Appendix 20.

SLR Consulting Australia (2020k) *Rum Jungle Rehabilitation – Stage 2A Detailed Engineering Design – Waste Storage Facilities and General Site Civil Works, Detailed Design and Construction Methodology Report*. Report to the Department of Primary Industry and Resources, Northern Territory.

NORTHERN TERRITORY GOVERNMENT

Department of **Primary Industry and Resources**

RUM JUNGLE REHABILITATION - STAGE 2A DETAILED ENGINEERING DESIGN

Waste Storage Facilities and General Site Civil Works Detailed Design and Construction Methodology Report

Prepared for:

Department of Primary Industry and Resources
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SLR

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BASIS OF REPORT

This report has been prepared by SLR Consulting Australia Pty Ltd (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Department of Primary Industry and Resources (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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DOCUMENT CONTROL

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CONTENTS

CONTENTS

CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

APPENDICES

CONTENTS

1 Introduction

1.1 Project Background

The Northern Territory Government (NTG), represented by the Department of Primary Industry and Resources (DPIR), proposes the rehabilitation of the former Rum Jungle Mine site (the Project), located 6 km north of Batchelor, Northern Territory (NT). The project location and regional setting are shown on **Figure 1**.

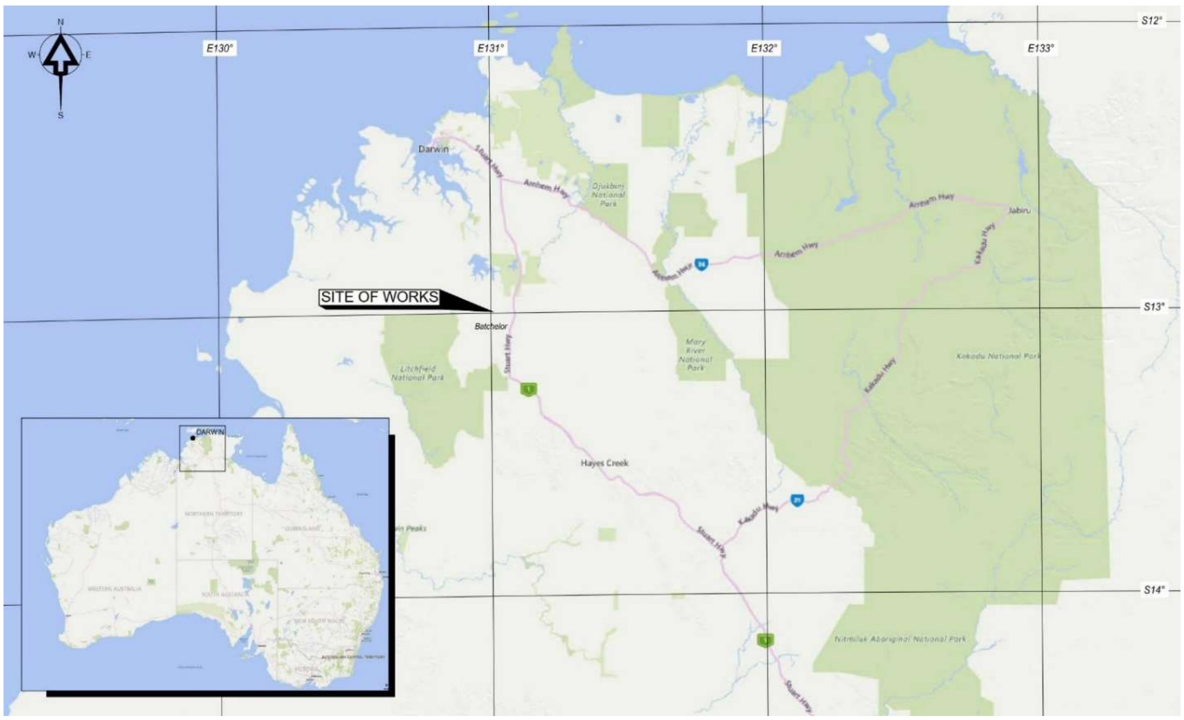


Figure 1 Project Location

The former Rum Jungle mine was rehabiliated in the 1980s, however recent studies indicate that not only has the site deteriorated and needs further rehabilitation, but that the traditional Aboriginal owners' cultural requirements have not been met. Since 2009, the NTG and the Australian Government have been working under a National Partnership arrangement to complete investigative work to inform a rehabilitation plan, deliver site maintenance and continue environmental monitoring. The results of these programs have been used to develop an improved rehabilitation strategy that is consistent with the views and interests of traditional Aboriginal owners and that meets contemporary environmental and mined land rehabilitation standards.

The Project's high-level objectives are two-fold and focus on environmental remediation and restoration of cultural values of the site as described below:

- Improve the environmental condition onsite and downstream of site within the East Branch Finniss River (EBFR). This includes the following key outcomes:
    - Improved surface water quality conditions within EBFR in accordance with locally derived water quality objectives (LDWQOs);
    - Achieve chemically and physically stable landforms;

    - Support self-sustaining vegetation systems within rehabilitated landforms; and
    - Develop physical environmental conditions supportive of the proposed Land Use Plan.
- Improve site conditions to restore cultural values. This includes the following key outcomes:
    - Restoration of the flow of the EBFR to original course as far as possible;
    - Remove culturally insensitive landforms from adjacent to sacred sites and relocate ensuring a culturally safe distance from the sacred sites;
    - Return living systems including endemic species to the remaining landforms;
    - Preserve Aboriginal cultural heritage artefacts and places;
    - Isolate sources of pollution including radiological hazards; and
    - Maximise opportunities for Traditional Owners to work onsite to aid reconnection to country.

1.2 Rehabilitation Strategy

The rehabilitation strategy has been developed from an understanding of current site conditions, contamination processes and a Land Use Plan goals as established with Traditional Owners. There are several key elements that have been incorporated in the strategy in order to satisfy the cultural needs of sacred site Custodians. Full details of the rehabilitation strategy, including a comprehensive project background description can be found in the Draft Environmental Impact Statement prepared by DPIR (NT-DPIR, December 2019).

1.2.1 Remediation Action Plan

The actions planned to address contamination processes and improve prospects of future land use are:

- Slow down or halt the Acid Metalliferous Drainage (AMD) production reactions from waste rock onsite by consolidating waste rock dumps (WRD) into one of three new facilities based on Potential Acid Forming (PAF) characteristics. These facilities are:
    - Main Pit backfill zone;
    - West Waste Storage Facility (WSF); and
    - East WSF.
- Slow down or halt the future generation and transportation mechanisms for copper and other metals in the new WSF by adopting leading practice methodology for storage of PAF waste rock.
- Treat existing groundwater sources (i.e. the Main and Intermediate WRDs) that contaminate the EBFR by pumping and treating these impacted waters.
- Treat other AMD-impacted groundwater that does not contribute to the EBFR copper load (i.e. old ore stockpile area) by pumping and treating these impacted waters.
- Isolate radiological and AMD affected soils at the Rum Jungle site and Mt Burton from environmental and human receptors by relocating these soils to the new WSFs on site.
- Isolate asbestos materials at the Rum Jungle site from environmental and human receptors by removing from surface soils and relocating to the new WSFs or by another approved means offsite.

1.2.2 Reestablishment of Cultural Values

The actions that are planned to address the compromised environmental and cultural values that are not related to contamination processes are:

- Return the EBFR to its original course as far as possible;
- Restore land parcels that are poorly vegetated such as the Old Tailings Dam area and vine thicket stand; and
- Revegetate new landforms to stabilise the surface and restore ecological function as far as practicable.

1.3 Stage 2A Detailed Engineering Design

SLR Australia Pty Ltd (SLR) has been engaged to deliver the Stage 2A detailed engineering design to meet the engineering requriements for construction of the rehabiliation strategy (referred to as Stage 3 Rehabiliation Construction). This WSF and general civil site works reports forms part of the design works. For full design details refer (SLR, 2020a).

2 Objectives and Scope of Civil Works

The scope of civil works covered in this design and constructability report are:

- New Waste Storage Facilities (WSFs);
- General earthworks covering:
  - Rehabilitation of excavated footprints; and
  - Rehabilitation of footprints after infrastructure removal (existing and construction related).
- Ancillary support works including:
  - Haul road development; and
  - Culvert river crossing;
- Cultural Centre.

Note that the design of civil and earthworks associated with the following are covered under separate reports:

- Surface water management and erosion and sediment control (SLR, 2020b);
- External borrow pit development (SLR, 2020c);
- Realignment of the EBFR (SLR, 2020d); and
- Re-profiling of the Main Pit rim (Drawing 680.10421.MPS.D15 and D16) (refer **Section 10.2**).

Objectives and scope for each of the above are detailed in the following sections.

2.1 Waste Storage Facilities

PAF waste rock and impacted soils from various locations across the Rum Jungle project are to be relocated to new WSFs. The scope has included:

- Design of the two new WSFs – East WSF and West WSF, including:
  - Siting;
  - Landform; and
  - Capping requirements.
- Recommended construction methodologies to meet:
  - Strict geochemical and geotechnical quality control requirements for the WSFs;
  - The Radiological Soils Management Plan (EcOz, 2019a); and
  - Consideration of weed management.

The primary purposes of the development of the WSFs is to encapsulate PAF waste rock and impacted soils, with the aim of preventing AMD from the WSFs and ongoing impacts to the groundwater and surface water systems.

The highest PAF (PAF-I) material is to be prioritised for backfill in the Main Pit, which includes the Intermediate WRD and Dysons Pit Overburden (Main Pit backfill details can be found in (SLR, 2020e)). The Main WRD will be prioritised for any remaining void capacity in the Main Pit after those.

The remaining waste locations will therefore be relocated to the WSFs including:

- Remainder of the Main WRD;
- Main North WRD;
- Mt Burton WRD;
- Radiological soils (that sit outside the WSF footprint);
- Copper impacted heap leach soils;
- Impacted soils in the old stockpile area (that site outside the WSF footprint); and
- Miscellaneous salt and metal impacted soils.

In addition to the above, waste rock at Mt Fitch is to be relocated to the Mt Fitch open pit.

To prevent AMD from the WSFs, the waste rock materials are to be placed and treated in line with strict geotechnical and geochemical quality requirements. Similarly, the radiological and impacted soils will require specific quality treatments. The footprints of the existing WRDs and contaminated soils will also require treatment to prevent surface and groundwater impact.

Figure 2 shows the layout of the WRDs and impacted soils and the footprints of the new WSFs.

Details of the WSFs designs can be found in **Section 3** as well as the Detailed Engineering Drawings referenced in **Section 10.2**.

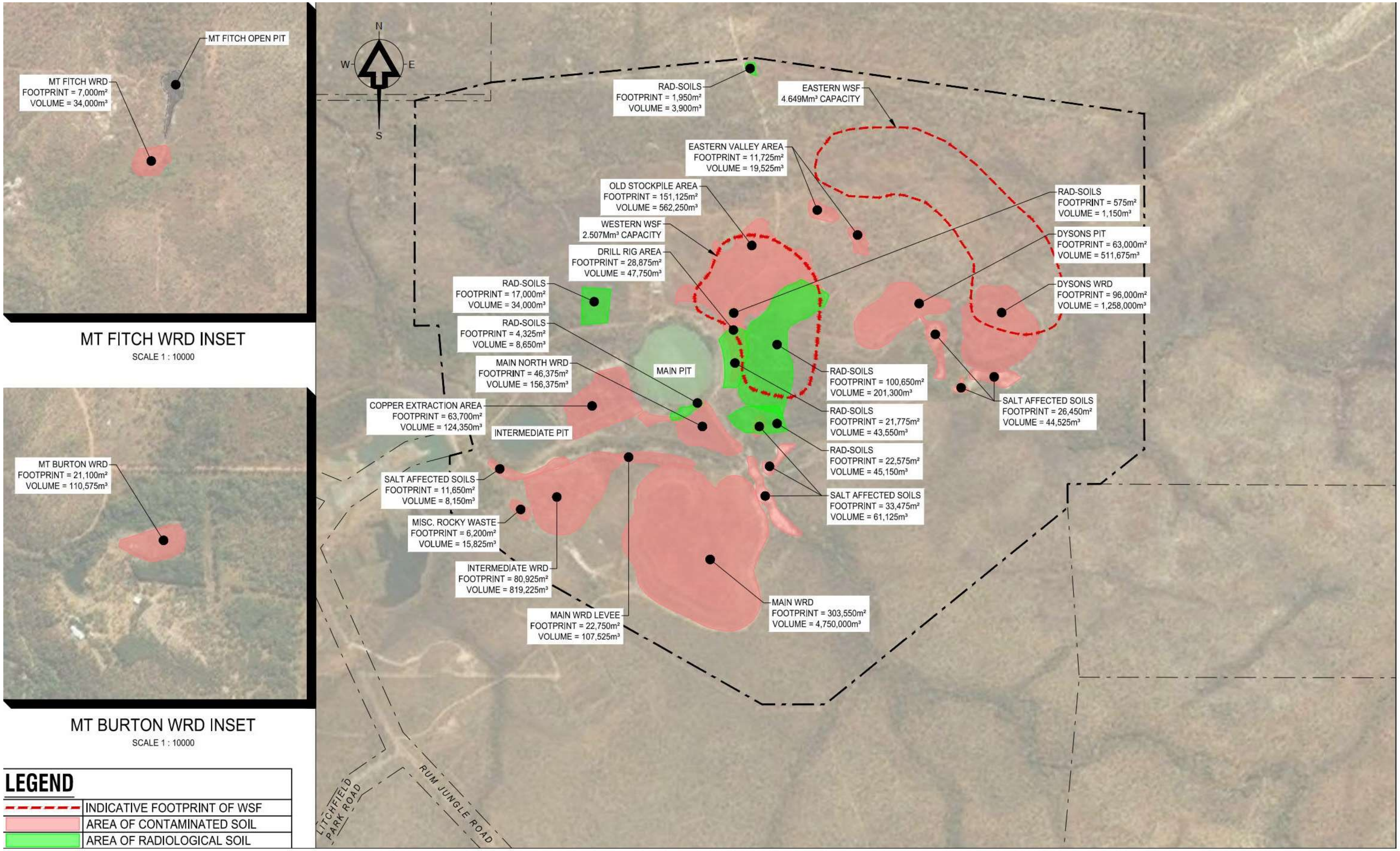


Figure 2 Waste Rock and Impacted Soil Areas

2.2 General Earthworks

After removal of the WRDs and other impacted materials remediation of the exposed footprints will be required as follows:

- WRDs that have been contributing AMD will require lime treatment of exposed footprints;
- All exposed footprints, including WRDs, areas of impacted soil and removed infrastructure will require backfilling to either grade or above grade, with general fill; and
- Dysons Pit Overburden footprint will require an engineered cap.

Design details are discussed in **Section 5.**

2.3 Ancillary Support Works

2.3.1 Haul Roads

All-weather haul roads are required to allow waste rock and impacted soils to be hauled to the new WSFs and Main Pit backfilling area as well as allow deliveries to site.

To meet the geotechnical and safety requirements for WSFs construction, including limited layer thickness placement and relatively narrow starter bunds, it is proposed that articulated dump trucks (ADTs) be used for material movement, and the internal haul roads have therefore been designed for 40t ADTs.

Details of the haul road design are contained in **Section 9.1**.

Haul roads are to be removed at the end of construction.

2.3.2 Diversion Drain Crossing

An all-weather haul road crossing is required at the EBFR Diversion Channel to allow waste rock to be hauled from the Intermediate WRD, Main WRD and various other impacted sites. The crossing will also support the delivery of materials to site.

SLR undertook an options assessment using a Multi-Criteria Analysis in January 2019 to establish the type of crossing and flood immunity required (SLR, 2019). The results, and ultimate agreement with DPIR, were:

- Culvert crossing; and
- 1:5 year ARI flood immunity.

Details of the culvert design are contained in **Section 9.2**.

The culvert is to be removed at the end of the construction works.

2.4 Cultural Centre

The Traditional Owners (TOs) have expressed a strong interest in the construction of a cultural centre. The cultural centre will communicate the history of Kungarakan and Warai peoples, and the importance of Rum Jungle to them: their displacement during mining, details of mining itself and the Rehabilitation Project. In addition, if artefacts require relocation during construction, they will be managed as per the Cultural Heritage Management Plan (CHMP) and potentially displayed within the cultural centre as per TO requirements. Further details of potential artefact relocation are detailed within Chapter 8 – Historic and Cultural Heritage of the Draft EIS (NT-DPIR, December 2019). While the proposed location of the cultural centre is yet to be decided, indicative locations are noted on Figure 2-7 of the EIS (Ref Drawing 680.10421.EIS.D07). The cultural centre is planned for construction in Stage 3, and the final location and layout for this facility will be determined in consultation with TOs.

A conceptual layout and list of minimum centre requirements are contained in the Cultural Centre design memo contained in **Appendix A**.

The Cultural Centre is proposed to remain on site as a permanent structure.

3 WSF Design

This design and construction methodology for the WSFs details the:

1. Design of the WSFs to establish landforms that meet environmental and cultural requirements;
2. Order of material movement, placement and treatment of waste rock and impacted soils to the WSFs;
3. Quality Assurance / Quality Control (QA/QC) requirements; and
4. Assumed construction production rates.

3.1 Siting

At the request of DPIR, SLR undertook a siting study to determine if the WSF footprint developed in the Stage 2 Design (OKC, 2016), i.e. the northern site, was still the preferred option. The study examined a total of four (4) sites to arrive at the most suitable based on meeting the following criteria:

- Are not prone to flooding in a 1:1,000 Average Recurrence Interval (ARI) event;
- Have suitable foundation geotechnical stability;
- Require minimal clearing of established vegetation;
- Minimise re-handling of radiological soils by covering the major remnants *in situ*;
- Do not disturb Aboriginal places, objects or artefacts; and
- Do not present unacceptable visual amenity impacts.

The study is contained in **Appendix B** with recommendations summarised below:

It is recommended that the central site (now referred to as the West WSF) be developed as first priority, with any remaining capacity requirements developed at the central east site (now referred to as the East WSF), however refinement of block modelling would be required to optimise material haulage and thus reduce costs (refer **Section 7**). No development at the southern or northern sites is recommended. In addition to the criteria discussed above, key considerations for the footprint development will be to ensure:

- Appropriate set back from the Main Pit to allow ongoing access for cultural reasons; and
- Appropriate set back from riverine areas.

The WSF footprint locations are shown in **Figure 2** and the Detailed Engineering Drawings referenced in **Section 10.2.**

3.2 Landform Modelling

Landform modelling has included consideration of:

- Volume of material to be placed;
- Maximum height; and
- Side slope angle and configuration.

3.2.1 Volume Calculation

Modelling has been undertaken to estimate the required volume of the WSFs based on:

- LIDAR data from 2015;
- Planned WRD and impacted soil footprint excavated depths; and
- Consideration of material to be placed as backfill in the Main Pit, using 2015 bathymetry.

The modelling indicates the volumes as shown in **Table 1**.

Table 1 WRD and Contaminated Soil Volumes

Location	Footprint Area	Volume*	Material Type
Intermediate WRD	80,925 m^2	734,900 m^3	PAF I
Main WRD	303,550 m^2	4,529,675 m^3	PAF II and PAF III
Dysons Pit Overburden	63,000 m^2	443,425 m^3	PAF I
Dysons Waste Rock Dump	96,000 m^2	1,190,250 m^3	PAF III and NAF
Main North WRD	46,375 m^2	119,000 m^3	PAF II and PAF III
Copper Extraction Area	63,700 m^2	143,050 m^3	Impacted soil
Radiation Soils (to be relocated)	74,325 m^2	135,725 m^3	Radiological soil
Old stockpile area (to be relocated)	16,850 m^2	62,700 m^3	Metal impacted soil
Metal and salt impacted soils	58,350 m^2	12,400 m^3	Impacted soil
Main WRD Levee	22,750 m^2	68,975 m^3	Impacted soil
Miscellaneous rocky waste	4,550 m^2	2,850 m^3	Impacted soil
Mt Burton WRD	21,100 m^2	110,575 m^3	PAF III
Mt Fitch WRD	7,000 m^2	10,000 m^3	PAF III
TOTAL VOLUME TO BE RELOCATED		**7,563,525 m^3**	

* Includes over-excavation of footprint area as per **Section 5.**

In order to minimise AMD generation, the highest PAF grade material is to be placed in the Main Pit as backfill (SLR, 2020e), which will be the Intermediate WRD and Dysons Pit Overburden, with any remaining capacity filled with Main WRD material. The material relocation strategy has been developed as shown in **Table 2**.

