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Assessing Landscape Reconstruction at the Ranger Mine Using Landform Evolution Modelling

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1 INTRODUCTION

The Energy Resources of Australia Ranger Mine (ERARM) mineral lease is surrounded by, but excised from the World Heritage-listed Kakadu National Park in the Northern Territory of Australia (Figure 1). The mine site is located on the left bank of Magela Creek and erosion products from the mine may impact the three small catchments to the north of the mine – Corridor, Georgetown and Coonjimba Creeks, and the large catchment of Gulungul Creek to the west of the mine. Downstream, Magela Creek debouches into the East Alligator River through a broad expanse of floodplain and wetlands listed as "Wetlands of International Importance" under the Ramsar Convention (http://www.ramsar.org, 2003). The mineral lease, which lies in the wet-dry tropics, receives high-intensity storms and tropical monsoons between October and April with little rain falling for the remainder of the year. The annual average rainfall is 1480 mm (Bureau of Meteorology, 1999).

The mine has been operational since 1981, with production of uranium concentrate currently planned to continue until 2014 (Johnston and Needham, 1999; Hollingsworth and Lowry, 2005). Mining is presently underway in the open-cut Pit 3 (Figure 1). Pit 1 is currently being used for tailings deposition, supplementing the existing above-grade tailing storage facility. At the completion of mining, tailings from the above-grade facility will be transferred to Pit 3, which, along with Pit 1, will be capped. The above-grade waste rock dumps will be rehabilitated. With the mine approaching the end of its life, attention is being increasingly focussed on the closure and the rehabilitation of the mine. This paper describes the process that will be used to assess the long term geomorphic stability of the proposed reconstructed landform.

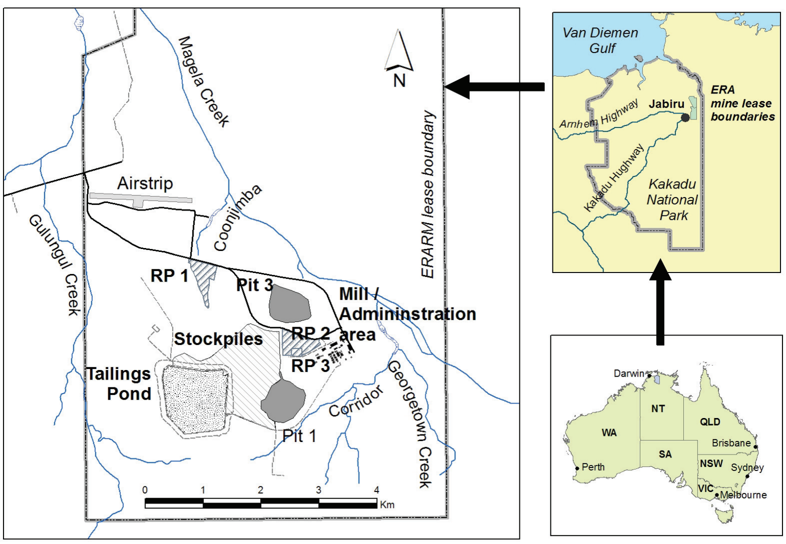


Figure 1 Location and layout of the Ranger uranium mine

2 ENVIRONMENTAL REQUIREMENTS FOR MINE CLOSURE

The goal for mine closure, as set out in the Environmental Requirements for the site states that:

> *"… the operator of the mine shall rehabilitate the Ranger Project Area to establish an environment similar to the adjacent areas of Kakadu National Park such that, in the opinion of the Minister with the advice of the Supervising Scientist, the rehabilitated area could be incorporated into the Kakadu National Park."*

In particular, the Environmental Requirements specify that the constructed landform and associated plant communities should be similar to those found in surrounding areas of Kakadu National Park and able to be managed as if they are part of the Park whilst not detracting from World Heritage values. Energy Resources of Australia (ERA) has adopted an ecological engineering approach to guide the design of the final landform, based on detailed assessment of natural landforms in the vicinity of the mine which are analogous to the scale and volume of a final mine landform. This approach recognises that the required goal would be unlikely to be met by the application of civil engineering construction principles alone (Nicolau, 2003).

