed does not intend to exactly replicate the natural analogue. This is important as mined material is physically altered from its natural condition and a strictly natural form would have unlikely met all the operational objectives, in particular haul distances, footprint and capacity constraints.

4.2 Predicted erosion rates

Low average erosion rates are predicted for the WRL, meeting the objectives for erosional stability and consistency over the 300-year timeframe modelled. Erosion of the WRL is inevitable, but a 'low' erosion classification indicates the erosion rate is acceptable and potential adverse environmental impacts have been

controlled. The positive results are attributed primarily to the low overall vertical relief of the WRL and the adoption of geomorphic features providing a mature geometry (compared with conventional forms).

The sediment basins provide secondary control of eroded sediments, providing substantial capacity to attenuate sediments eroded from the WRL. Over time their capacity can be expected to diminish as they fill with sediments.

Even though erosion results are presented as values (including predicted erosion rates and depth), the accuracy of the assessment is considered qualitative due to aspects not limited to:

- The inherently predictive nature of landscape evolution modelling.
- Potential variability and heterogeneity in the materials evaluated from practice.
- Scaling considerations, such as physical scaling relationships derived from erosion flume test work to a larger-scale WRL.
- Environmental extremes and climate change.

In this respect, the predicted erosion rates are not intended to be definitive but to provide a basis for assessing the ability to meet design objectives.

4.3 Observed performance to date

Over the approximately 16 months since construction, the area has experienced above average rainfall of approximately 326 mm, recorded in Cue (Bureau of Meteorology weather station 007017). Recent investigations (May 2022) indicate minimal erosion development (illustrated in Figures 12 and 13), despite the rainfall conditions and recent construction. Future monitoring will provide further validation of continued performance.



Figure 12 Embankment with toe drain in the foreground



Figure 13 Embankment slope

References

- Curry, PJ, Payne, AL, Leighton, KA, Hennig, P & Blood, DA 1994, 'An inventory and condition survey of the Murchison River catchment, Western Australia', *Technical Bulletin 84*.
- Hancock, GR, Loch, RJ & Willgoose, GR 2003, 'The design of post-mining landscapes using geomorphic principles', *Earth Surface Processes and Landforms*, vol. 28, no. 10, pp. 1097–1110, <https://doi.org/10.1002/esp.518>
- Hancock, GR & Willgoose, GR 2017, 'Sustainable mine rehabilitation – 25 Years of the SIBERIA landform evolution and long-term erosion model', *From Start to Finish: Life-of-Mine Perspective*, Australasian Institute of Mining and Metallurgy, Melbourne.
- Sheridan, GJ, So, HB, Loch, RJ, Pocknee, C & Walker, CM 2000, 'Use of laboratory scale rill and interill erodibility measurements for the prediction of hillslope-scale erosion on rehabilitated coal mines soils and overburden', *Australian Journal of Soil Research*, vol. 38, no. 2, pp. 285–298.
- Toy, TJ & Chuse, WR 2005, 'Topographic reconstruction: a geomorphic approach', *Ecological Engineering*, vol. 24, issues 1–2, pp. 29–35
- Westgold 2020, *Cuddingwarra Project Mine Closure Plan, April 2020*, rev. 1, version 1, Perth.
- Willgoose, GR 2012, *User Manual for SIBERIA, Version 8.33*, Telluric Research, Scone, https://www.telluricresearch.com/siberia_8.30_manual.pdf
- Willgoose, GR, Bras, RL & Rodriguez-Iturbe, I 1991a, 'A physically based coupled network growth and hillslope evolution model: 1 theory', *Water Resources Research*, vol. 27, no. 7, pp. 1671–1684.
- Willgoose, GR, Bras, RL & Rodriguez-Iturbe, I 1991b, 'A physically based coupled network growth and hillslope evolution model: 2 Applications', *Water Resources Research*, vol. 27, no. 7, pp. 1685–1696.
- Willgoose, GR, Bras, RL & Rodriguez-Iturbe, I 1991c, 'A physical explanation of an observed link area-slope relationship', *Water Resources Research*, vol. 27, no. 7, pp. 1697–1702.