Table 2 Material Relocation Strategy

Source Location	Destination Location	Volume
Intermediate WRD	Main Pit	734,900 m^3
Dysons Pit Overburden	Main Pit	443,425 m^3
Main WRD	Main Pit	295,783 m^3
	WSF	4,233,892 m^3
Dysons WRD	WSF	1,190,250 m^3
Main North WRD	WSF	119,000 m^3
Copper Extraction Area	WSF	143,050 m^3
Radiation Soils (to be relocated)	WSF	135,725 m^3
Old stockpile area (to be relocated)	WSF	62,700 m^3

Source Location	Destination Location	Volume
Metal and salt impacted soils	WSF	12,400 m^3
Main WRD Levee	WSF	68,975 m^3
Miscellaneous rocky waste	WSF	2,850 m^3
Mt Burton WRD	WSF	110,575 m^3
Mt Fitch WRD	Mt Fitch open pit	~10,000 m^3
	TOTAL VOLUME TO MAIN PIT	1,474,108 m^3 (SLR, 2020e)
	TOTAL VOLUME TO WSF	**6,079,417 m^3**

3.2.2 Maximum Height

To maintain sight lines for cultural requirements, the maximum height of the WSFs between the sacred sites nominated on the AAPA certification is RL98m. This applies to all of the West WSF and the southern section for the East WSF (**Appendix B**).

3.2.3 Side Slopes

The angles of the side slopes have been established to ensure overall slope stability and minimise erosion of the proposed capping. Full details of the side slope development are discussed in **Appendix C**.

3.2.3.1 Slope Selection

Historically, many reclaimed landforms have adopted linear slope designs. This approach offers simplicity, but the long-term landform performance is often unacceptable. Various studies have demonstrated that concave slopes offer a sediment transport reduction up to three-fold compared to linear ones (Priyashantha, 2009). As one of the main purposes for this assessment is to propose a landform able to minimise erosion, it was decided to test different concave shapes and determine the best option to implement in the final WSF design.

The initial WSF design (O'Kane Consultants Pty Ltd, 2016) contemplated the storage of more than 8.5Mm^3 which translated into a landform approximately 40m high accompanied by a trilinear concave slopes of 1:5 to 1:3.5 to 1:2.5 (see **Figure 3)**. According to (O'Kane Consultants Pty Ltd, 2016), this configuration was designed to maximise long term stability, provided the combination of gradients and climate, vegetation is expected to establish favourably on the lower shallower slopes.

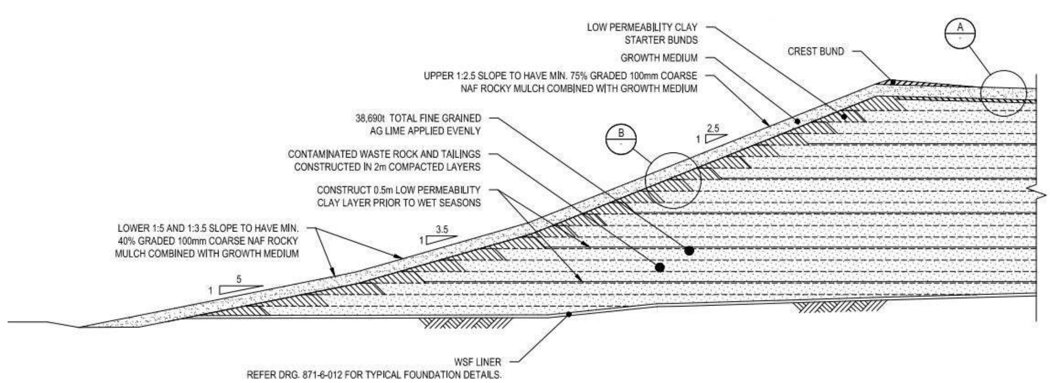


Figure 3 Typical Section, Containing a Trilinear Slope, Source: (O'Kane Consultants Pty Ltd, 2015).

The updated WSF design stores a smaller volume of around ~7Mm^3 (including covers) and with a lower height. Consequently, the updated proposed slope configuration was decided by removing the flatter lower segment (1:5). Eventually, an option of 1:3.5 to 1:2.5 (or 16° to 22°) was proposed, and subsequently two additional dual-slope options were proposed for assessment, one steeper and one flatter. The change in slope is located at the mid-height of the batter.

The capping design was established in the Stage 2 Engineering Design phase by O'Kane Consultants (OKC, 2016) and the details are discussed in **Section 3.5** following. In summary a 2.5m cap is proposed.

3.2.3.2 Erosion Modelling

Detailed erosion modelling has been undertaken based on flume laboratory testing and using the commercially available SIBERIA modelling software. The aim was to establish optimal side slopes that would minimise the likelihood of the 2.5m deep capping eroding, via either sheet erosion or gullying, leaving the waste rock exposed. Full details of the flume testing and SIBERIA modelling are given in the Erosion Modelling Report (SLR, 2020f) contained in **Appendix C**.

Stage 1 comprised the assessment of three slope scenarios modelled using representative soil erosion parameters with no vegetation cover for 500 years. The East WSF was selected to perform this series of analyses as it has more geometric variety compared to the West WSF. **Table 3** graphically represents the dual slopes that have been considered in these assessments, together with the hillshades of the three concave dual slopes for Stage 1 pre-erosion condition at East WSF.

The modelling indicates that the low concave slope with the geometry as shown in **Table 3** performed better than the other two. Thus, 9° to 14° dual slope was used to include vegetation establishment and assess its erosion performance for 500 years in stage 2. Both WSF's were included in the assessment and the soils loss maps and hillshades are shown in **Table 4** .

Table 3 Dual-slope Scenarios and Their Respective Hillshade Representation for EWSF Pre-Erosion.

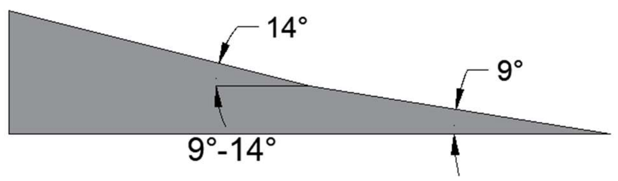
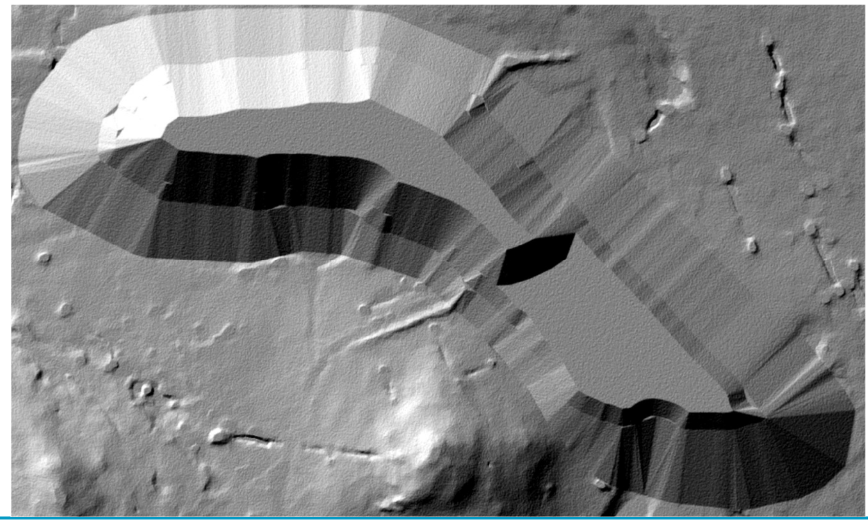
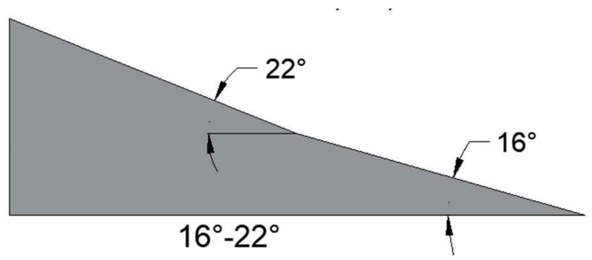
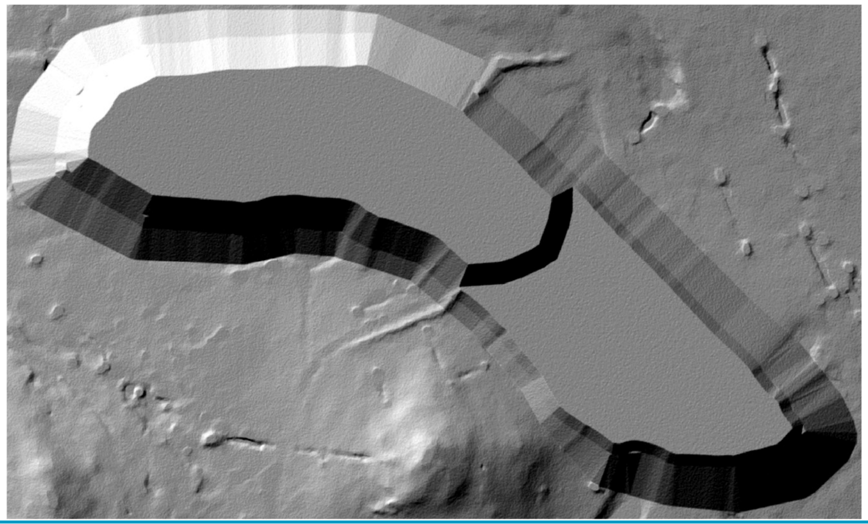
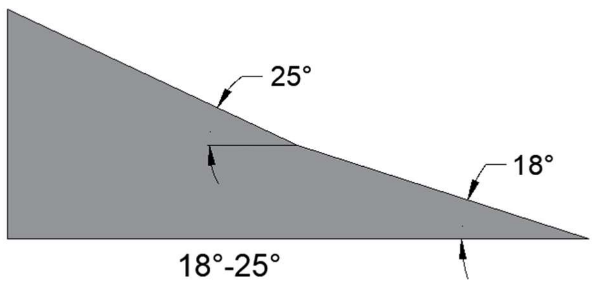
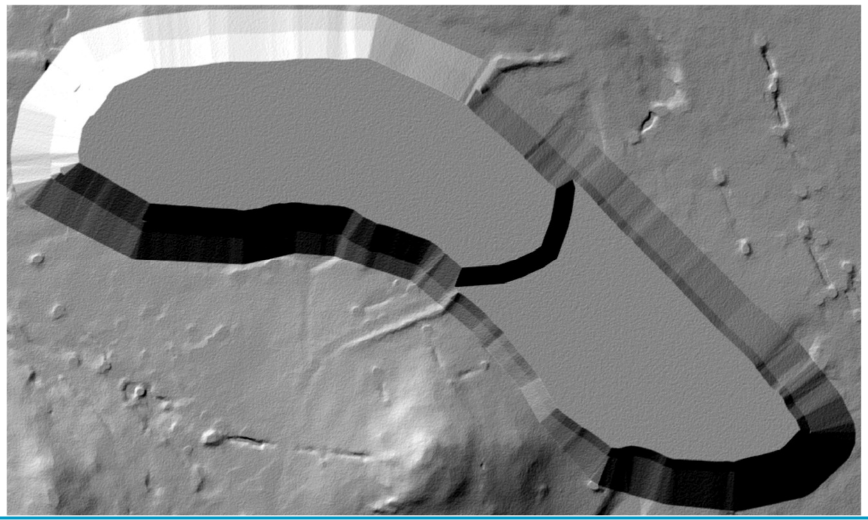
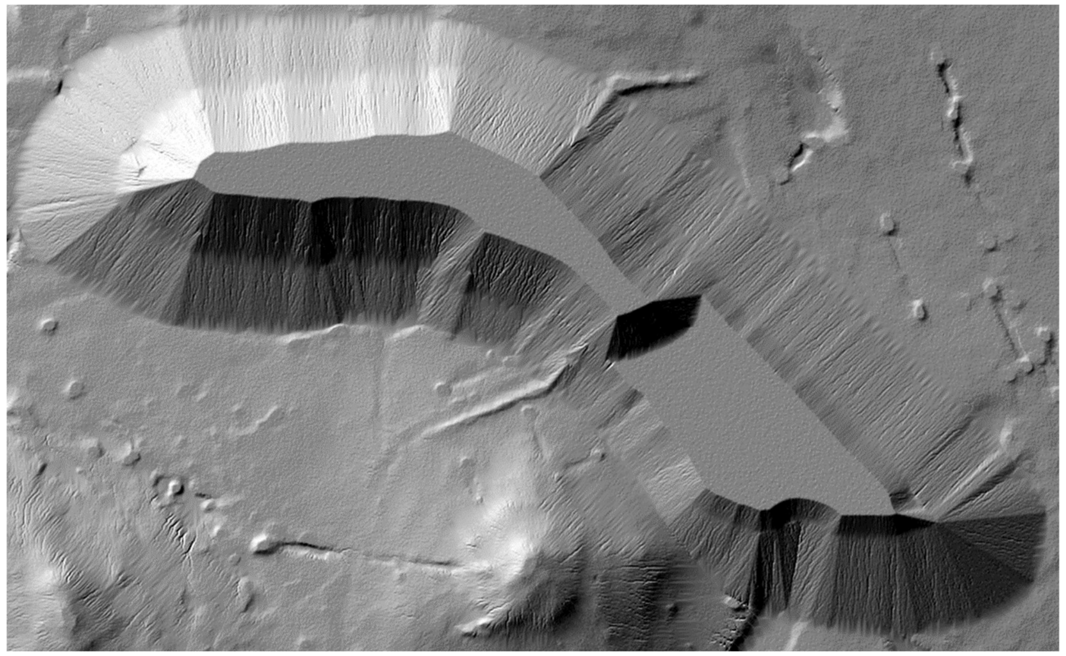
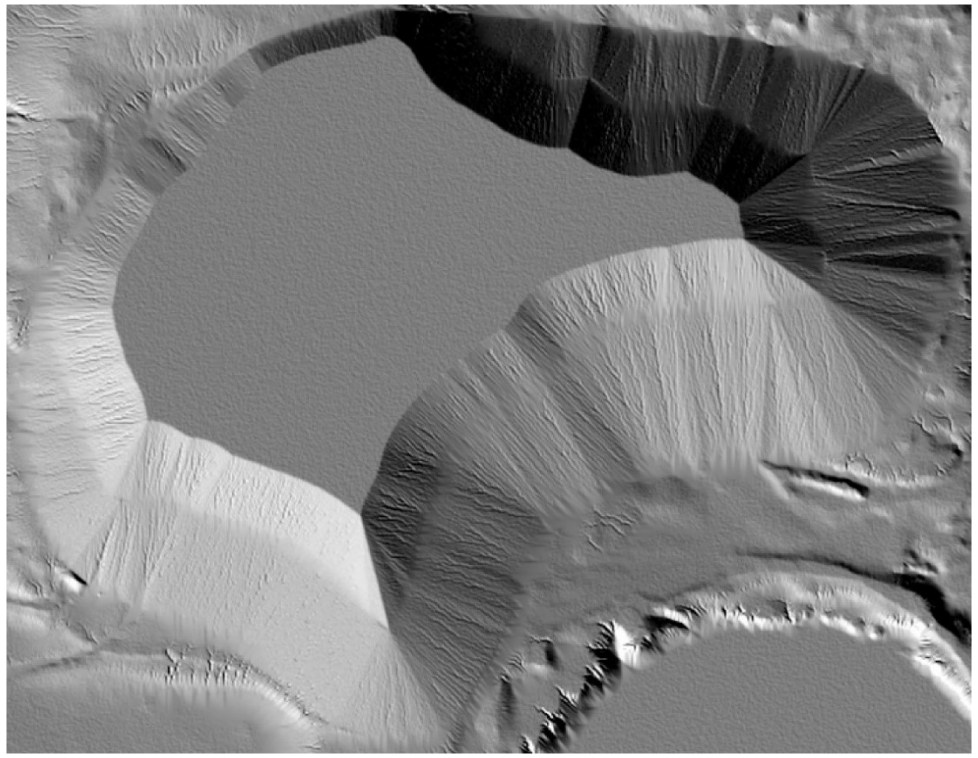
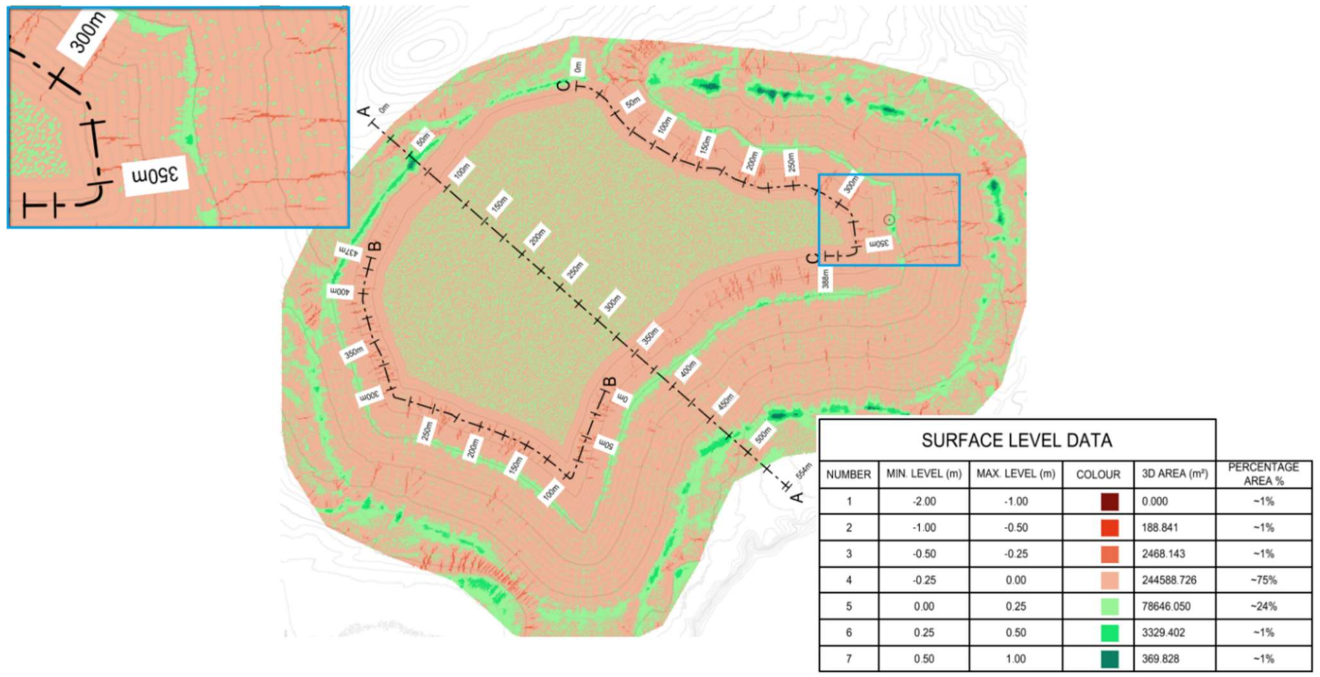
Dual Slope Scenarios	Hillshades	Description
		**Low Slope** **9° to 14°** (1:6.25 to 1:4 (V:H))
		**Medium Slope** **16° to 22°** (1:3.5 to 1:2.5 (V:H))
		**High Slope** **18° to 25°** (1:3.08 to 1:2.14 (V:H))

Table 4 Stage 2 Hillshades and their respective Soil Loss Maps for EWSF and WWSF After 500 Years.