Application of this approach to derive design criteria has been used to develop a conceptual post-mining landform, which is consistent with the 2002 life-of-mine plan in terms of the size of pits and the amounts of waste rock materials.

3 DESIGN APPROACH TO CREATION OF POST-MINING LANDFORM DESIGN

Post-mining landform rehabilitation design at the ERARM is based on vegetation composition and terrain analysis of nearby natural analogue sites (Hollingsworth and Lowry, 2005). A significant closure objective with respect to site erosion is "erosion characteristics which, as far as can reasonably be achieved, do not vary significantly from those of comparable landforms in surrounding undisturbed areas". The following two-stage assessment process can be used to determine if the erosion closure criterion is met:

- Determine landform stability.
- Determine sediment delivery from landform to stream.

With respect to meeting this closure objective the main issues will be to limit physical damage (e.g. severe gullying) to the rehabilitated landform, and impact of fine suspended sediment on downstream water quality.

A design approach based on natural landscape analogues has been proposed to define the key attributes of the post-mining landform at Ranger Mine (East and Cull 1988; Riley 1994; Riley and Rich 1998; Hollingsworth et al*.,* 2003). More recently, ERA has funded work to identify appropriate natural analogues for mine landform design (Hollingsworth et al*.,* 2003). This work has been based on the life-of-mine plan as a starting point and has developed a process to select end point habitats in analogous landforms in the adjacent landscape.

The iterative design process is shown schematically in Figure 2. Circles represent process actions that depend on stakeholder consultation and agreement. The process connects life-of-mine planning with final landform construction planning via a range of environmental design and evaluation tasks and hinges on review by traditional owners.