<table>
<tr><th>Eroded Hillshades</th><th>Soil Loss Maps</th><th>Description</th></tr>
<tr><td></td><td>
</td><td>East Waste Storage Facility

9° to 14° Dual Slope
(1:6.25 to 1:4 (V:H))</td></tr>
<tr><td></td><td>
</td><td>West Waste Storage Facility

9° to 14° Dual Slope
(1:6.25 to 1:4 (V:H))</td></tr>
</table>

SLR

Based on the results presented in this report it is conclude that:

- The recommended batter slope to prevent excessive erosion/gully incision into the capping materials is 9°to 14° dual-slope.
- Vegetated cover models predict that the proposed cover depth of 2.50 m is not likely to be reached after 500 years.
- The maximum gully depths are localised and represent a minor percentage in terms of area.
- Although the models show a good performance in terms of erosion, it is recommended that:
    - The portion of the dual slope whose slope is 14° and localised near the top of the batter is the most vulnerable part of the East WSF, so a different vegetation configuration should be prescribed, using species able to withstand larger runoff speed compared to the plateau;
    - The change in slope needs to be smoothed in the construction phase (refer Section 3.2.3.3), so the abrupt change does not become an erosion seeding feature;
    - A rapid and consistent vegetation cover should be chosen to minimise the chance to cause early deterioration of the bare soil; and
    - Rock armouring is a good option to prevent erosion, however, direct sun exposition can lead to hot temperatures that may 'cook' the vegetation in contact. Therefore, this solution should only be adopted under specific circumstances where the associated risk can be overcome.
- There is currently no wide agreement on what can be considered as 'acceptable' rate of erosion on a mine site. However, the Queensland Department of Minerals and Energy (QDME) 'target erosion rate' for rehabilitated spoil is 12 to 40 t/ha/yr (Society for Mining, Metallurgy, and Exploration, Inc., 2000). The proposed vegetation establishment shows that after 500 years the erosion rate is around 0.4 m^3/ha/yr. Considering a material bulk density of 1.25 t/m^3 the erosion rate can be expressed as 0.5 t/ha/yr. This value is significantly lower than the specified by QDME.
- The selected slope provides a landform able to accommodate the volume within the desired footprint. In addition, it offers a similar visual scenario compared to the existing surrounding natural features.

3.2.3.3 Recommendations for Construction Stage

It is important to note that the WSF landforms that have been used were in draft at the time of initial modelling. Although the results indicate that the erosional performance is acceptable, it is important to understand that modelling relies on assumptions and/or simplification in order to obtain results. These assumptions relate to shape (plan and elevation geometry) and material (soil and vegetation) and it is recommended that these be assessed or refined further before the design is ready for construction.

Recommendations for finalising the design relate to activities that can be undertaken during the construction phase, include:

- All borrow materials tested and modelled are assumed to be representative of all borrow materials. Geotechnical parameters should be reassessed via flume testing and/or field tests prior to construction to ensure that the they comply with specification envelopes; alternatively, materials can be conditioned to meet the values required here and/or modelling could be updated.

- The type and rate of revegetation is critical to controlling erosion. The Project revegetation plan (which is to be developed by DPIR prior to construction) should be representative of the data provided within this report; alternatively modelling to estimate likely erosion under the proposed revegetation plan should be undertaken.
- Sharp edges at crests, change of batter slope and the toe should be avoided as these act as seeds for localised gully erosion. A continuous and soft concave interface should be developed as shown in **Figure 4**.

  Smoothing the WSF's in these three aspects will result in a more natural, visually pleasant geometry which combined with the 9° to 14° dual slope will blend with the natural surroundings.

Figure 4 Final expected concave shape including vegetation

- The final landform should be based on the DTMs that have been provided by SLR as part of the final design package (SLR, 2020a). However, it is acknowledged that the WSFs landform may change from the final design due to changes in material assumptions during construction (i.e. bulking factors, compaction factors etc.) or unexpected finds on site. Therefore, ongoing updates to the WSF design, including consideration of erosion requirements, will be required during design.
- Quality control is crucial in terms of material placement such as foundation preparation, density and compaction, layer thickness, organic material content or any other specification need to be among the desirable limits to assure integrity and stability. Failure to provide this will translate in failure of the designed facilities even at a small scale, where a simple settlement will act as an initial state to deteriorate a whole capping system.

3.3 Foundation Preparation

As per (RGC, November 2019) there is to be no lining of the base of the WSFs as the foundation geology has been assessed to have the capacity to neutralise AMD before it reaches the EBFR, i.e. seepage will be managed by natural attenuation. Foundation preparation will include ripping and compacting of the top 300mm to an equivalent density of 98% Standard Maximum Dry Density, and a moisture content within the range of ± 3 % of Standard Optimum Moisture Content.

The foundation surface is to be compacted to provide a stiff, stable surface of adequate bearing strength. The surface will be free from areas of soft material, proof rolled and inspected for soft areas and free from debris, roots and unsuitable material.

3.4 Starter Embankments and Oxygen Scavenging

Starter bunds are to be formed around the circumference of the WSFs to provide stability and a competent platform on which to form the cover system (refer **Section 3.5**). As recommended by (RGC & Jones, 2019) an oxygen scavenging layer is also to be formed over PAF material and beneath the formal cover system if sufficient material is available. This oxygen scavenging layer provides an additional barrier to reduce oxygen influx to the PAF material.

Dysons WRD material is generally considered non-acid forming (NAF) to very low PAF and has been identified as oxygen scavenging. It is therefore proposed to use it to form the starter bunds as well as beneath the formal cover system on the plateau of the WSFs.

Dysons WRD contains approximately 1,190,250 m^3 of NAF/low PAF waste rock. A nominal depth of 2m is recommended for the oxygen scavenging layer. The distribution of Dysons WRD is therefore to be as follows:

- East WSF Plateau – 2m layer, totalling 135,000m^3
- West WSF Plateau – 2m layer, totalling 167,000m^3
- Remaining volume for starter bunds is 888,000m^3

The starter bund geometry has been determined based on the following:

- Maximum height: 1.00m
- Crest width: 7.00m
- Available volume: 888,000m^3
- The above starter bund dimensions give approximately 1.70m thick oxygen scavenging layer perpendicular to the slope on upper 1V:4H WSF slopes and 1.10m thick oxygen scavenging layer perpendicular to slope on the 1V:6.25H WSF slope. The dimensions also provide a safe height and width for construction.
- The thickness objective for the oxygen scavenging layer is 2.0m perpendicular to slope (**Figure 5)**. Current modelling indicates there is insufficient volume in Dysons WRD to provide the volumes necessary for this objective. The current starter bund dimensions reflect the optimal dimensions to provide the greatest thickness considering material availability and construction scheduling. Starter bund dimensions should be reviewed periodically throughout construction against Dysons WRD material availability. Where possible, priority shall be given to widen the starter bund crest within the 1V:6.25H slopes if projected material availability allows.
    - A starter bund crest width of 8.20m on 1V:4H WSF will provide ~2.0m perpendicular oxygen scavenging layer thickness.
    - A starter bund crest width of 13.00m on 1V:6.25H WSF will provide ~2.0m perpendicular oxygen scavenging layer thickness.

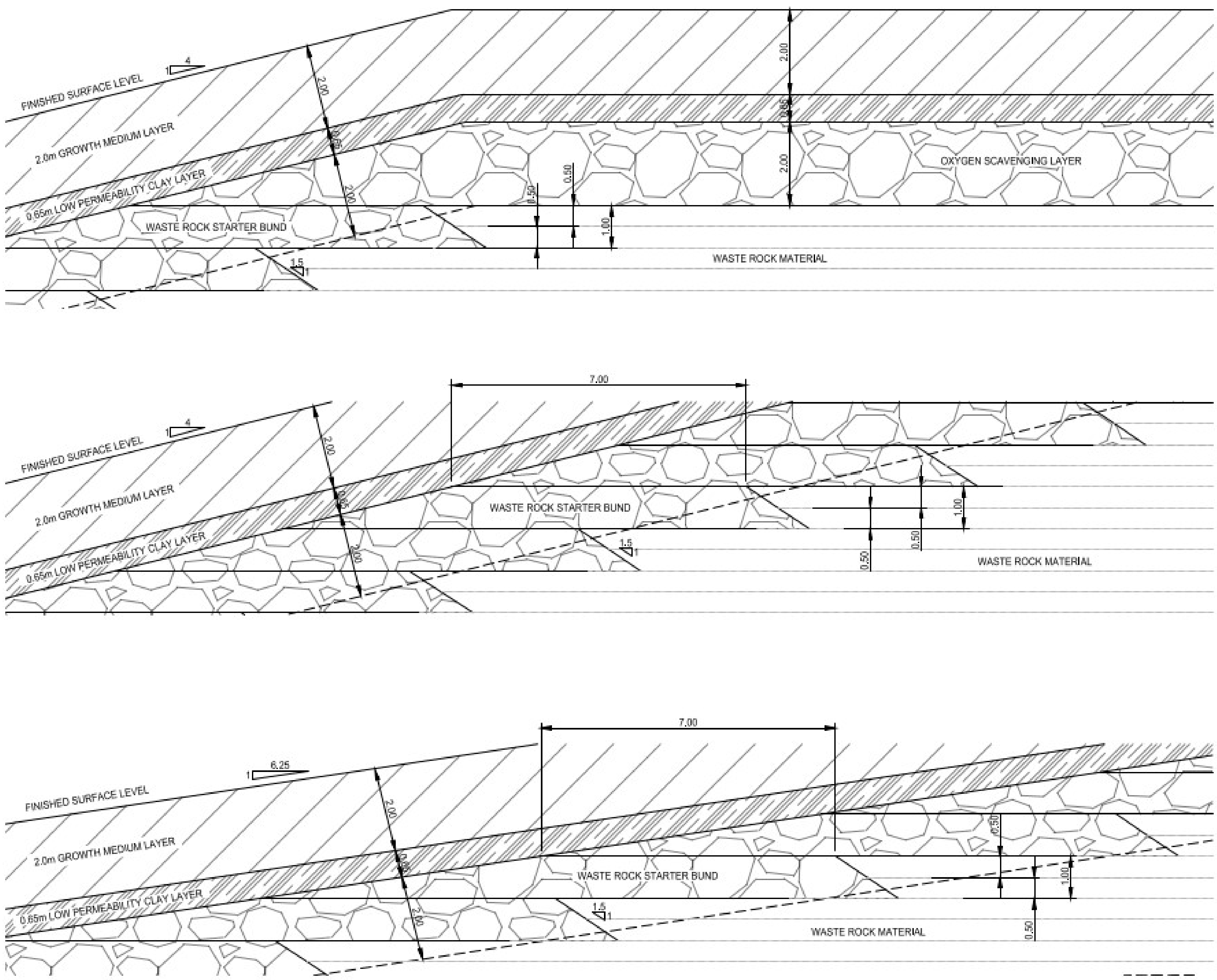


Figure 5 Starter Bund Geometry

Whilst generally performing as NAF, it is recommended that the Dysons WRD material be treated as low-PAF material and will therefore require lime treatment, refer **Section 4.8**.

Placement and compaction of the starter bund layers is to be undertaken in accordance with Australian Standard AS 3798-2007 *Guidelines on earthworks for commercial and residential developments* and **Table 5.**

Table 5 WSF Starter Bunds Specification

Parameter	Specification
Material Source	Dysons Waste Rock Dump
Starter Bund Maximum Height	1.00 m
Starter Bund Maximum Crest Width	7.0 m
Starter bund outer slope	In accordance with WSF Landform Design
Maximum Lift thickness	0.25 m
Number of Lifts	≥4 total, WSF heights between 29-32m
Maximum Particle Size	200 mm
Maximum Lime Dose Rate	Refer Table 8
Compaction Density/Placement Requirements	• An equivalent density of 95 % of Standard Maximum Density; • Moisture content within the range of ±3% of Standard Optimum Moisture Content; • No deformation or spring observed in proof roll; and • No observed water ponding or over wet zones in layer.

3.5 Cover Design

Detailed cover modelling was undertaken by (OKC, 2016) as part of the Stage 2 rehabilitation design, and as agreed with DPIR (personal communication), no further modelling was required as the design was considered robust. The key components to the capping design, aimed at reducing oxygen and water ingress, included:

- 0.5m compacted low permeability layer (overlying the waste rock); and
- 2m growth medium layer.

In addition to the above (OKC, 2016) recommended:

- 0.5m rock mulch overlying the growth medium.

At the request of DPRI, SLR conducted an options analysis using the Multi-Criteria Analysis (MCA) approach to assess if any variations to the preferred capping design should be considered (excluding variation to capping thickness recommended by (OKC, 2016)). The MCA (SLR, 2020g) indicated:

- Capping for the WSFs crest should include:
    - Topsoil; overlying
    - 2m growth medium; then
    - 1.5mm LLDPE; then
    - 0.5m compacted clay liner.

- Capping for the WSFs batter slopes should include:
  - Topsoil; overlying
  - 2m growth medium; then
  - 0.5m compacted clay liner.
- Revegetation for all areas should include:
  - Broadcast native cover (the details of which are to be further developed by DPIR in consultation with their vegetation experts).

Figure 6 shows the recommended cover design.

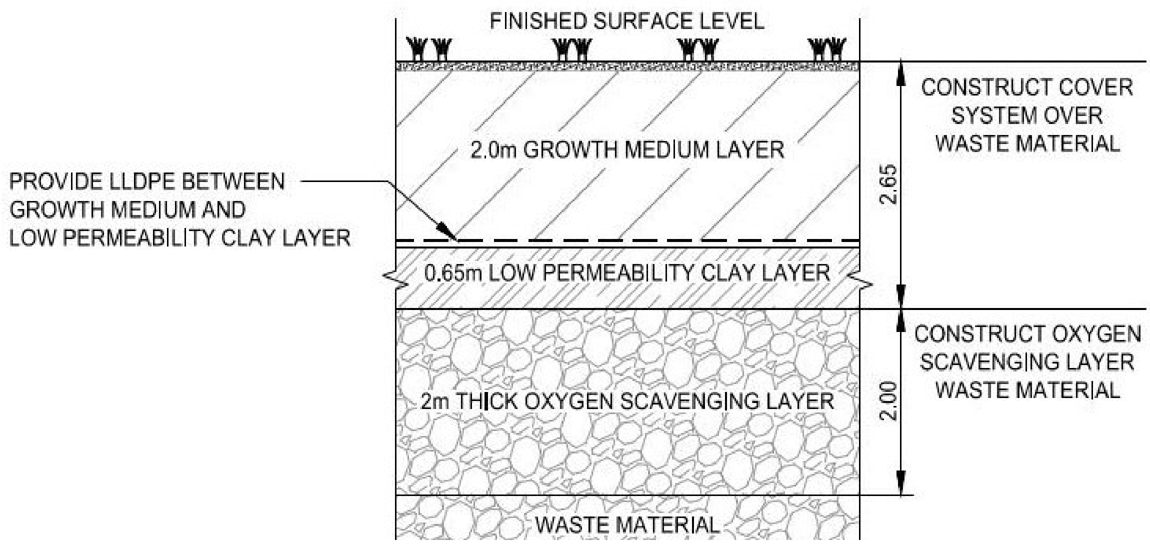


Figure 6 Cover Design

3.5.1 Growth Medium

A purpose-designed growth material has been designed to cover the new WSFs. The growth material is to provide a long-term, sustainable growing medium for selected native revegetation species. It is also to provide a reduced likelihood of, equal to or better than baseline for the area, sheet, rill, and gully erosion over the proposed life of the WSFs capping. The growth material will need to provide for moderately rapid stormwater infiltration and be moderately permeable to reach field capacity but also have sufficient clay content to provide some structure, water holding capacity, and mineral exchange and nutrient adsorption capacity to support revegetation with, and long-term sustainability of, native shrubs and grasses.

Full details of the proposed growth medium design are contained in the technical memo contained in **Appendix D.** This has design has been included in the erosion report contained in **Appendix C**.

3.5.2 Monitoring

3.5.3 Erosion Monitoring

The first 20 years after construction of the WSF's are vital to ensure that erosion performs according to the modelled predictions. It is recommended to develop a monitoring program for the first 7 years until vegetation establishment has achieved a minimum of 90% soil cover, with field checks every 6 month and/or after any storm event that produces runoff. In parallel, two DEM (LiDAR) checks are also required to assess whether there are any signs of deviation from the modelled predictions/normality developing that may not be readily visible in the field. These are required at the following frequency: one at 3.5 years and the second at 7 years.

From 7 to 20 years, provided vegetation has established to provide a soil cover greater than 90%, the majority of monitoring will be performed by DEM (LiDAR) monitoring in parallel with ground-truthing in the field. One DEM (LiDAR) check every 4 years and field checks every 12 months.

Should the aforementioned monitoring activities indicate the WSF's are presenting dissimilar behaviour compared to the modelled predictions, it is critical that immediate investigations are undertaken to identify the root causes of failure to design and implement appropriate maintenance works as early as possible.

The procedure to follow in order to determine possible issues, their causes and the corrective actions, if required, is provided in (SLR, 2020f) in **Appendix C** and will be included in the Owners Team Monitoring and Management Plan.