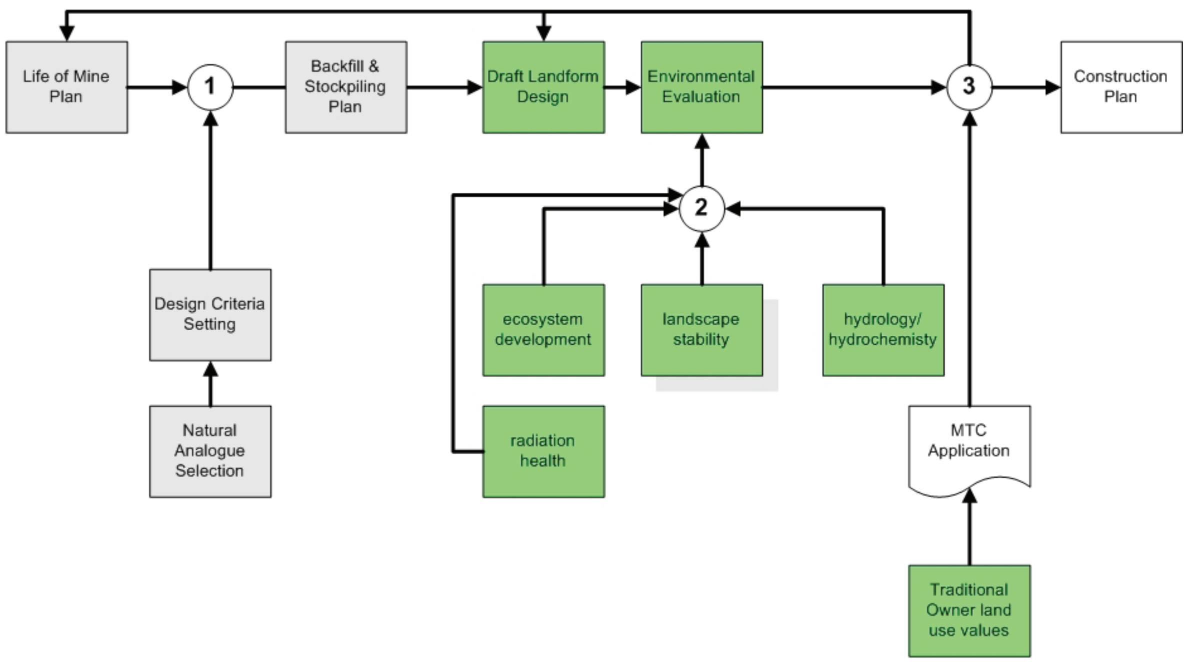


Figure 2 **Schematic representation of the design process**

ERA engineers use terrain analysis of natural analogues to develop design criteria and life of mine plans to draft an above-grade landform. Landform cover specifications depend on closure requirements for ecosystem support, containment and erosion resistance. Options for cover design include selecting and mixing weathered and unweathered clean waste rock, surface ripping to stabilise and promote vegetation and rock lining to protect concentrated flow lines.

The post-mining landform design used in this study has low relief (< 50 m) and comprises a north south ridge between backfilled Pit 3 and the Tailings Pond and an east west ridge between backfilled Pit 1 and the southern wall of the tailings dam (Figure 3).

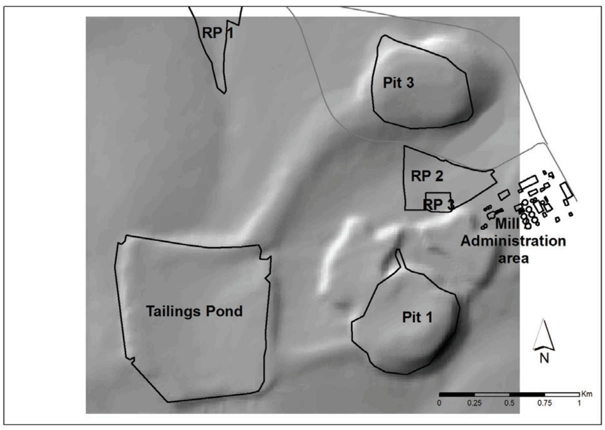


Figure 3 **Proposed rehabilitated landform for Ranger mine**

4 DESIGN EVALUATION AND ASSESSMENT METHODS

Once a design for a landform has been produced, predictive modelling using the SIBERIA landform evolution model (LEM) (Willgoose et al., 1989) was used to evaluate landform stability and assess catchment impact. A schematic diagram of the landform design and modelling process is shown in Figure 4.

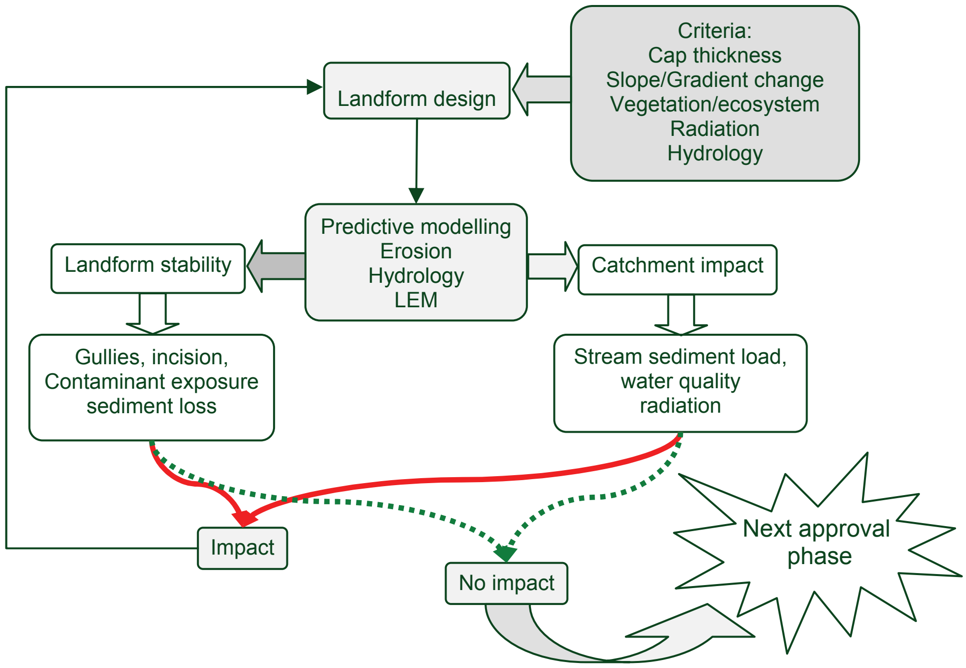


Figure 4 Schematic representation of the landform design and modelling process

Landform stability assessment considers the size and distribution of gullies; incision on capped areas resulting in contaminant exposure; and sediment loss or denudation rate (Evans, 2000). Post closure landform stability can be quantified through inspection, which includes mapping gully distribution and depth; assessment of ecosystem health; and measurement of radon emanation or contaminant exposure.

Catchment impact assessment considers whether landform erosion will cause an elevation of stream sediment concentration (particularly the silt and clay component of the sediment) above background levels downstream of the minesite (Evans 2000). If both landform stability assessment and water quality (i.e. turbidity) impact assessment show no impact then the design is acceptable. If the assessments show an impact, then the landform design should be reconsidered.

Catchment impact can be assessed through monitoring the catchment for increased areas of erosion or deposition; changes in stream channel stability; or changes in water quality through increases in stream sediment load. Stream sediment loads are most likely to be elevated during the rehabilitated landform construction process and for a short period following construction as the landform attains equilibrium.

The streams receiving runoff from ERARM have monitoring systems in place and pre-rehabilitation conditions are being quantified so their post-rehabilitation condition can be assessed. This paper does not discuss the derivation of post-mining management trigger values (for example, turbidity in receiving streams) against which the extent of impact can be assessed. Trigger values have not yet been defined and issues such as length of post-mining monitoring time frames are still being discussed by stakeholders.

5 SIBERIA MODEL

The SIBERIA LEM is a sophisticated three-dimensional topographic evolution model, which models long-term changes in elevation with time from the average effect of mass transport processes, such as tectonic uplift, fluvial erosion, creep, rainsplash and landsliding. The model describes how a catchment will look, on average, at a given time.

To date, the model has been used to investigate post-mining rehabilitated landform design at the ERARM (Evans et al., 1998; Willgoose and Riley, 1998; Moliere et al., 2002; Hollingsworth and Lowry, 2005), and the ERA Jabiluka mine (Boggs et al., 2000; Boggs et al., 2001). These previous studies used observed data (rainfall, runoff and sediment loss) collected at field sites, located on the landform or within the catchment to be modelled, to parameterise SIBERIA. Assessments of earlier proposed landform design were provided to

ERA for the purpose of facilitating iterative enhancement of each successive landform design. The assessment of the current landform will be used to enhance future landform designs of the ERARM.

In order to model a landform, the SIBERIA program requires three basic data inputs, namely a hydrologically-correct digital elevation model (DEM) representing the proposed landform, a boundary file and a region file.

A hydrologically-correct DEM is required to ensure that drainage flows in the correct direction (e.g. not uphill), and removes sinks from the landform. The boundary file contains boundary information for an irregularly shaped catchment area, including the location of catchment outlets. In this case, a simplified drainage network was generated from the DEM which identified four catchment outlets for the landform. The region file describes the surface condition of the various areas of the landform using erosion and hydrology parameter values. In this case, it was assumed that the landform would be composed of two surface conditions:

- Those areas on the landform which had a slope of greater than 10%, which were regarded as being likely to be treated with rock batters and mulching. This area is assumed to be covered with an armour of coarse rock material and has negligible vegetation cover.
- The remainder of the landform, which was regarded as possessing ‘natural’ characteristics. The natural characteristics reflect the surface conditions of the Koolpinyah surface, which has been described by Nanson et al. (1990) as the landform with the highest geomorphological stability in the Alligator Rivers Region and which has very low denudation rates (~0.03 mm/y).