3.5.4 Capping Performance

Field performance monitoring systems are required to demonstrate that the facilities are meeting closure objectives. Assessment of oxygen and water ingress (during construction and post-construction), and water levels and quality are required to assess performance of the WSFs in terms of reducing net percolation and thus, the reduction in the formation and transport of oxidation products from the waste rock into the surface water and groundwater. The designed monitoring system consists of elements to measure surface water balance, net percolation, internal conditions of the waste rock (pore-gas concentrations, temperature and moisture conditions) and groundwater levels and quality (inside and outside the footprint of the facility). The proposed monitoring system includes a series of lysimeters and soil moisture monitoring stations as shown on **Drawings 680.10421.WSF.D12 to D14**. Typical details are given in **Figure 7** and **Figure 8.**

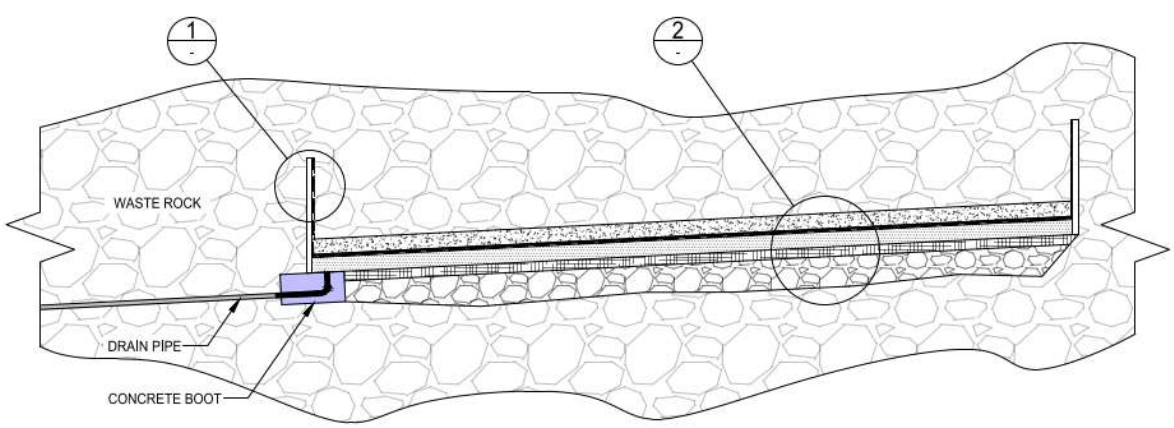


Figure 7 Typical Lysimeter Details

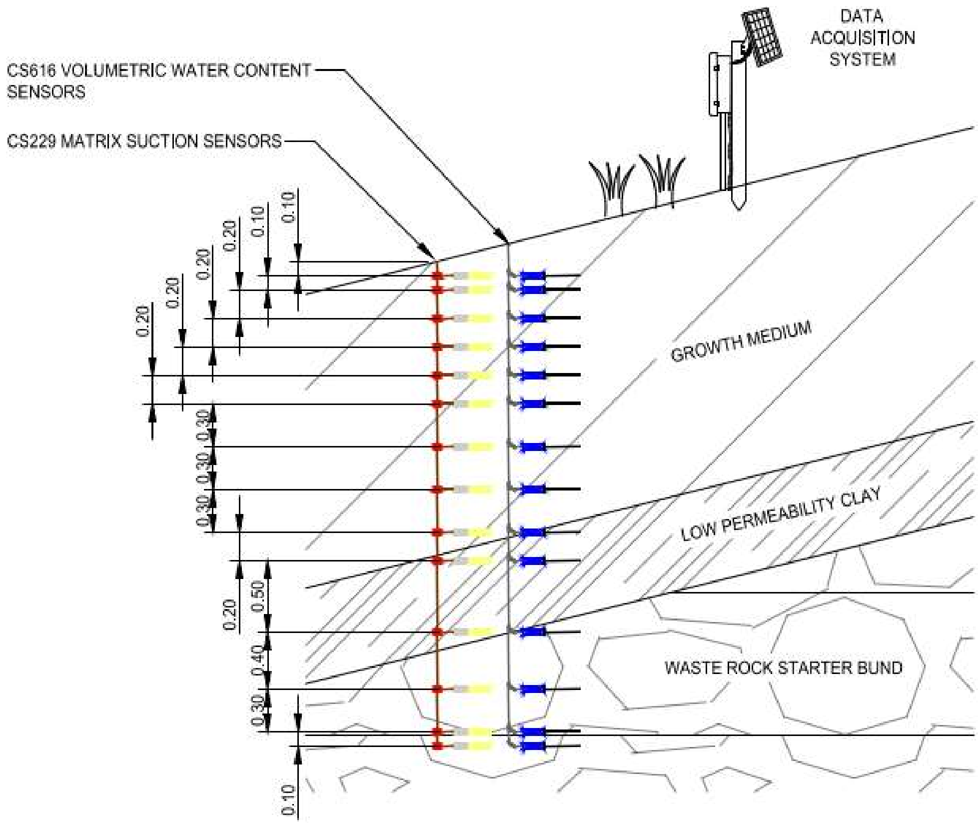


Figure 8 Typical Soil Monitoring Station Details

4 Material Movement and Construction Requirements

4.1 Objectives and Approach

Relocation of waste rock and impacted soils is to be scheduled so as to:

- Limit worker health and safety by minimising exposure to radiological materials during construction;
- Limit open faces of both the existing WRDs (during deconstruction) and the new WSFs (during construction) during wet season to minimise potentially contaminated runoff; and
- Ensure the worst PAF (PAF II and PAF III) are stored at the lowest elevation within the WSFs.

The construction methodology proposed therefore includes:

- Dysons WRD material will be used to form the starter embankments and beneath the formal cover system, to act as an oxygen scavenging layer.
- Upon placement, waste rock (including starter embankments) will be lime-treated and then compacted in controlled layers (starter embankments at 0.3m and waste rock at nominally 0.5 m layers) to increase density, water residence time and saturation, and create an alkaline environment;
- The WSF will be built up vertically over a number of cells to allow part or all of the cover system to be constructed prior to the Wet season for each cell;
- Construct outer surfaces to final geometry within the placement cycle to expedite final surfaces available for revegetation covers;
- Construction of cover systems progressively alongside the waste rock lifts and progressive revegetation of cells and cover system surfaces to reduce rainfall infiltration during construction and to stabilise the outer surfaces as rapidly as possible; and

Based on the above, a high-level approach to the construction of the WSFs can summarised as follows:

- Cell 1:
    - Install ESCP relevant to the Cell;
    - Foundation treatment;
    - Form starter bund from Dysons WRD (1st lift);
    - Place relocated WRD and/or impacted soils (in the order as per **Section 4.2**);
    - Place low permeability cover layer (in parallel with WRD/impacted soil works);
    - Place growth medium to cover layer;
    - Revegetate; and
    - Move to next lift within the Cell and repeat until maximum height achieved.
- Move to Cell 2 and repeat.

4.2 Material Prioritisation

Material prioritisation to the WSFs is based on limiting human health and environmental impacts, as well as practical constructability requirements, and is recommended to be as follows:

1. All radiological soils must be relocated and covered as first priority.
2. Dysons WRD is to be used progressively to form the starter embankments and final cover.
3. Main North WRD to be relocated as soon as practical (preferably Year 1) to allow room for the Main Pit backfill activities to be undertaken (SLR, 2020e).
4. While Main WRD is to be given preference for relocation to the WSFs (ahead of other WRD and impacted soils) it is essential that sufficient volume is retained for relocation to Main Pit, as storage in the Main Pit is preferred for this higher PAF material.
5. Mt Burton WRD material should be the next priority.
6. Relocation of the copper extraction area, Main WRD levee, metal and salt impacted soils and miscellaneous rocky waste may occur in any order, to optimise construction timing.

   Note, some metal and salt impacted soils are in restricted areas, meaning Traditional Owner supervision will be required.

4.3 Potential Radiological Soil and Rock Management

Working with radioactive materials is a heavily regulated activity. The Radiation Management Plan (EcOz, 2019a) addresses the potential radiological risks and necessary mitigation measures associated with the excavation, transport and placement of radiologically contaminated materials at the Rum Jungle Mine site. Key to the design, the controls outlined in the Radiation Management Plan include:

- Radiological soils are to be relocated and capped with 0.5m of low permeability material and/or covered *in situ* as the highest priority.
- All equipment that has potentially been exposed to the radiological material (including plant air-conditioner filters and engine air filters) will be cleaned and checked for contamination before being allowed to leave the project area at the completion of the works program. The equipment will be decontaminated on a wash-down pad which drains into an onsite approved sump.
- In order to avoid excessive decontamination works, vehicle truck movement on and off site will therefore be limited to 'Public Access Zone' and 'Construction Only Access Zone' as follows:
  - The Construction Only Zone will be everything inside the Rum Jungle Boundary and the Finniss River Aboriginal Land Trust (FRALT) borrow area (Borrow Area B). This would include all construction equipment, including light vehicles and trucks that bring material from the FRALT borrow area; and
  - The Public Access Zone will include areas outside the Rum Jungle Boundary and the Coomalie Council borrow area (Borrow Area A). This would include all personnel vehicles and trucks bringing material from the Coomalie Council borrow area.
  - To facilitate the restricted vehicle movements, a staging area will be required near the access to the Rum Jungle Mine site. The location of this staging area, which will involve vehicle parking either side of the boundary, will need to be agreed with FRALT.

- The exception to the above restrictions would be delivery vehicles, specifically fuel and lime supply. These vehicles would need to undergo decontamination after every delivery. It is understood (personal communication) that this process takes approximately 3 hours.

4.4 Mt Burton

Mt Burton WRD is to be relocated to the new WSFs on Rum Jungle site, and the excavated footprint treated as outlined in **Section 5**.

4.5 Mt Fitch

Mt Fitch WRD is to be relocated to the adjacent Mt Fitch open pit, and the excavated footprint treated as outlined in **Section 5**.

4.6 WSF Development

Development of the WSFs should consider:

- Preference is to commence at East WSF moving from either end, ensuring Dysons WRD remains accessible for full construction period.
- West WSF – Maximum footprint and height are fixed, to comply with Traditional Owner requirements.
- East WSF – Footprint and height have flexibility to be changed in the northern section.

4.7 Material Placement

Placement and compaction of the waste rock fill within the WSFs is to be undertaken in accordance with **Table 6** and the Technical Specifications (which supersede this report) (SLR, 2020h).

Table 6 Waste Rock Placement Specification

Parameter	Specification
Material Source	Main WRD, Main North WRD, Mt Burton WRD
Maximum Lift Thickness	Discrete lifts having a loose thickness of 500 mm thick
Maximum Lime Dose Rate	Refer Table 8

Compaction Density/Placement Requirements	• An equivalent density of ≥90 % of Standard Maximum Dry Density.
	• No soft spots or over moistened areas prior to placement of next layer.
	• Larger rock sizes incorporated into layer so as to not protrude above layer surface to hinder compaction.
	• Compaction via vibratory steel drum rollers.
	  ○ Vibrations in the range of 1,200 to 1,500 vpm. Roller speed of approximately 3.2 km/hr.
	  ○ Static drum weight ≥ 8 tonne, Dynamic Drum Weight ≥ 15 tonne.
	  ○ 4 to 6 passes (to be determined in trials).

Placement and compaction of the impacted soils is to be undertaken in accordance with **Table 7** and the Technical Specifications (which supersede this report) (SLR, 2020h).

Table 7 Impacted Soils including Radiation Soils Placement Specification

Parameter	Specification
Material Source	Salt Affected Soils, Radiation Affected Soils, Copper Leachate Pad Affected Soils & Miscellaneous Soils
Maximum Lift Thickness	Discrete lifts having a loose thickness of 500 mm thick
Maximum Lime Dose Rate	Not required
Compaction Density/Placement Requirements	• An equivalent density of ≥90 % of Standard Maximum Density. • No soft spots or over moistened areas prior to placement of next layer. • Larger rock sizes incorporated into layer so as to not protrude above layer surface to hinder compaction. • Compaction via vibratory steel drum rollers. ○ Vibrations in the range of 1,200 to 1,500 vpm. Roller speed of approximately 3.2 km/hr. ○ Static drum weight ≥ 8 tonne, Dynamic Drum Weight ≥ 15 tonne. ○ 4 to 6 passes (to be determined in trials).

4.8 Lime Treatment

To prevent AMD from the WSFs, the waste rock materials are to be placed and treated in line with strict geochemical quality requirements. Similarly, the resulting excavated footprints, which are likely to have some residual contamination are to be treated.

Treatment is to be with lime (finely crushed limestone). Significant geochemical work has been undertaken to establish treatment rates (RGC & Jones, 2019) and these are summarised in **Table 8** and the Technical Specifications (which supersede this report) (SLR, 2020h).

Table 8 Lime Treatment Rate (from (RGC & Jones, 2019))

Material to Treat	Placement Location	Lime Treatment Rate	Total Lime*
Main WRD	WSFs	Max 15 kg $CaCO_3$ per tonne of WRD	160,375 tonnes (Max)
Main North WRD	WSFs	Max 15 kg $CaCO_3$ per tonne of WRD	4,519 tonnes (Max)
Dysons WRD	WSFs	Max 4.9 kg $CaCO_3$ per tonne of WRD	14,765 tonnes (Max)
Excavated Footprints			
Intermediate WRD Footprint	Top 0.20m *in situ*	24 kg $CaCO_3$ per tonne of footprint	927 tonnes
Dyson's Overburden WRD Footprint	Top 0.20m *in situ*	24 kg $CaCO_3$ per tonne of footprint	632 tonnes
Main WRD Footprint	Top 0.20m *in situ*	15 kg $CaCO_3$ per tonne of footprint	2,176 tonnes
Main North WRD Footprint	Top 0.20m *in situ*	15 kg $CaCO_3$ per tonne of footprint	446 tonnes
Dysons WRD Footprint	Top 0.20m *in situ*	4.9 kg $CaCO_3$ per tonne of footprint	202 tonnes

* Total lime assumes a lime availability of 79%

The treatment rates may vary at the time of works depending on the results of the field geochemistry procedure (refer **Section 8.2.4**).

4.9 WSF, Dysons Overburden and Radiological Soils - Cover Construction

4.9.1 Low Permeability Material

A compacted low permeability (clay) capping layer is required for:

- West WSF and East WSF capping;
- Dysons Overburden capping; and
- Radiological soil capping.

Suitable fill materials are to be sourced from the Coomalie Council Borrow Area (Borrow A) (SLR, 2020c), (SLR, 2020i) and must meet the following requirements and the Technical Specifications (which supersede this report) (SLR, 2020h):

- Comprise cohesive materials of high plasticity;
- Be free of organic material;
- Have the following properties:
  - An *in situ* co-efficient of permeability/hydraulic conductivity of less than $1x10^{-9}$ m/s when measured in a triaxial cell;
  - Maximum particle size of 50 mm;
  - Soil plasticity index > 10%;
  - ≥ 50% material passing 4.75mm sieve;
  - ≥ 30% material passing 0.075mm sieve; and
  - > 10% materials passing 0.002mm sieve.

The construction shall be undertaken as follows:

- The material shall be placed in loose layers such that when compacted, each layer does not exceed 250 mm thickness;
- Each layer is to be compacted to a dry density of at least 98% of Standard Maximum Dry Density, with moisture content within the range of 0 % to +3 % of Optimum Moisture Content;
- The finished low permeability clay layer must have a minimum (non-scarified) thickness of 500 mm measured at right angles to the slope as shown on the Construction Drawings; and
- Clay capping on the WSF slopes to have a compacted thickness of 650 mm and have the surface scarified to a maximum depth of 150mm (WSF Slopes only). Scarification to occur immediately prior to growth medium placement to prevent drying out of the clay layer.

4.9.2 Growth Medium

The specifications are detailed in **Appendix D**.

4.9.3 Geosynthetic Liner

The geomembrane shall:

- Consist of 1.5 mm thick, unlaminated, linear low-density polyethylene (LLDPE);
- Be textured on both sides;
- Be produced from pure (non-recycled) resins and contain no fillers, plasticisers or additives of any kind, with the exception of carbon black; and
- Comply with the Materials Criteria in the Technical Specifications (SLR, 2020h).

4.9.4 Dysons Pit Overburden

The capping system for Dysons Pit Overburden was developed by (OKC, 2016) and review and update of this design was not part of the SLR Stage 2A design scope as it is considered leading industry standard.

The capping design is understood to be as follows:

- The overburden is to be excavated down to the top of existing rock blanket;
- Surface rip-rap material is to be scavenged for reuse;
- A 1m rock layer is to be placed over the existing rock blanket; and
- A new cap is to be constructed over this including:
  - 0.5m low permeability layer;
  - 0.5m coarse rock layer; and
  - 2m growth medium layer.

The proposed capping (OKC, 2016) is shown in **Figure 9**.

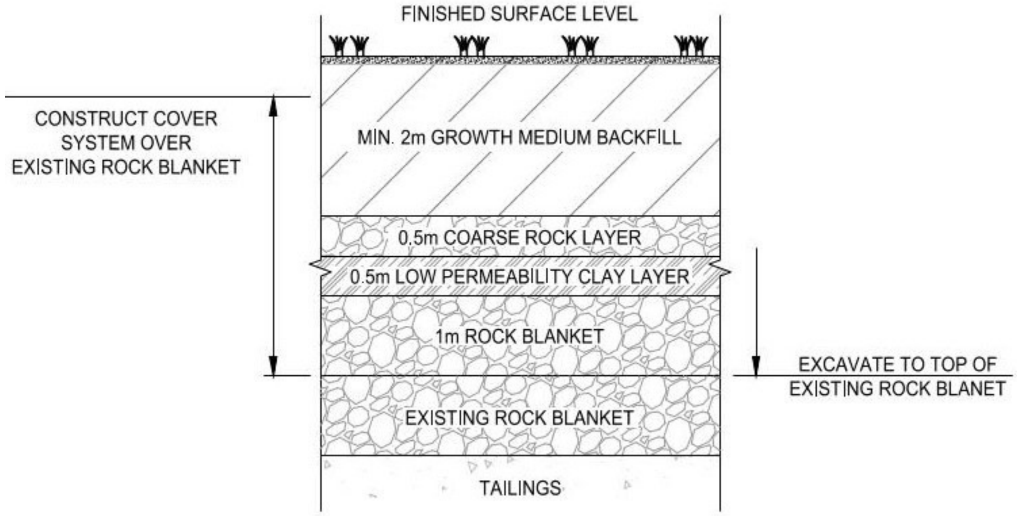


Figure 9 Dysons Overburden Cover System

Appropriate surface water management and erosion and sediment control will be implemented during vegetation establishment phases (SLR, 2020b).

5 Excavated Footprint Treatment

Excavated footprints are to be treated to ensure no ongoing surface or groundwater contamination.

Extensive geochemical testing and modelling has been undertaken (RGC & Jones, 2019), together with radiological studies (EcOz, 2019a) (EcOz, 2019b). Based on these, the recommended approach to treatment includes:

- The following areas will be excavated to 2m below assumed natural ground, treated with lime at the rate matched to that landform, allowed to flush for a minimum of 1 wet season and then backfilled with growth medium to a depth of 3m, i.e. 1m above assumed natural grade. This will allow for treatment of AMD in the unsaturated zone below the footprint and ensure the final landform considers potential settlement so that it remains self-shedding:
    - Intermediate WRD;
    - Main WRD; and
    - Copper Extraction Area.
- For the copper heap leach area:
    - This area is to be excavated to a depth 2 m below the current surface elevation, and the excavated material relocated to the WSF. The top 0.2 m of substrate will be grid sampled, tested for paste soil pH and dosed accordingly with lime to achieve an approximate paste pH of 8. It is estimated that 8 kg CACO3 per tonne of footprint will be required;
    - The footprint will be allowed to flush for a minimum of 1 wet season; and
    - A backfilled layer of growth substrate over the footprint will be placed to bring the final surface up to approximately 1 m above grade to result in a final landform that is water shedding for the purpose of slowing down any future release of final copper loads and will support revegetation. Total backfill thickness will therefore range from 2-3m allowing for natural fall of the surface.
- The following areas will be excavated to 2m below assumed natural ground then backfilled with growth medium to a depth of 3m, i.e. 1m above assumed natural grade. This will allow for settlement and ensure that the footprint areas remain self-shedding:
    - Main WRD levee; and
    - Main North WRD.
- Radiological soils:
    - Those soils within the footprint of the West WSF are to be left *in situ* and covered by relocated radiological waste then a 0.5m low permeability cover; and
    - Areas outside the West WSF will be excavated to 2m and relocated. It should be noted though this may be as shallow as 0.4m depending on quality testing undertaken during excavation.
- The following areas will be excavated and backfilled with growth medium to depths as specified:
    - Dysons WRD (2m);
    - Mt Burton WRD (0.3m);
    - Mt Fitch WRD (0.3m);
    - Salt and metal impacted areas (0.3m); and

  - Miscellaneous rocky piles (stripped to natural grade, no backfill required).

The designs for the excavated footprint have been based on the following considerations:

- The base of the excavation will not be compacted prior to liming (if applicable) or backfill. The intent is to allow vertical flushing of the unsaturated zone toward the groundwater interception bores which are being installed as part of the water treatment strategy (SLR, 2020j).
- There is no requirement for rock mulch or other erosion measures as the backfilled landforms are relatively flat slopes. Appropriate surface water management and erosion and sediment control will be implemented during vegetation establishment phases (SLR, 2020b).
- Vegetation will be as per the Project Revegetation Plan, to be developed by DPIR.

6 Construction Parameters

Through consultation with DPIR, SLR design team and experienced construction personnel, the construction parameters for movement of all waste rock and impacted soil have been developed as shown in **Table 9**.

Table 9 Basis of Design Parameters

Parameter	Value	Comments
Dry Season	01 May – 30 November (approx. 30 weeks)	
Wet Season	1 December – 30 April (approx. 17 weeks)	Includes a 4-week break over Christmas period
Operational hours/days for WSF construction	12 hours per day, 7 days per week	Typical efficiency of 70% means 8.4 hours of working per day
Waste rock bulking factor in WSF (allowing for addition of lime)	0.9	
Haulage bulking factor (all materials, from *in situ* to truck)	15%	
Radiation soils, salts etc bulking factor in WSF	0.9	No lime addition
Dry season WSF construction rate (PAF soils)	5000 m^3/day	These may be varied if all Geotech and Geochem quality requirements are met
Wet season WSF construction rate (PAF soils)	3000 m^3/day	
Dry season WSF construction rate (salt, radiation, miscellaneous soils)	7500 m^3/day	
Wet season WSF construction rate (salt, radiation, miscellaneous soils)	5000 m^3/day	
Dry Season Borrow Materials – Borrow Area A (Clay & Growth Medium)	5000 m^3/day	Clay materials for low permeability WSF cover. Growth Medium for WSF slopes.
Wet Season Borrow Materials – Borrow Area A (Clay & Growth Medium)	3000 m^3/day	
Dry Season Borrow Materials – Borrow Area B (Growth Medium)	7500 m^3/day	Growth Medium for WSF plateaus and excavated footprints.
Wet Season Borrow Materials – Borrow Area B (Granular Material & Growth Medium)	5000 m^3/day	

7 Deswik Block Modelling

7.1 Modelling

In order to optimise the material movement and construction sequencing, preliminary block modelling using Deswik has been undertaken (MEC, 2020). A copy of the report by MEC is contained in **Appendix E**. Key points to note are:

- The block modelling is a reference design / model and has been used to inform optimal vehicle movements.
- Material movement has been based on the production rates and movement order provided by SLR. The WSF siting report in **Appendix B** and discussed in **Section 3.1**, recommended that the West WSF be developed first followed by the East WSF. In initial discussions MEC recommended that developing the East WSF might be more optimal for access and haulage, hence the decision was made to develop the block model in the configuration as follows:
    - East WSF from north to south; then
    - West WSF from north to south.
- The schedule of deconstruction of WRDs and impacted soils is shown in **Figure 10**.

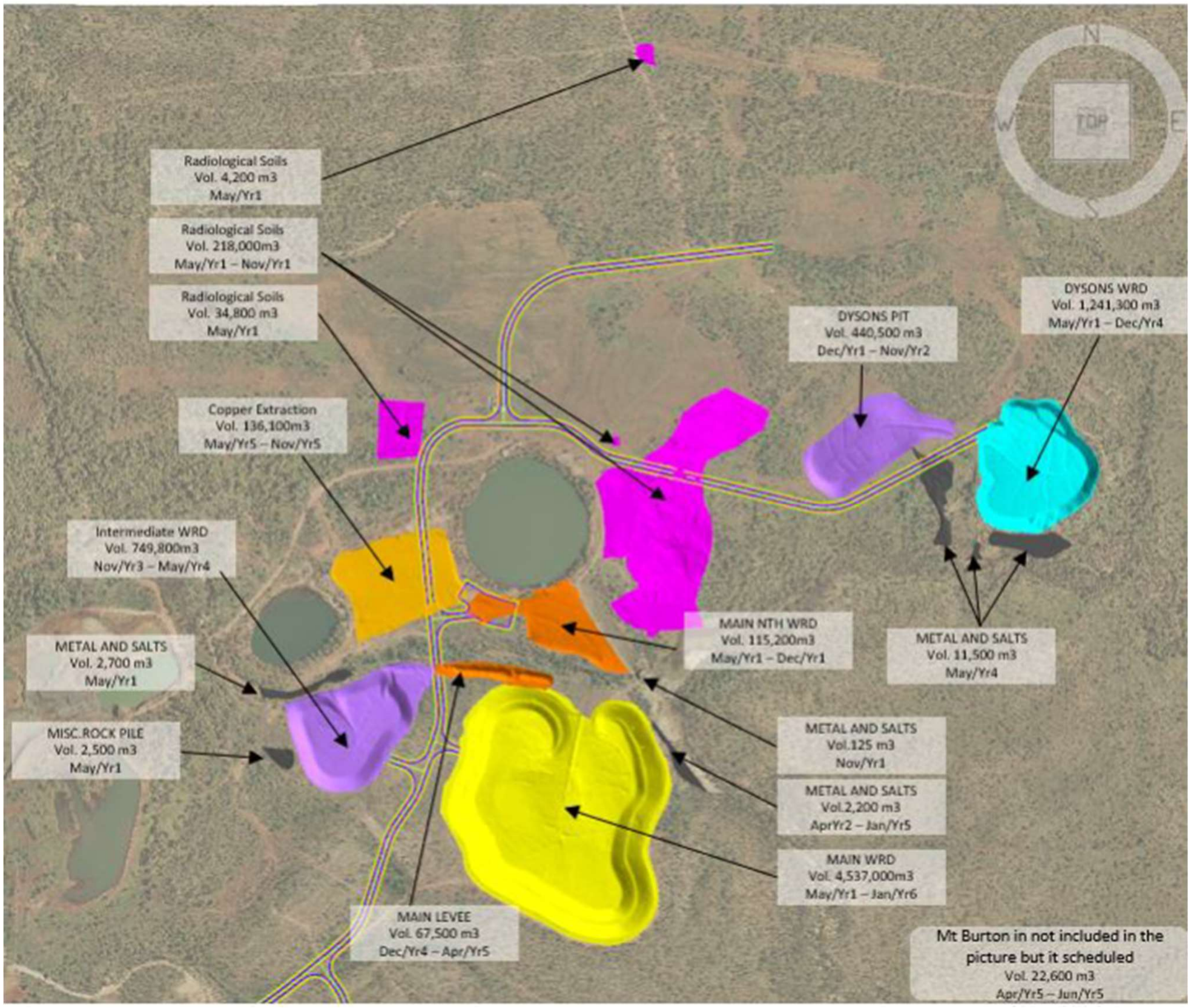


Figure 10 WRD and Impacted Material Movement Schedule

- The schedule of construction of the new WSFs is shown in **Figure 11**.

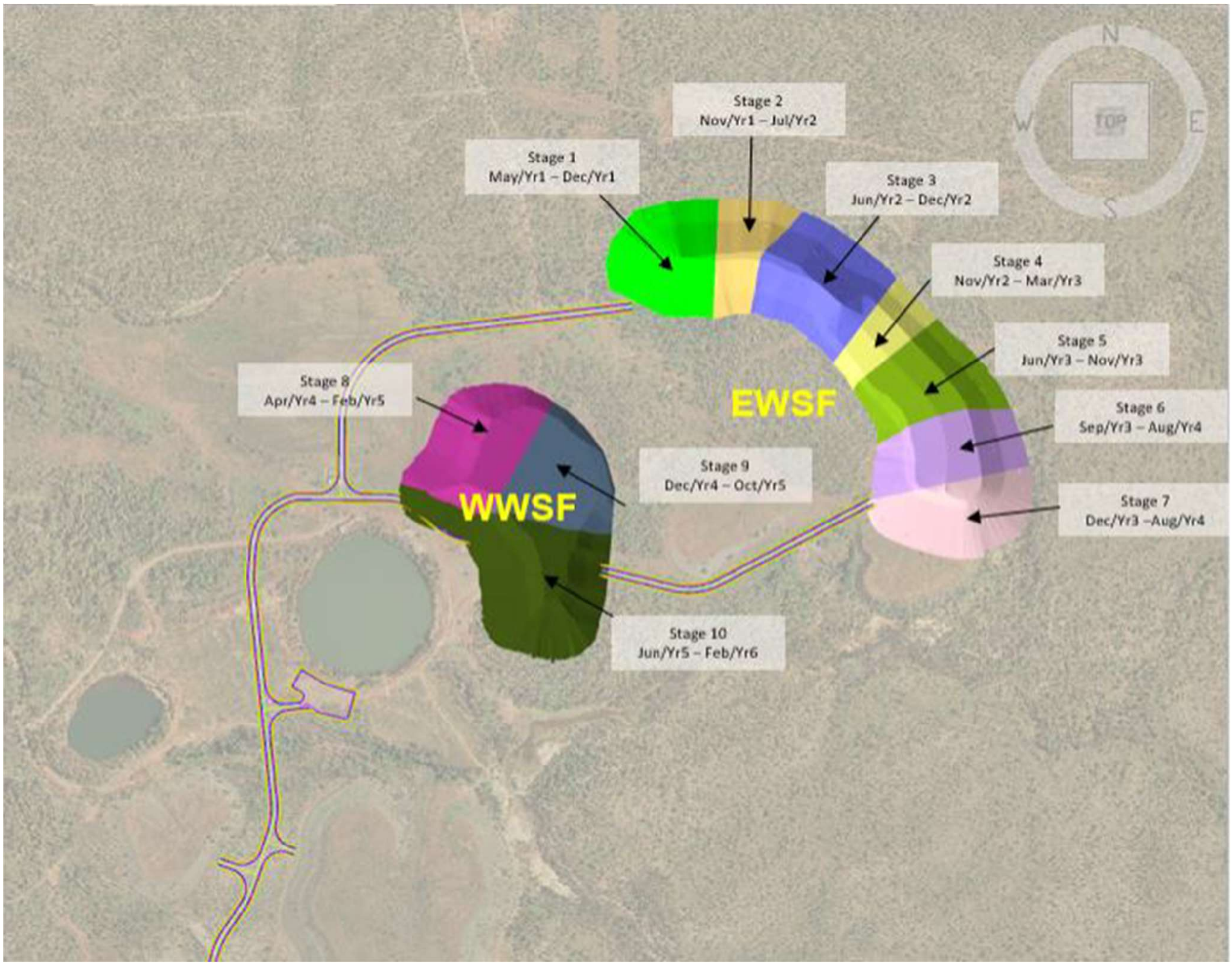


Figure 11 Waste Storage Facilities Construction Sequence

- The schedule for backfilling excavated footprints (after any lime treatment and flushing if required) is shown in **Figure 12**.

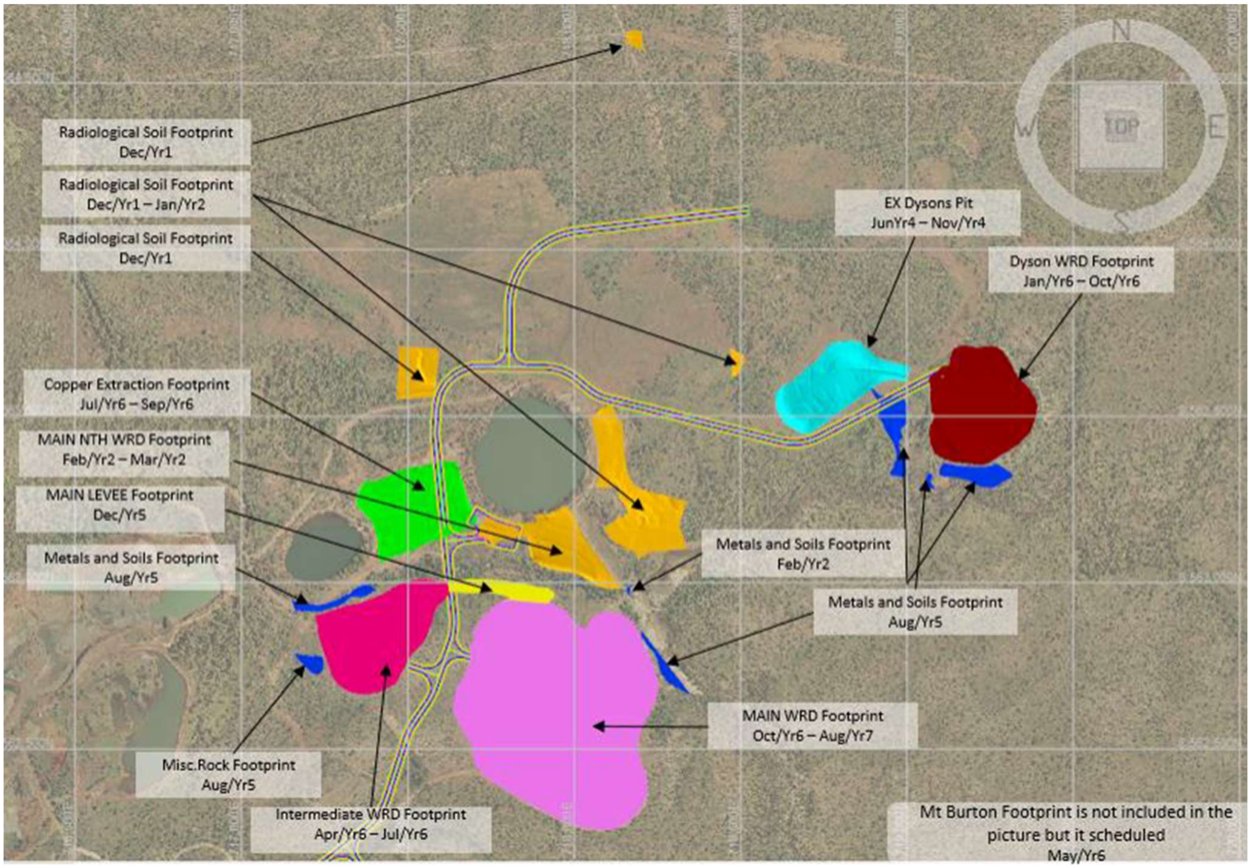


Figure 12 Excavated Footprint Backfill Schedule

Additional to the above, the output of the modelling includes truck numbers and hours.

As a value-add MEC has also developed the layout for the barging facility to be used for the Main Pit Backfilling (SLR, 2020e). The layout includes:

- Loader fed Crushing and Screening Plant (CSP);
- Loader fed Barge hopper and conveyor system;
- Raw stockpile;
- Product stockpile;
- Area for the CAT740B dump truck and the loader activities; and
- Boat ramp and maintenance area for the barge has been assumed to be situated at the top of the pit ramp

The layout is shown in **Figure 13**.

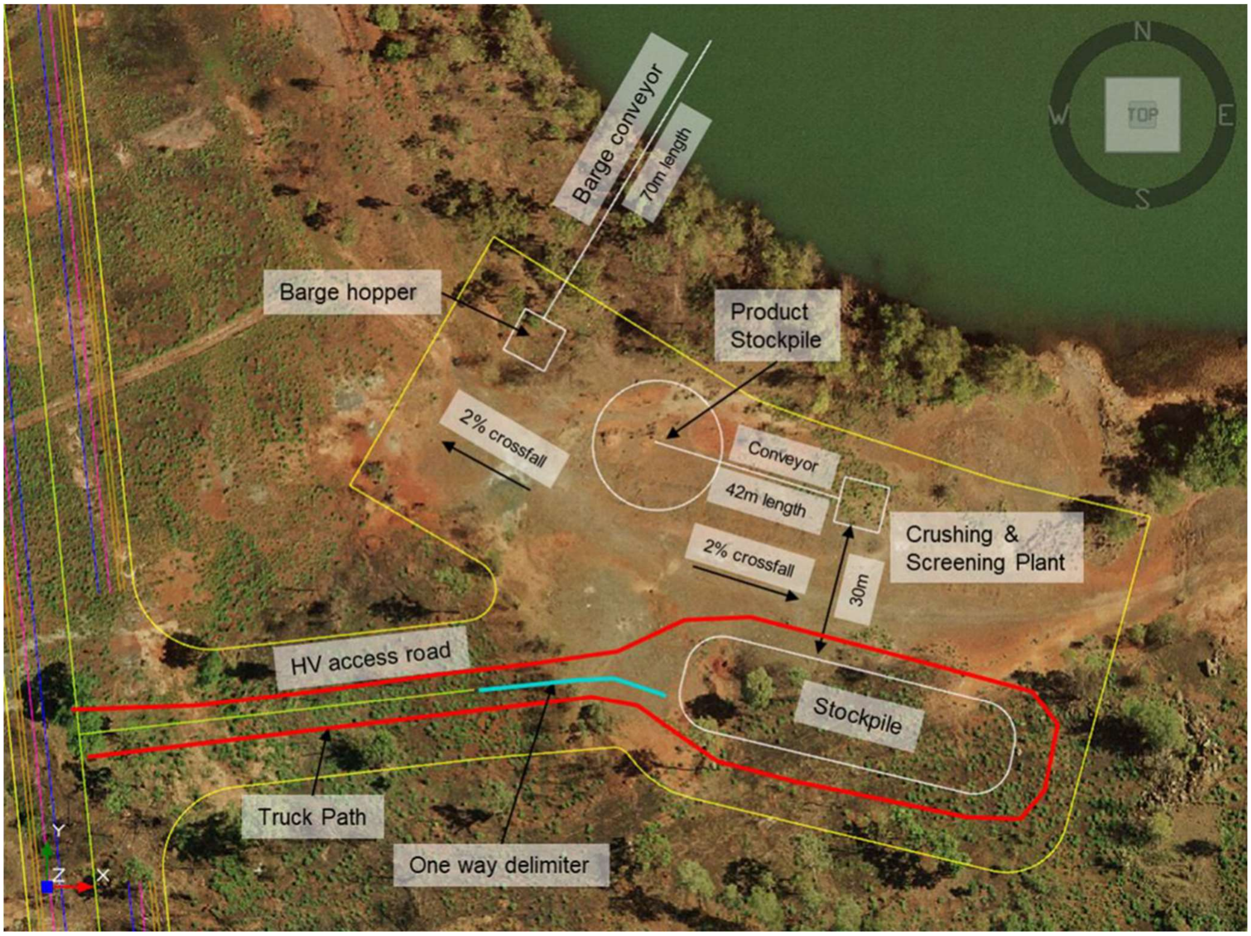


Figure 13 Main Pit Backfilling Barging Facility Layout

7.2 For Construction

It is the intention that the Deswik block modelling be updated by the Construction Contractor on award of the Project work in order to optimise material movements.

8 WSF Construction Quality Assurance

8.1 Geotechnical Requirements

Geotechnical quality control will be in accordance with relevant Australian Standards and Northern Territory Department of Infrastructure, Planning and Logistics (DIPL) requirements. These are detailed in full in the Earthworks Work Package – Technical Specifications (SLR, 2020h).

8.2 Geochemical Requirements

8.2.1 Lime Spreading and Mixing

To prevent AMD from the WSFs, the waste rock materials and contaminated footprints are to be placed and treated in line with strict geochemical quality requirements. The following subsections outline the minimum lime (finely crushed limestone) spreading and mixing requirements to be adopted. These rates may vary at the time of works depending on the results of the field geochemistry procedure described below. Lime treatment rates are described earlier in **Table 8** however for the purpose of the WSF, a field test must be completed to confirm the lime dose rate for the waste rock being placed in the WSF and this procedure is outlined in **Section 8.2.4**.

8.2.2 Lime Spreading Method

Self-unloading trucks or tailers should be used to distribute lime pneumatically or mechanically using aggregate-type spreaders. Equipment capable of negotiating adverse ground conditions will be required.

Lime can be applied as a dry powder, aggregate or slurry with the method subject to approval by the Principal, with due consideration of health and safety hazards. Spreading equipment must utilise monitoring equipment (utilizing GPS tracking and load cells) to ensure even application across sites to monitor lime rates and quantities applied.

8.2.3 Lime Mixing

Ensuring homogenous mixing of the lime through the waste rock is paramount to the success of the Project.

Larger cobbles/boulders will be present within the waste rock materials (>1.0 m diameter). Such boulders are occasional within the dumps but are likely to pose a jamming and breakage risk to typical road soil mixers.

It is envisioned mixing of the lime will occur using either a grader pulled or tractor pulled ripper/tyne/harrow that will be able to manage the expected undulating terrain and occasional larger pieces within the waste rock.

8.2.4 Field Procedure

The following field procedure has been developed by DPIR and DRJEE (DPIR correspondence).

The safe long-term waste rock storage within the WSFs requires that the existing acidity within this waste rock is neutralised during the construction of the new WSFs.

The geochemical control program is required to be incorporated with geotechnical control over the waste rock placement.

The following procedure is to be adopted for neutralant (finely crushed limestone) dosing of waste rock for long-term storage within the WSF to achieve a target matrix pH of 7.

8.2.4.1 Part A – Procedure for Lime Dosing Every Block:

The procedure must be carried out for lime dosing of every block:

8.2.4.1.1 Step 1 Determine paste pH:

1. Waste rock is to be paddock dumped then loosely levelled in 0.5m thick loose layers within designated blocks for the purpose of volumetric calculations. In this example, a block of 50m x 100m will be assumed (2,500m^3 block). Additionally, the loose density will be assumed to be:

    a. *In situ* density within current WRDs – 2.0 t/m^3.

    b. Swell factor – 30%

    c. Therefore, placed loose density on WSF – 1.54 t/m^3.

    d. Therefore, placed loose mass per block – 3,850 t.