For the purposes of this study, two scenarios were identified: a ‘best case’ scenario (Figure 5) in which those areas of the landform with slopes of greater than 10% were treated with rock mulch and batter erosion parameters, with the remainder of the landform treated with natural erosion parameters; and a ‘worst case’ scenario. In the latter case, the entire landform surface was assumed to comprise rock mulch and batter, irrespective of landform slope. As noted earlier, the natural parameter values were derived for the Koolpinyah Surface, an extremely stable peneplain with low erosion rates.

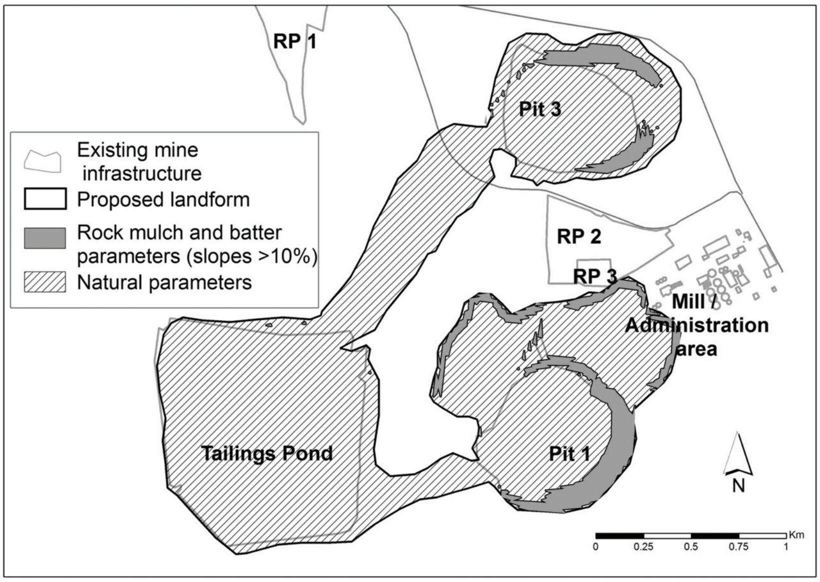


Figure 5 Distribution of parameters used for simulating the ‘best case’ scenario

5.1 Parameter derivation

SIBERIA predicts the long-term average change in elevation of a point by predicting the volume of sediment lost from and added to a node on a DEM using the fluvial sediment transport equation:

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

where: q_s = sediment transport rate (m_3 y_{-1}), S = slope (m/m), β_1 = sediment transport rate coefficient; and m_1 and n_1 are fitted parameters.

SIBERIA does not directly model runoff, but uses a sub-grid effective parameterisation (Willgoose et al., 1992) which conceptually relates discharge to area (A) draining through a point as follows:

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

To run the SIBERIA model for a field site it is necessary to derive parameter values for β_1, m_1, n_1 (eqn 1) and β_3, m_3 (eqn 2). Parameter values for equations (1) and (2) are derived by:

- Extending the observed runoff record collected at the field sites by calibrating a rainfall-runoff model.
- Fitting parameters to a sediment transport equation using sediment concentration and runoff data collected from field sites (n_1, m_1).
- Using the results of steps 1 and 2 above to derive long-term average SIBERIA model parameter values for the landform being modelled (β_1, β_3, $m3$).

A detailed description of the process is given in Willgoose and Riley (1998), and Evans et al., (1998). The input parameters that were used for modelling the draft Ranger landform are shown in Table 1.