    It is important to note that these assumptions need to be tested and refined during the method refinement phase of the WSF construction.

2. For each 2,500m^3 block ten composite grab samples shall be taken across a rough 25 x 25m grid across the block to test for paste pH from which to determine the correct lime dosing rate. Map the sample layout for each block for recording purposes. The 10 subsamples should be:

    a. Taken from the full 0.5m thick profile at each sample point.

    b. Sieved on site to retain the <2mm sample fraction for paste pH field analysis.

    c. If weather conditions are wet (cannot field sieve, take 10 x 2kg subsamples to laboratory for drying and processing).

3. Weigh out 25g of sample and mix with 50g of deionised water for a 2:1 paste pH.
4. Allow the sample to equilibrate for 1 hr with mixing of the sample at 15 min intervals.
5. Measure pH of settled solution with a calibrated field probe.

8.2.4.1.2 Step 2 Determine the lime dosing rate:

1. For each block with 10 samples use **Table 10** and **Table 11** to determine the correct lime dosing rate:

Table 10 Dose Rates Main Waste Rock Dump Materials

	If 5 or more samples paste pH <5.5	If 4 or more samples paste pH >5.5
Existing Acidity	14.7 kg H_2SO_4/t	3.2 kgH_2SO_4/t
Equivalent Demand Factor	1.02	1.02
Neutralant Demand	15.0 kg $CaCO_3$/t	3.3 kg$CaCO_3$/t

Table 11 Dose Rates Dysons Waste Rock Dump Materials

	If 5 or more samples paste pH <5.5	If 4 or more samples paste pH >5.5
Existing Acidity	4.8 kg H_2SO_4/t	0.2 kg H_2SO_4/t
Equivalent Demand Factor	1.02	1.02
Neutralant Demand	4.9 kg $CaCO_3$/t	0.2 kg $CaCO_3$/t

2. Select correct Existing Acidity to use for dose calculation. Convert this value to lime t to add to the block. *For example*:
    a. For a block of waste rock from Main Waste Rock Dump (**Table 8**).
    b. 8 samples return pH<5.5 therefore select 15.0 kg $CaCO_3$/t.
    c. Adjust Neutralant Demand to account for activity of the crushed limestone (as an example 79%).
    d. Calculate mass of limestone for the block.
    e. Convert mass of limestone for the block to t.

    Total Block Limestone Mass = 15.0 kg$CaCO_3$/t x (1/0.79) x 3,850 t x (1/1000)

    Total Block Limestone Mass = 73 t

3. Review the layout of results over the block to determine if a portion of the block should receive a slightly higher portion of the total lime dose for the block. This is not to be quantified but rather a qualitative approach. Record the calculated lime dose for the block.

8.2.4.1.3 Step 3 Lime Dosing and Mixing

For the dosing and mixing of the lime onto the block. The following minimum steps will apply.

1. Once the dose rate is determined the value is to be relayed immediately to construction personnel.
2. The block is to be ripped with the grader tynes at full depth prior to lime dosing.
3. The lime is to be dosed evenly over to the block following the specified procedure. The delivered mass of lime to the block is to be documented for each block and recorded as part of the QA/QC process.
4. Record the actual lime mass dosed to the block.
5. The grader at full tyne depth is to make a minimum of three full passes over the block to ensure adequate mixing of lime and waste rock. Future test work during establishment phase may confirm that this can be reduced.
6. Once mixed, the block is to be moisture condition and compact to the geotechnical specifications.
7. Work blocks must be signed off as passed before additional layers can be placed.

It is important to note that the method outlined above is a reference method only, and it should be refined during the preliminary WSF construction phases. This will ensure the most efficient use of mixing equipment is established. Additionally, once substantial data sets are developed, the lime dose calculation method can be refined by agreement with the Principal and Project Geochemist.

8.2.4.2 Part B – Validation Program:

A validation program is required for 1 block in every 10 blocks to confirm that the paste pH method is performing as expected. To do this, 1 block in 10 should be sampled and analysed as described here.

At a high level, five 5kg samples of <2cm material should be taken from the block to compare the paste pH with the total existing acidity as determined by:

1. dry and then crush the 5kg sample of <2cm material to <75µm (pulp)
2. determine titratable (i.e. immediately available) acidity by titrating a subsample of the pulp with sodium hydroxide solution to pH7:
    a. **Titratable acidity**: Titratable acidity is determined by slowly titrating (to pH 7) a slurry that consists of 75 g of high purity water and 15 g of a crushed, sub-sample of waste rock (i.e. a 5:1 liquid-to-solid ratio) (see Jones, 2014, for additional details).
3. Determine water soluble and total sulfate, with the difference between the 2 numbers being used (methods below):
    a. **Water Soluble sulfate**: measured by water extraction, ALS method ED040S.
    b. **Total extractable sulfate**: measured by leaching with sodium carbonate solution (ALS method GRA06). This method involves:
        i. Boiling a sample with a sodium carbonate solution for 30 minutes.
        ii. Removing any insoluble materials by filtration (and reducing ferric iron to ferrous iron by the addition of hydroxylamine hydrochloride).
        iii. Precipitating barium sulfate by adding barium chloride to the filtrate.
        iv. Filtering, igniting and weighing the precipitate to determine the SO_4 and jarosite content of the original sample (which is expressed as % S).
4. Total acidity is the sum of titratable and jarosite acidity.
5. Compare this value to the paste pH. Compare the values of total acidity with the dose rate determined using the paste pH for the block. If the values of total acidity are greater than or comparable with the dose rate determined using pH, then the pH approach is validated. If the reverse is found, then further investigation will be required to determine what modifications will be needed to the pH procedure. Over time, continuing data patterns may allow for reduction in the block testing regime if the material is found to be more consistent than predicted.

9 Haul Road and Diversion Drain Crossing Design

9.1 Haul Road Design Details

SLR commissioned MEC Mining to undertake the design of the internal haul roads, including the haul road to the FRALT borrow area. The design details and construction drawings are contained in **Appendix F**.

The scope of design included:

- Road geometry;
- Pavement thickness design;
- Superelevation design;
- Intersection design and signage;
- Speed limit designation;
- Cut and fill volumes;
- Drainage control; and
- Construction plans.

The purpose of this work is to design a haulage network that will be constructed and used during the rehabilitation project at Rum Jungle. The haul road design and associated speed limits will also be used as the basis of the Deswik haulage model (refer **Section 7**). **Figure 14** provides the proposed haul road alignment.

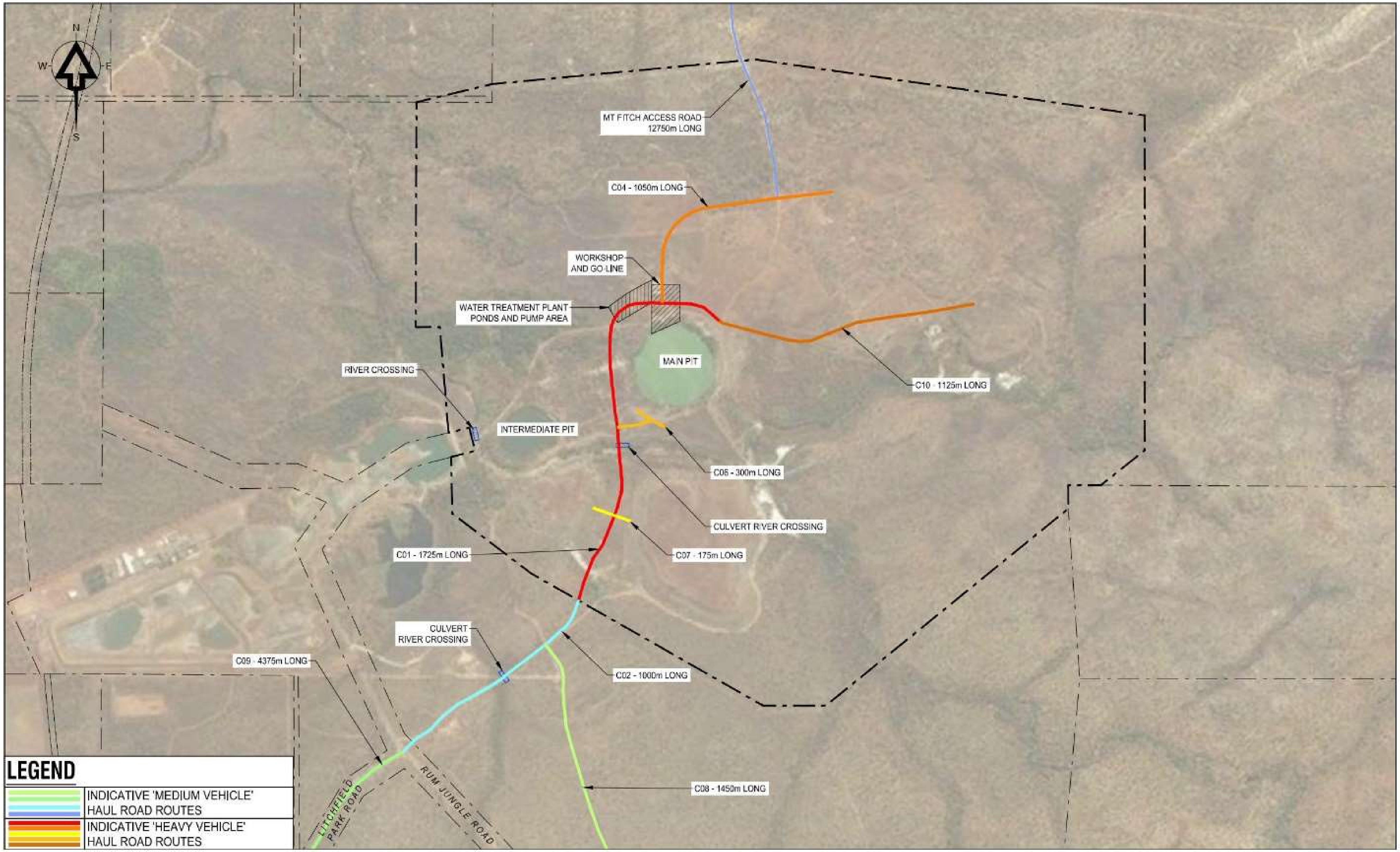


Figure 14 Haul Road Alignment

The basis of design includes:

- The largest haul truck assumed for the haul road design is the articulated CAT745C. This haul truck has a maximum width of 4.17m and wheel height of 1.9m. The running width of the haul road is required to be 3.5 times the maximum width of the largest truck, 14.6m. The windrow height is required to be half the wheel height of the largest haul truck, 1.0m. **Figure 15** shows the design specifications of the haul road geometry.

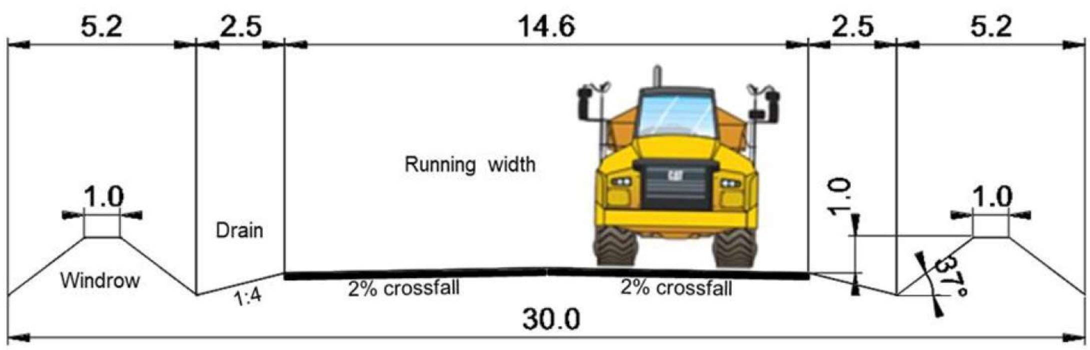


Figure 15 Haul Road Geometry

- Pavement thickness design has been based on CBR values supplied by (SLR, 2020i).
- Design is for up to 10 years.
- Design specifications have been based on:
  - Recognised Standard 19: Design and construction of mine roads August 2019. Available at: https://www.dnrme.qld.gov.au/__data/assets/pdf_file/0008/1453175/recognised-standard-19-mine-roads.pdf;
  - Guidelines for Mine Haul Road Design, by Dwayne D. Tannant and Bruce Regensburg, 2001. Available at: https://www.researchgate.net/publication/277759950_Guidelines_for_Mine_Haul_Road_Design
  - Various standard internal mining company specifications

9.2 Diversion Drain Crossing Design Details

An all-weather haul road crossing is required at the EBFR Diversion Channel to allow waste rock to be hauled from the Intermediate WRD, Main WRD and various other impacted sites. The crossing will also support the delivery of materials to site. The location of the crossing (and general haul road alignment) is shown in **Figure 16** and the typical environment at the crossing location is shown in **Figure 17**.

Figure 16 Location of EBFR Diversion Channel Crossing

Figure 17 Conditions at the EBFR Diversion Channel Crossing

The Stage 2 rehabilitation strategy identified that a bridge with a flood immunity of 1 in 100 year Annual Return Interval (ARI) was the preferred crossing solution, however no details of how this was selected or any design details were available. As part of Stage 2A, a Multi-Criteria Analysis (MCA) options assessment was undertaken to identify the optimal crossing type and flood immunity required (SLR, 2019).

The results, and ultimate agreement with NT DPIR, were:

- Culvert crossing; and
- 1:5 year ARI flood immunity.

An indicative design was developed by SLR (**Figure 18**) to undertake hydraulic analyses to ensure that there would be no impact on upstream culturally significant sites during flood events due to the presence of the crossing.

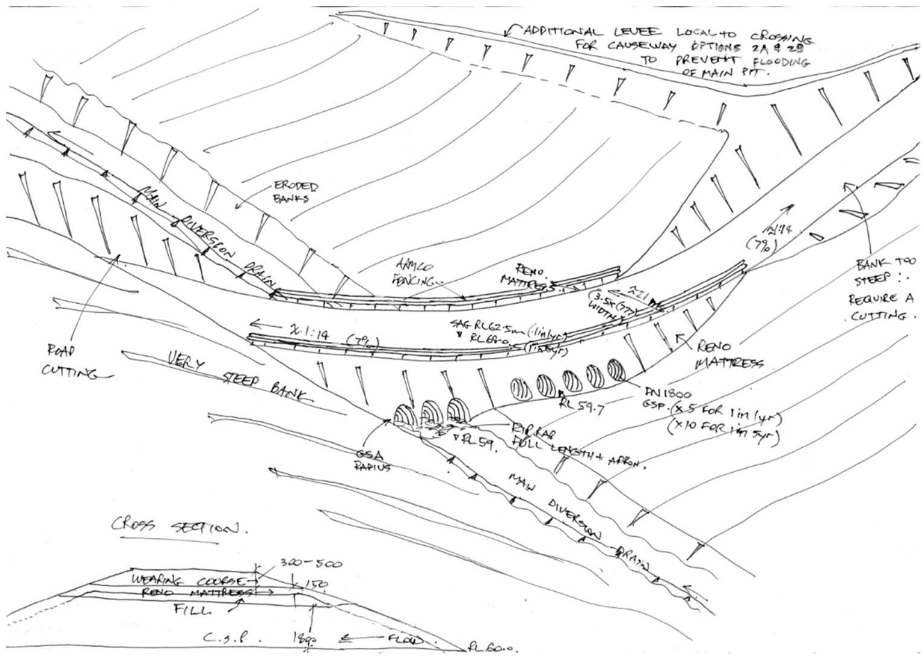


Figure 18 Indicative Culvert Crossing

Geotechnical assessment of the crossing area was undertaken to confirm foundation conditions (SLR, 2020a) and detailed survey carried out.

Pritchard Francis were commissioned by SLR to undertake the detailed design of the culvert crossing based on the supplied data. The crossing design was developed in conjunction with input data from MEC regarding the haul road design (refer **Section 9.1**). **Figure 19** gives an indication of the detailed design by Pritchard Francis.

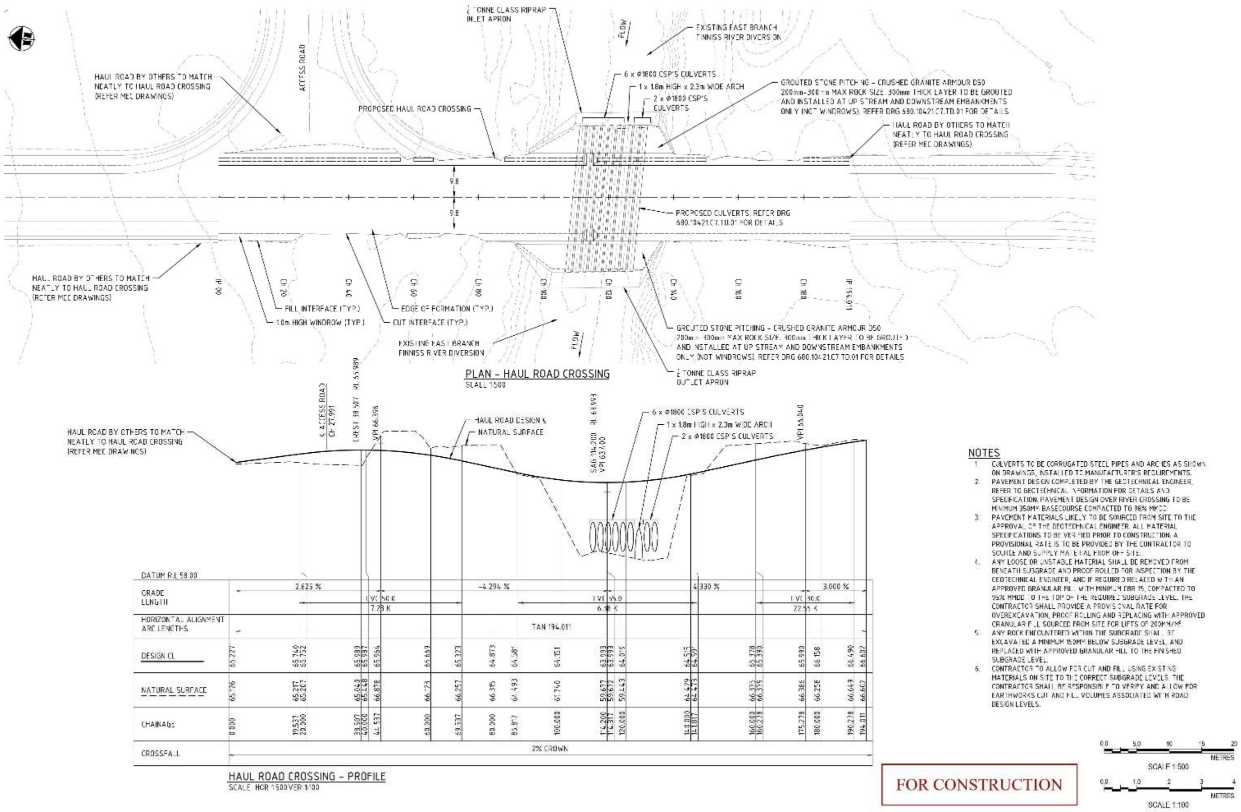


Figure 19 Pritchard Francis Culvert River Crossing Design

The culvert is to be removed at the end of the construction works.

The Pritchard Francis design drawings are referenced in **Section 10.2**.

10 List of Supporting Documentation

10.1 Design Reports

This WSF and supporting civil and earthworks design and construction methodology report is intended as a standalone report, however it forms part of a wider rehabilitation strategy for Rum Jungle and it is recommended that it be read in conjunction with the documentation listed in the Bibliography. Particular reference should be made to the overarching Detailed Engineering Design Report (SLR, 2020a).

10.2 Design Drawings

A summary of drawings associated with these design works is given in **Table 12**.