Table 1 SIBERIA parameter values for each region of the Ranger study area

Region	Source of information	SIBERIA parameter				
		m_1	n_1	β_3	$m3$	$*\beta_1$
Natural, surrounding landscape	Koolpinyah surface (Moliere et al., 2002)	1.12	0.69	0.00017	0.81	5.64
Slopes greater than 10% - rock mulch and batter	Ranger waste rock dump (Moliere et al., 2002)	2.52	0.69	0.00016	0.81	23551

*** β_1 values were revised in this study to correspond with the DEM resolution (12.68m grid size)**

Once mining is completed and the landform rehabilitated, there is an ongoing requirement to continue to assess the landform stability, and potential catchment impacts, to determine if the constructed rehabilitated landform is equilibrating with the surrounding catchment. Landform stability of the pre-rehabilitated mine site is being monitored and assessed through inspections of gully inspection, and radiation levels, whilst catchment impact is being assessed through analysis of channel stability, stream sediment transport, and water chemistry. The periodicity and duration of the monitoring and evaluation of these characteristics for the post-mining, rehabilitated landform is currently being negotiated.

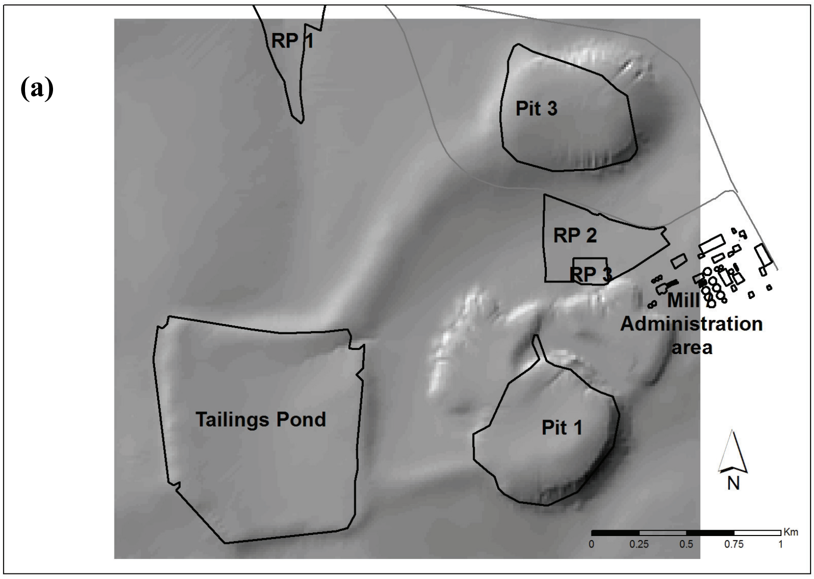
5.2 Results of landform evolution modelling

Using the methodology described in Lowry et al., (2004), the proposed landform (Figure 3) was modelled for a simulation period of 1000 years, with the hydrological parameters (m_3, $\beta 3$) for each region applied to the entire landform. Using the SIBERIA software, it was possible to identify areas of potential erosion/deposition by subtracting the 1000-year modelled surface from the proposed surface, for separate 'best case' and 'worst case' scenarios (Figure 6).

Analysis of the simulations indicated that over a period of 1000 years, gullies up to 8 metres deep may form on the areas of the rehabilitated surface formerly occupied by Pit 1 and Pit 3 in the 'worst case scenario'. In addition, erosion gullies up to 3 metres deep may occur within the area of the landform occupied by the tailings pond, and up to 5 metres deep in the area to the southwest of Retention Ponds 2 and 3 (RP 2 and RP3), north of Pit 1. Deposition of material to a depth of up to 3 metres may occur at the outlet of the gullies on Pit 3, and the gullies to the north of Pit 1.