Table 12 Supporting Design Drawings

Drawing No.	Title
GENERAL	
680.10421.GEN.D00	Locality Plan and Schedule of Drawings
680.10421.GEN.D01	Existing Site Conditions
680.10421.GEN.D02	Site Construction Works Layout
680.10421.GEN.D03	Rehabilitation General Arrangement Plan
680.10421.GEN.D04	Site Exclusion Zones
WASTE STORAGE FACILITY	
680.10421.WSF.D01	WSF General Arrangement Plan
680.10421.WSF.D02	EWSF Foundation Plan
680.10421.WSF.D03	EWSF Layout Plan
680.10421.WSF.D04	EWSF Fill Elevation Plan
680.10421.WSF.D05	EWSF Sections
680.10421.WSF.D06	WWSF Foundation Plan Radiological Soil Treatment
680.10421.WSF.D07	WWSF Foundation Plan
680.10421.WSF.D08	WWSF Layout Plan
680.10421.WSF.D09	WWSF Fill Elevation Plan
680.10421.WSF.D10	WWSF Sections
680.10421.WSF.D11	Typical Details
680.10421.WSF.D12	WSF Lysimeter Layout Plan
680.10421.WSF.D13	Lysimeter Details
680.10421.WSF.D14	Soil Monitoring Stations Details
BULK EARTHWORKS	
680.10421.BEW.D01	Material Excavation Summary
680.10421.BEW.D02	Rip-Rap Scavenging Plan Summary

Drawing No.	Title
680.10421.BEW.D03	Detailed Excavation Plan – Sheet 1 of 4
680.10421.BEW.D04	Detailed Excavation Plan – Sheet 2 of 4
680.10421.BEW.D05	Detailed Excavation Plan – Sheet 3 of 4
680.10421.BEW.D06	Detailed Excavation Plan – Sheet 4 of 4
680.10421.BEW.D07	Detailed Excavation Sections – Sheet 1 of 4
680.10421.BEW.D08	Detailed Excavation Sections – Sheet 2 of 4
680.10421.BEW.D09	Detailed Excavation Sections – Sheet 3 of 4
680.10421.BEW.D10	Detailed Excavation Sections – Sheet 4 of 4
SITE REHABILIATION	
680.10421.REH.D01	Detailed Rehabilitation Plan – Sheet 1 of 4
680.10421.REH.D02	Detailed Rehabilitation Plan – Sheet 2 of 4
680.10421.REH.D03	Detailed Rehabilitation Plan – Sheet 3 of 4
680.10421.REH.D04	Detailed Rehabilitation Plan – Sheet 4 of 4
680.10421.REH.D05	Detailed Rehabilitation Sections – Sheet 1 of 4
680.10421.REH.D06	Detailed Rehabilitation Sections – Sheet 2 of 4
680.10421.REH.D07	Detailed Rehabilitation Sections – Sheet 3 of 4
680.10421.REH.D08	Detailed Rehabilitation Sections – Sheet 4 of 4
HAUL ROADS	
680.10421.HR.D00	Haul Roads – Cover Sheet
680.10421.HR.D01	Haul Roads – Drawing List
680.10421.HR.D02	Haul Roads – Overview
680.10421.HR.D03	Haul Roads – Section A1 – Long Section
680.10421.HR.D04	Haul Roads – Section A1 – Cross Sections
680.10421.HR.D05	Haul Roads – Section A2 – Long Section
680.10421.HR.D06	Haul Roads – Section A2 – Cross Sections
680.10421.HR.D07 and D08	Haul Roads – Section A3 – Long Section
680.10421.HR.D09 and D10	Haul Roads – Section A3 – Cross Sections
680.10421.HR.D11	Haul Roads – Section A4 – Long Section
680.10421.HR.D12 and D13	Haul Roads – Section A4 – Cross Sections
680.10421.HR.D14	Haul Roads – Section A5 – Long Section
680.10421.HR.D15	Haul Roads – Section A5 – Cross Sections
680.10421.HR.D16	Haul Roads – Section A6 – Long Section
680.10421.HR.D17	Haul Roads – Section A6 – Cross Sections
680.10421.HR.D18	Haul Roads – Section A7 – Long Section
680.10421.HR.D19	Haul Roads – Section A7 – Cross Sections
680.10421.HR.D20	Haul Roads – Section A8 – Long Section

Drawing No.	Title
680.10421.HR.D21	Haul Roads – Section A8 – Cross Sections
680.10421.HR.D22 and D23	Haul Roads – Section A9 – Long Section
680.10421.HR.D24 to D26	Haul Roads – Section A9 – Cross Sections
DIVERSION DRAIN CROSSING	
680.10421.C0.CS.01	Haul Road Crossing – Cover Sheet and Drawing List
680.10421.C1.BD.01	Haul Road Crossing – Basis of Design
680.10421.C1.GN.01	Haul Road Crossing – General Arrangement
680.10421.C5.RP.01	Haul Road Crossing – Plan and Profile
680.10421.C7.TD.01	Haul Road Crossing – Sections and Details

The design drawings are not appended to this report, rather they are available as a separate design package.

11 Bibliography

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SLR. (2020c). *680.10421.90010 Borrow Pit Development-M03-v1.0 Issued for Implementation (Memo).*

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SLR. (2020f). *Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design - Erosion Assessment of New Waste Storage Facilities.*

SLR. (2020g). *Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design - WSF Cover Options Analysis.*

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SLR. (2020i). *Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design, Geotechnical Investigation.*

SLR. (2020j). *Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design, Technical Specification, Water Treatment Plant.*

Society for Mining, Metallurgy, and Exploration, Inc. (2000). *Slope Stability in Surface Mining.*

APPENDIX A

Culture Centre Design Memo

Memorandum

To:	Jackie Hartnett	**At:**	DPIR
From:	Ben Tarrant	**At:**	SLR Consulting Australia Pty Ltd
Date:	21 May 2020	**Ref:**	680.10421-M04-v1.0 Cultural Centre.docx
Subject:	Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design Cultural Centre		

1 Preliminary

Design and Construction of the Cultural Centre will be the responsibility of the Earthworks Contractor.

The information provided herein outlines the minimum requirements of the Cultural Centre that may not be specifically addressed within the Earthworks Specification.

Both Kungarakan and Warai have expressed a strong interest in the construction of a cultural centre. The cultural centre will communicate the history of Kungarakan and Warai peoples, and the importance of Rum Jungle to them: their displacement during mining, details of mining itself and the Rehabilitation Project. In addition, if artefacts require relocation during construction, they will be managed as per the Cultural Heritage Management Plan (CHMP) and potentially displayed within the cultural centre as per Traditional Owner requirements. Further details of potential artefact relocation are detailed within Chapter 8 – Historic and Cultural Heritage of the Draft EIS (NT-DPIR, December 2019). While the proposed location of the cultural centre is yet to be decided, indicative locations are noted on Figure 2-7 of the EIS (Ref Drawing 680.10421.EIS.D07). The cultural centre is planned for construction in the Construction phase, and the final location and layout for this facility will be determined in consultation with Traditional Owners.

2 Description of Area

The proposed location of the Cultural Centre, as shown in EIS Figure 2-7 (Drawing 680.10421.EIS.D07), is located within the Rum Jungle Mine Site, adjacent to the existing Rum Jungle Site access track to the immediate west of the current Main Waste Rock Dump. The area has largely been cleared from mining and care/maintenance activities and is relatively flat with minimum cut/fill works anticipated to establish foundation.

3 Estimated Area

The Cultural Centre is estimated to require a cleared area of 700m^2 to 1000m^2 to facilitate the Centre and associated ancillary structures.

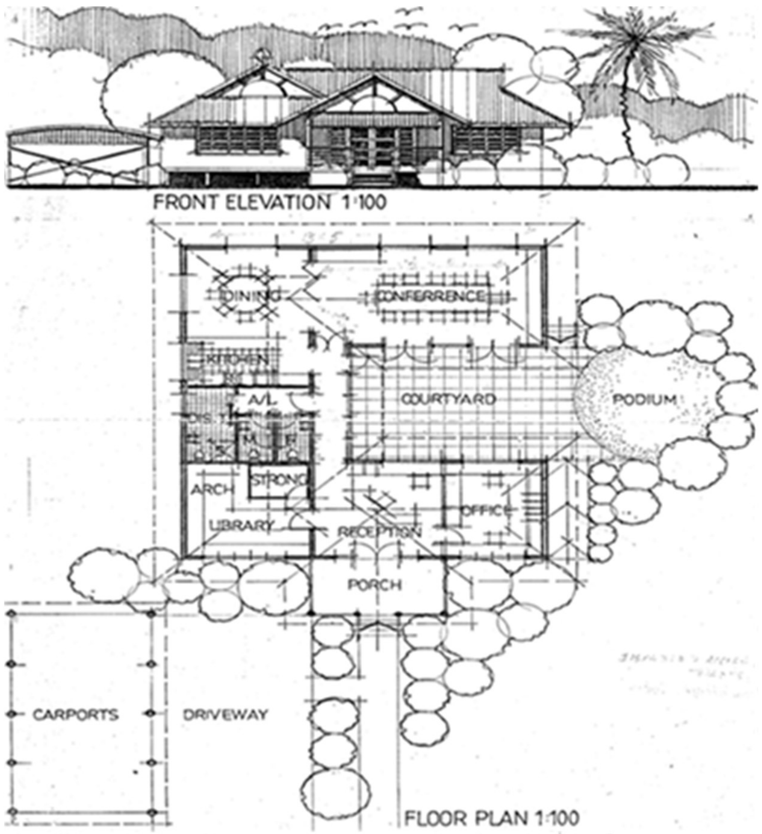
4 Requirements

Minimum facility requirements for the Cultural Centre are detailed below:

- Storage Shed for land management equipment;
- Undercover car park for:
    - Land management truck; and
    - Fire Fighting Truck
- Training / Meeting Room;
- Ablution and lunchroom;
- Male and Female change room, showers and toilets;
- Storage space for environmental monitoring and sampling equipment;
- 3 x offices;
- Electricity supply (Solar Power);
- Telecommunications supply;
- External car park for public and staff;
- 2 x 90,000 L Rainwater Tanks;
- Water Management for grey and black water;
- Recycle wastewater onto garden grounds; and
- Low water toilets, taps and fittings.
- Fire Alarm and suppression system.

Preliminary architectural concept design is shown in Figure 1.

Figure 1 Cultural Centre Preliminary Architectural Concept



5 Execution

5.1 Design

Design of Culture Centre is to be commission by the Earthworks Contractor. Location, final design and facilities to be determined in consultation with Traditional Owners and approved by Principal prior to construction (Hold Point).

5.2 Geotechnical Investigation

Prior to construction of the Cultural Centre, a geotechnical site classification investigation is to be undertaken for the proposed Centre location in accordance with Australian Standards AS 2870-2011 Residential Slabs and Footings and AS1726-2017 Geotechnical Site Investigation. As a minimum, the investigation will provide:

- Report on strata encountered at each test location including reduced levels;
- Site Classification as to AS2870;
- Recommend footing types and foundation material for the proposed development, including but not limited to allowable bearing pressures, shaft adhesion (if piles recommended) and anticipated settlements;
- Geology Profile;
- Report any groundwater found; and

- Provide advice regarding earthworks and foundation preparation.

5.3 Clearing and Grubbing

- Target area to avoid significant vegetation. Where unavoidable, species to be relocated to rehabilitation areas as determined by Superintendent.
- The Contractor shall clear and grub all vegetation from structure footprint and foundation area prior to construction.
- All trees, bushes and other vegetative matter not removed shall be chipped and stockpile in nominated location or placed elsewhere as directed by Superintendent.
- The chipped vegetation stockpile shall not exceed 2 m in height or have side slopes steeper than 1V:3H.
- Prior to any cutting earthworks, grubbing shall be carried out for the full extent of areas to be developed. Grubbing is defined at the removal of all stumps and roots, greater than 100 mm in diameter to a depth of 600 mm below the natural surface and removal of all other vegetation and boulders (particles greater than 200 mm in diameter) to a depth of 300 m below the natural surface.
- Clearing and grubbing shall not result in unnecessary waste of materials required for use elsewhere.
- The grubbed debris shall be deposited in the designated stockpile areas.
- Any clearing and stripping that the Contractor elects to perform for its own purposes, such as construction of temporary haul roads, equipment yards etc shall be subject to the approval of the Superintendent and shall be performed at the Contractors own expense. At the end of the Contract, all such areas shall be reinstated and rehabilitated by the Contractors at is won expense to meet the Principal's requirements and environmental obligations and to the satisfaction of the Superintendent.

5.4 Topsoil Stripping

- On completion of clearing, the Contractor shall strip and remove the topsoil from the foundation area to the approval of the Superintendent.
- The stripped topsoil shall be placed in stockpiles not exceeding 2m in height. Side slopes shall not be steeper than 1V:3H.
- A 250mm thick layer of chipped vegetation shall be placed on top of completed stockpiles to assist in erosional soil loss.
- Topsoil shall be defined as soil of any gradation or degree of plasticity which contains significant quantities of visually identifiable vegetative matter, sod, roots or humus. Stripping means the removal of all topsoil to a nominal depth of 200 mm below natural surface or as directed by Superintendent.

5.5 Foundation Preparation

Preparation for foundation of the Cultural Centre shall be in accordance with design drawings and as recommended in Geotechnical Classification Report.

5.6 Timing

The Cultural Centre is to be constructed as part of the Site Establishment Works at the beginning of the Rum Jungle Project.

6 Standards and Certification

Construction of the Cultural Centre must be in accordance with applicable Australian Building Codes, the Building Act 1993 and applicable Australian Standards. The construction must be certified at the applicable construction stages in accordance with Department of Planning and Infrastructure *Guidelines for Inspection Class 1 to Class 10 Buildings or Structures*, 2006 and Policy regarding 'In all Material Respects' 2006 with all certification documentation provided to the Principal for approval (hold points).

6.1 Building Control Area

The Rum Jungle Mine Site falls outside the Northern Territory 'Building Control' area and as such does not need a building permit or a fidelity fund certificate to build.

6.2 Wastewater Works Approval

In accordance with Northern Territory Building and development. Wastewater works design approval must be obtained prior to construction and submitted to the Principal for review (hold point). Guidelines for approval are provided in Northern Territory Government, *Guidance for submitting an application for a wastewater works design approval*, 2019.

Wastewater systems to be designed in accordance with applicable Northern Territory codes and guidelines for waste water found online at:

https://nt.gov.au/property/building-and-development/install-a-wastewater-system/wastewater-management/codes-and-guidelines

7 Measurement and Payment

Payment of Cultural Centre construction will be based on completion of Geotechnical Classification Inspection, Design Approval (including wastewater works approval) and progress claims based on certified stages in accordance with Guidelines for Inspection Class 1 to Class 10 Buildings or Structures:

- Pre-Pour Stage.
- Frame Stage
- Masonry Wall Stage
- Fire Separation Stage
- Waterproofing Stage; and
- Final Stage.

Checked/
Authorised by: Danielle O'Toole

APPENDIX B

Siting Study

Memorandum

To:	Jackie Hartnett	**At:**	DPIR
From:	Danielle O'Toole	**At:**	SLR Consulting Australia Pty Ltd
Date:	28 February 2020	**Ref:**	680.10421.90010 MO2 WSF Site Selection v1.0 Issued.docx
Subject:	WSF Technical Memo on Site Selection		

1 Introduction

As part of the current rehabilitation strategy (Stage 2A) for the former Rum Jungle mine site, the initial scope of works was to finalise the design of the proposed new Waste Storage Facility (WSF).

The Stage 2 rehabilitation strategy identified the preferred location of the WSF as an area of undisturbed ground on the northern boundary of the site. O'Kane Consulting (OKC) conducted a Multi-Criteria Analysis (MCA) (OKC, October 2015) identifying 3 preferred sites – northern, central and southern. The MCA identified that either the central or northern sites were the preferred site. According to the Failure Mode and Effects Analysis (FMEA) Report (OKC, September 2015) no final decision had been made on the location, however the design at that stage would be based on the northern site owing to "*OKC's current understanding of DPIR and stakeholders preferred location*".

DPIR has requested SLR revisit the site selection process to assess if the northern site is in fact the optimal location for the WSF. The process needs to evaluate:

- Engineering and environmental requirements, including:
  - Geotechnical (foundation) conditions;
  - Groundwater conditions;
  - Surface water flooding impacts;
  - Vegetation disturbance; and
  - Visual amenity.
- Traditional Owner requirements.

2 Potential Sites

The initial 3 sites identified as potential locations were:

- Southern site near the Intermediate Waste Rock Dump (WRD);
- Central site (old stockpile area to north east of Main Pit); and
- Northern site.

DPIR requested that SLR add a further site to the east of the central site (called central east). The four sites are shown in Figure 1.

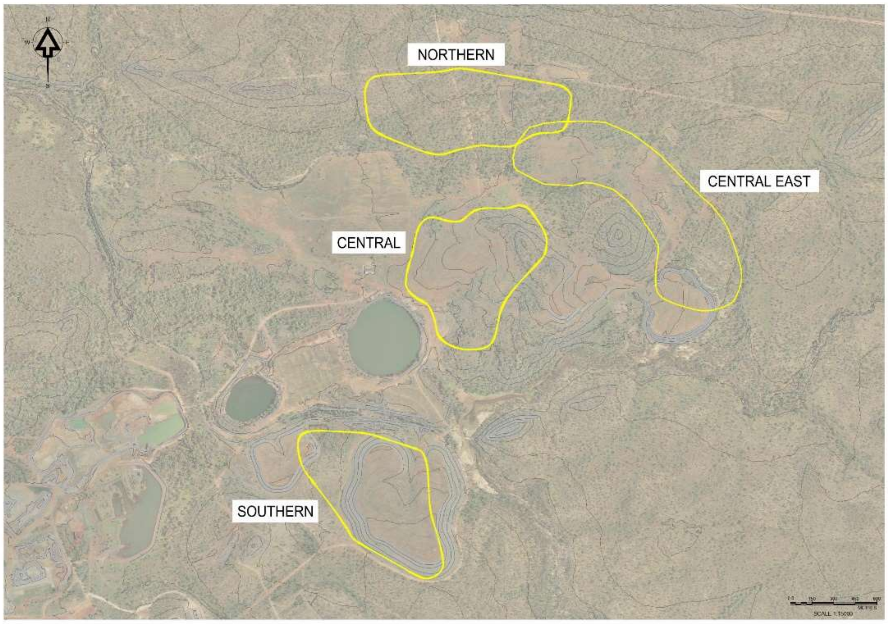


Figure 1 Potential WSF sites

3 Engineering and Environmental Assessment

3.1 Previous MCA by OKC

The OKC Baseline MCA is shown in Table 1 (note Existing = Southern site).

Table 1 OKC Baseline MCA (OKC, October 2015)

	Weighting	Northern	Central	Existing
Traditional Aboriginal Owner Acceptance and Visual Amenity	**5**	3	1	1
Seepage Collection and Treatment	**3**	2	3	1
Capital Cost	**2**	1	2	3
Geotechnical stability	**3**	1	3	3
Groundwater Contamination Risk	**3**	2	3	1
Surface Water Management	**3**	2	3	3
Disturbance and Re-vegetation	**1**	1	2	3
	Score	**39**	**47**	**38**
	comparative baseline Rank	**2**	**1**	**3**

A sensitivity analysis (i.e. where the weightings of each criteria were varied) was also carried out by OKC. The results, combined with the baseline MCA, clearly ruled out the southern (existing) site and noted that the central and northern sites scores were similar, and no clear alternative could be recommended (based on the information available to them at the time).

3.2 Present MCA by SLR

Building on the OKC MCA, an engineering and environmental high-level MCA has been carried out by SLR considering the northern, central and central east sites. For each criteria, the sites have been ranked qualitatively (1 = best to 3 = worst). The results are summarised in Table 2.