In contrast, the 'best case' scenario indicates that considerably less erosion will occur on the areas of the landform previously occupied by Pit 1 and Pit 3, with gullies up to a depth of 3 metres potentially forming over a period of 1000 years. No gullies were visible within the area of the landform formerly occupied by the Tailings Pond, or to the north of Pit 1. However, the best case simulation indicated that deposition would occur in the same areas as the worst case scenario, albeit in reduced quantities to a depth of 2 metres. A longitudinal profile of the differences between the two modelled surfaces is shown in Figure 7.

Simulated surface denudation rates for both 'worst case' and 'best case' scenarios were calculated using the GIS interface to SIBERIA, and found to be 0.04 and 0.03 mm/y, respectively. These compare favourably with regional denudation rates of 0.04 mm/y for natural undisturbed surfaces (Cull et al., 1992).



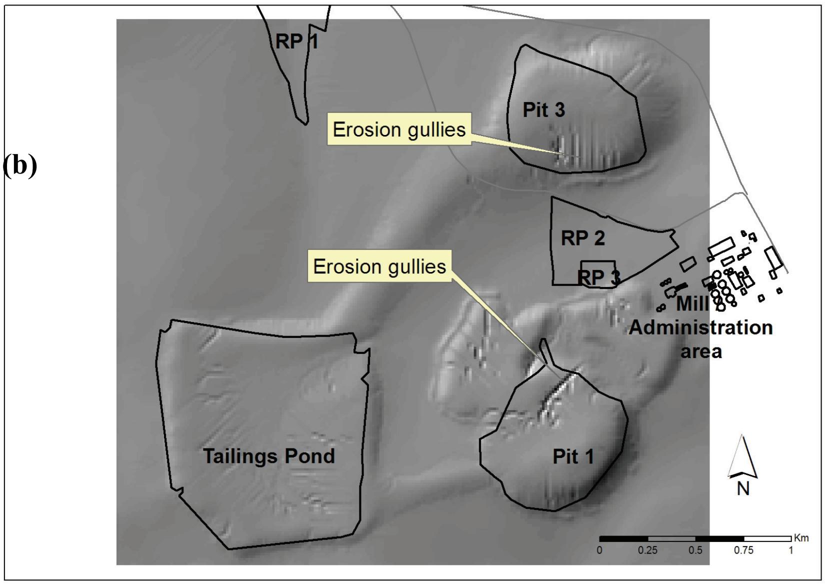


Figure 6 Areas of potential erosion / deposition on proposed landform after 1000 years under (a) best case; and (b) 'worst case' scenario

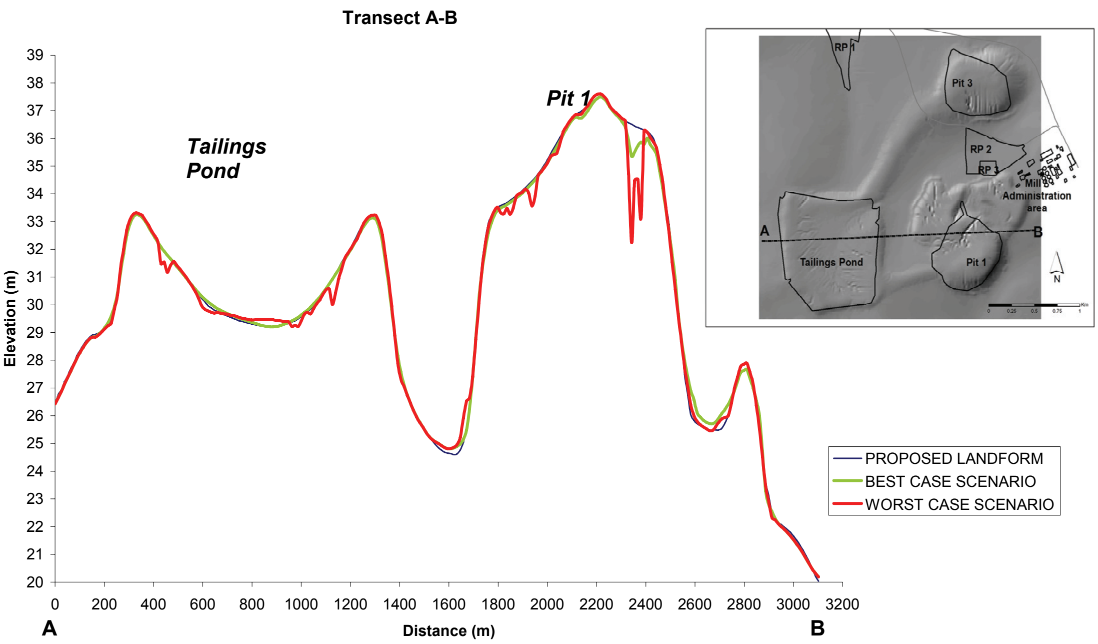


Figure 7 Comparison of different landform profiles at Ranger mine

6 SUMMARY AND CONCLUSIONS

6.1 General Assessment of Landform Design

The landform design process has been a collaborative research and development program between the Supervising Scientist Division of the Department of the Environment and Heritage, ERA and Earth-Water-Life (EWL) Sciences. Proposed design criteria have been derived from terrain analysis of natural analogue sites (Hollingsworth and Lowry, 2005). The physical parameters are slopes >10% are rock mulched and slopes <10% will be revegetated to surrounding natural conditions. Drainage lines generally drain through pre-mining drainage lines.

SIBERIA modelling was conducted to simulate 'best case' and 'worst case' scenarios at the end of a 1000-year period. Gully depth ranging from up to 3 metres (in the 'best case') to 8 metres (in the 'worst case') on the areas of the landform formerly occupied by Pits 1 and 3. This would indicate that further design work is required in these areas to minimise erosion.

The results of the design and modelling process described here are under review with the aim of addressing salient design issues and having an agreed construction plan when mining ends in 2008. Detailed understanding of the long term ecological implications of landform design are still being developed from better descriptions of ecosystem variation and the water balance in analogue areas. The results of the SIBERIA landform modelling will be incorporated into the design process such that the final landform design will be both physically stable and ecologically sustainable over the long term.

6.2 Future Work and Direction

A trial landform area will be constructed in the late dry season of 2006 using run of mine materials and landform design and cover specifications described above. This landform will provide a large scale platform on which to test the effectiveness of the proposed design parameters for meeting the erosion stability objective and to assess the effects of a developing vegetation community on controlling erosion processes. In addition, this work will establish what constraints waste rock cover materials are likely impose on long-term ecological outcomes, particularly from a water balance perspective.

Further work needs to be done, specifically to update the boundary files used in the modelling to incorporate more detailed drainage characteristics, which would enable areas of open water or deposition zones to be included in the model. However, the current process is able to perform distributed erosion modelling. This has enabled 'best case' and 'worst case' scenarios to be modelled with confidence within a range of erosion and deposition parameters.

In addition, we plan to further upgrade the modelling capabilities of SIBERIA to enable the modelling of extreme rainfall events. Currently, SIBERIA uses long-term average rainfall characteristics as input into the model. The incorporation of extreme events into the modelling process is a critical component of the validation of the proposed design parameters.

As the life-of-mine plan is updated with details of pit void and waste rock volumes, further design work and evaluation is required to:

- Account for retention or dismantling of mine infrastructure.
- Account for constructed wetlands that may be needed to improve water quality in drainage from the post-mining landform.
- Provide detail on surface treatments for drainage and revegetation.
- Provide cost comparisons for different landform options.
- Simulate soil development and geomorphic change in the landform and identify possible changes to hydrological properties and ecological function over time.
- Assess the impacts of erosion / deposition on the rehabilitated landform to the broader catchment.

Stakeholder assessment and community consultation on cultural heritage and land use values need to proceed in close consultation with mine planning processes to ensure that acceptable design outcomes are achieved.

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