Table 2 High Level Engineering and Environmental MCA

<table>
<tr><th>Criteria</th><th>Site</th><th>Assessment</th><th></th></tr>
<tr><td rowspan="3">Geotechnical</td><td>Northern</td><td>Underlain by Coomalie Dolostone, encountered as low to high strength, extremely to moderately weathered with variable profile with depth due to groundwater flow paths. Coomalie Dolostone has been known to be karstic. Geophysical surveys in the area were inconclusive but suggested some probability of localised karstic features, which may be subject to collapse under loading. Foundation collapse could compromise the integrity of the WSF landform and capping. Further targeted investigation recommended to validate findings.</td><td>3</td></tr>
<tr><td>Central</td><td>Area predominantly underlain by Geolsec formation, described as haematitic breccia, and encountered as extremely to moderately weathered, of extremely low to moderate strength with depth. Geolsec formation is susceptible to weathered soil bands and pockets.
Southern portion is underlain by Whites Formation described as calcareous and carbonaceous pyritic mudstone/siltstone, dolomitic mudstone and rare quartzite, and encountered as extremely weathered, extremely low strength becoming readily more competent with depth. Whites Formation is subject to acid generation if exposed and allowed to oxidise.
Some foundation compression may occur under WSF loading, but this would predominantly during construction phase and differential settlement is not expected in the long term.
It will be important to set back the toe of the WSF an appropriate distance from the Main Pit to ensure it does not influence instability of the Main Pit wall.</td><td>1</td></tr>
<tr><td>Central East</td><td>Area is underlain by Coomalie Dolostone (northern portion), Whites Formation (Central portion) and Geolsec Formation (southern portion).
The northern portion has been previously stripped of soil deposits (used as borrow). Filter cake from previous rehabilitation works has been backfilled into the borrow area. Surface deposits comprise of weathered bedrock of variable strength and weathering with depth.
There is potential for foundation collapse in the dolostone, which could compromise the integrity of the WSF landform and capping. Further targeted investigation recommended to validate findings.
Some foundation compression may occur under WSF loading, but this would predominantly during construction phase and differential settlement is not expected in the long term.</td><td>2</td></tr>
<tr><td rowspan="2">Groundwater contamination risk</td><td>Northern</td><td>Dolostone has high copper attenuation properties, which is highly favourable as foundation material, as it will mitigate any contaminant load reaching the East Branch Finniss River (EBFR).</td><td>1</td></tr>
<tr><td>Central</td><td>Haematitic breccia has less copper attenuation ability than the dolostone, however modelling (RGC, November 2019) indicates that the attenuation will be sufficient to reduce contamination to below the locally derived water quality objectives (LDWQO) in the EBFR.</td><td>3</td></tr>
</table>

Criteria	Site	Assessment	
	Central East	The dolostone unit in the north is highly favourable. The rock units in White and Geolsic Formations in the central and southern areas, respectively, have less copper attenuation ability than the dolostone, however modelling (RGC, November 2019) indicates that the attenuation will be sufficient to reduce contamination to below the LDWQO in the EBFR.	2
Surface water and flood conditions	**Figure 2** shows the extent of flooding expected on site (after realignment of the EBFR) for a 1:1,000 year flood event (SLR, 2020).		
	Northern	Southern and western toes of the WSF could be impacted by flooding. Substantial bunding along these toes would need to be constructed for protection.	3
	Central	South-west corner toes could be impacted, minor bunding would need to be installed for protection.	1
	Central East	North-west and south-east toes could be impacted, minor bunding would need to be installed for protection.	2
Vegetation disturbance	Northern	Undisturbed, full vegetation clearance required.	3
	Central	Disturbed, no clearance required.	1
	Central East	Predominantly disturbed however some clearance will be required.	2
In situ buried contaminated soils	Northern	Not applicable	3
	Central	Radiation soils is located beneath footprint. Burying these beneath the WSF would be very beneficial.	1
	Central East	Filter cake from previous rehabilitation and water treatment is located beneath footprint. Burying these beneath the WSF would be very beneficial.	2
Visual amenity	Northern	Large dump on relatively flat ground, observable from all parts of site.	3
	Central	Visible from Main Pit but can be shaped to integrate with adjacent hillside.	2
	Central East	Not visible from Main Pit and can be shaped to surrounding hillsides.	1
Access to Dysons WRD		It has been identified that the use of Dysons WRD as an 'oxygen scavenging' layer beneath the WSF capping will provide additional risk mitigation for AMD (RGC & Jones, 2019). Therefore, ongoing access to Dysons WRD will be required throughout the construction.	
	Northern	No impact.	1
	Central	No impact.	1
	Central East	Construction must commence at the northern end.	3
SUMMARY OF SCORES	Northern	Total = 17	**3**
	Central	Total = 10	**1**
	Central East	Total = 14	**2**

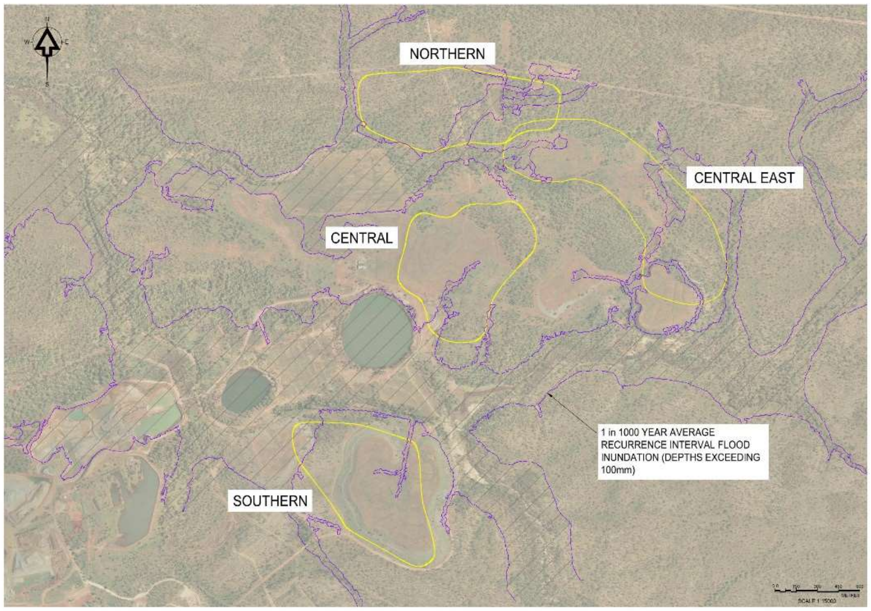


Figure 2 Areas Represented by Hatched Purple Lines Indicate Extent of 1:1,000 Year Flooding

4 Traditional Owner Requirements

The location of the WSFs must also meet Traditional Owner requirements. These include:

- Avoidance of identified sacred sites and objects (as shown on the AAPA certificate issued in October 2019 – not included here as it is culturally sensitive);
- Minimal disturbance of large cycads; and
- No disruption of the site line between 2 sacred sites (nominated on AAPA) – meaning that a maximum height of RL 98m AHD should be maintained.

It is understood that DIPR presented the options of the northern, central and central east locations to the Traditional Owners over a period of several months in 2019, including site visits with interested parties and Darwin and Batchelor based workshops, with agreement being reached that the central and central east locations were acceptable locations.

5 Recommendation

It is recommended that the central site be developed as first priority, with any remaining capacity requirements developed at the central east site, however refinement of block modelling would be required to optimise material haulage and thus reduce costs. No development at the northern site is recommended. In addition to the criteria discussed above, key considerations for the footprint development will be to ensure:

- Appropriate set back from the Main Pit to allow ongoing access for cultural reasons and geotechnical limitations; and
- Appropriate set back from riverine areas.

6 Bibliography

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Checked/
Authorised by: B Tarrant / D O'Toole / D Trani

APPENDIX C

Erosion Modelling Report

RUM JUNGLE REHABILITATION - STAGE 2A DETAILED DESIGN

Erosion Assessment for the New Waste Storage Facility

Prepared for:

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SLR Ref: 680.10421.90010-R03
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BASIS OF REPORT

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Reference	Date	Prepared	Checked	Authorised
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TABLE OF CONTENTS

DOCUMENT REFERENCES

TABLES

FIGURES

APPENDICES

1 Introduction

1.1 Overview

The Northern Territory Government (NTG), represented by the Department of Primary Industry and Resources (DPIR), proposes the rehabilitation of the former Rum Jungle Mine site (the Project), located 6 km north of Batchelor, Northern Territory (NT), and approximately 105 km south of Darwin CBD as shown in **Figure 1**.

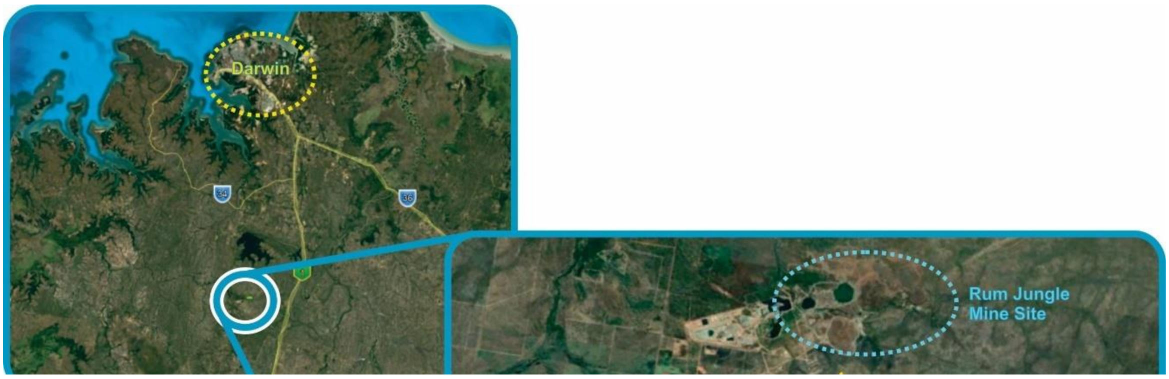


Figure 1 Former Rum Jungle Uranium Mine location

SLR Consulting Australia Pty Ltd (SLR) was engaged by DPIR to undertake the detailed design to meet the engineering requirements for construction of the rehabiliation design.

This report details the landform erosion modelling and assessment carried out to support the rehabilitation design of the new Waste Storage Facilities (WSFs). It is recommended that this report be read in conjunction with the SLR Detailed Engineering Design Report (SLR, 2020a).

1.2 Background Information

1.2.1 Overarching Project Objectives

The Project's high-level objectives are two-fold and focus on environmental remediation and restoration of cultural values of the site as described below:

- Improve the environmental condition onsite and downstream of site within the East Branch Finniss River (EBFR). This includes the following key outcomes:
  - Improved surface water quality conditions within EBFR in accordance with locally derived water quality objectives (LDWQOs).
  - Achieve chemically and physically stable landforms.
  - Support self-sustaining vegetation systems within rehabilitated landforms.
  - Develop physical environmental conditions supportive of the proposed Land Use Plan.
- Improve site conditions to restore cultural values. This includes the following key outcomes:
  - Restoration of the flow of the EBFR to original course as far as possible.

- Remove culturally insensitive landforms from adjacent to sacred sites and relocate ensuring a culturally safe distance from the sacred sites.
- Return living systems including endemic species to the remaining landforms.
- Preserve Aboriginal cultural heritage artefacts and places.
- Isolate sources of pollution including radiological hazards.
- Maximise opportunities for Traditional Owners to work onsite to aid reconnection to country.

A more detailed description of the overarching project objectives is contained in Section 1.2 of the SLR Detailed Engineering Design Report (SLR, 2020a).

1.2.2 Rehabilitation Strategy

One of the key actions planned to address contamination processes and improve prospects of future land use is to slow down or halt the Acid Metalliferous Drainage (AMD) production reactions from waste rock onsite by consolidating existing waste rock dumps (WRD) into one of three new facilities based on Potential Acid Forming (PAF) characteristics. These facilities are:

- Main Pit backfill zone;
- West WSF; and
- East WSF.

This erosion assessment addresses both the West WSF and East WSF.

1.2.3 Proposed WSFs

The footprints of the proposed WSFs in a 3-dimensional representation are shown in **Figure 2Error! Reference source not found.**. It is important to note that the WSF landforms used were in draft at the time of initial modelling, hence there are some variations in the final footprint with respect to the design issued in the SLRs Detailed Engineering Design Report (SLR, 2020a). Nonetheless, the results and recommendations from this report remain valid and have been applied to the final design.

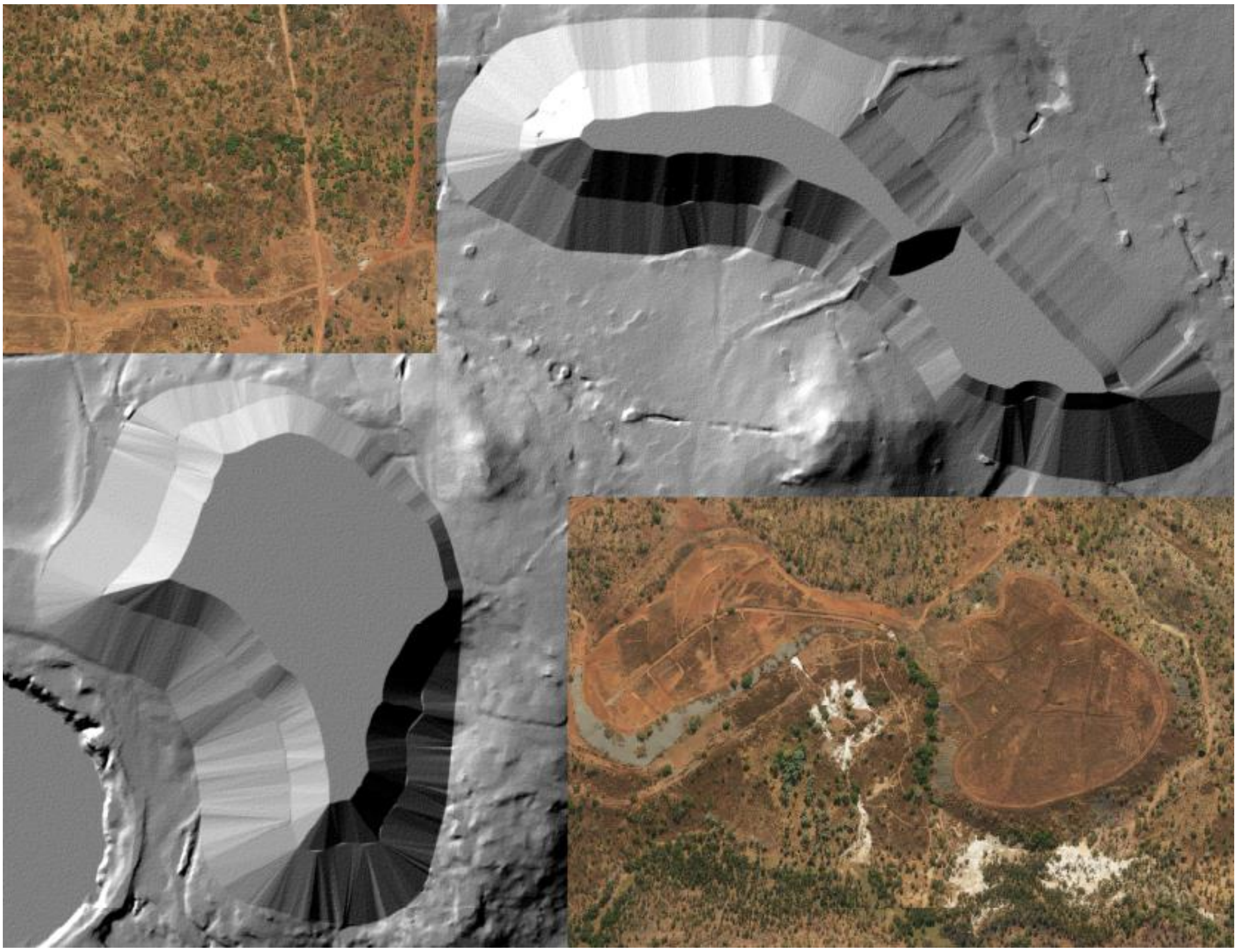


Figure 2 West and East WSF Proposed Locations

The WSF locations had been selected based on the following criteria:

- are not prone to flooding in a 1:100 Average Recurrence Interval (ARI) event;
- have suitable foundation geotechnical stability;
- require minimal clearing of established vegetation;
- minimise re-handling of radiological soils by covering the major remnants *in situ*;
- do not disturb Aboriginal places, objects or artefacts; and
- do not present unacceptable visual amenity impacts.

The details of the selection process are provided in the WSF Technical Memo on Site Selection (SLR, 2020b).

1.2.4 Existing Site Conditions

The Rum Jungle decommissioned uranium mine site consists of a 655ha parcel of land located immediately to the northeast of Rum Jungle Road and Litchfield Park Road intersection and immediately east of Browns Oxide Mine Site. The site extends approximately 2.6 km east and 2.0 km north from Rum Jungle Road – Litchfield Park Road intersection. Access to the site is typically from the east via Rum Jungle Road or Browns Oxide Mine. An unsealed access track also exists to the north of the site allowing access. For more details refer to Section 2 in the SLR Detailed Engineering Design Report (SLR, 2020a).

1.2.5 Capping Design of WSFs

The typical details of the proposed capping system is shown in **Figure 3** (extracted from (SLR, 2020a)). Typical details of the capping system overlying the side slopes and the starter bund is shown in **Figure 4**, and is composed of three layers:

- 1.0m thick High Compacted Waste Rock Starter Bund, which will be in direct contact with the Waste Material;
- 0.65m thick Low Permeability Clay Liner to limit water flow and oxygen ingress and retain water to provide moisture to the Growth Medium Layer; and
- 2.0m Growth Medium Layer to provide the selected vegetation with the required moisture and nutrients.

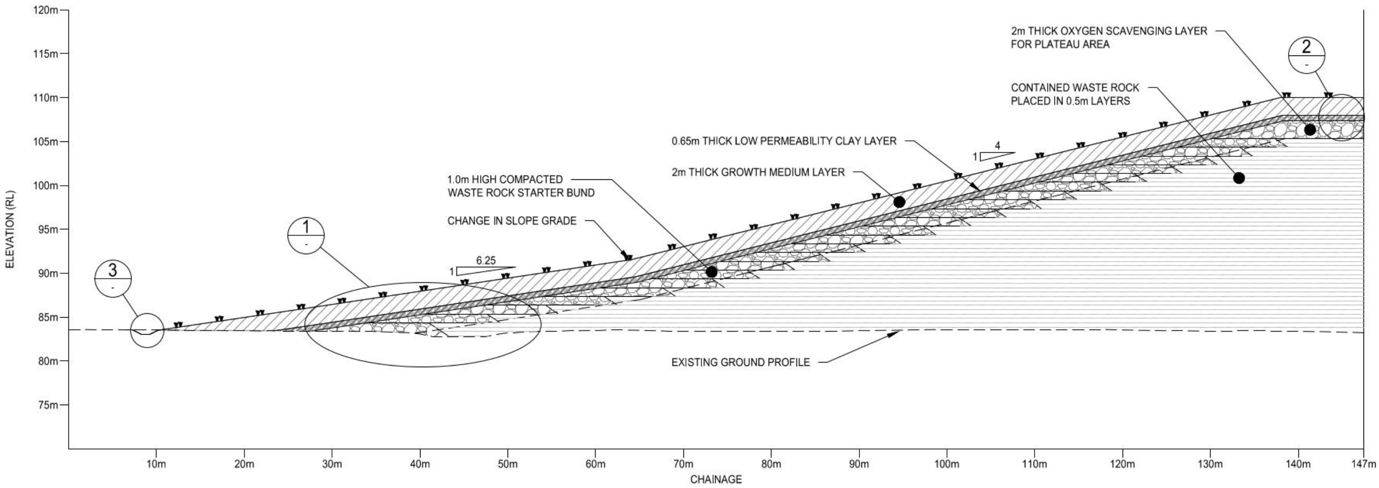


Figure 3 Typical WSF Capping Section.

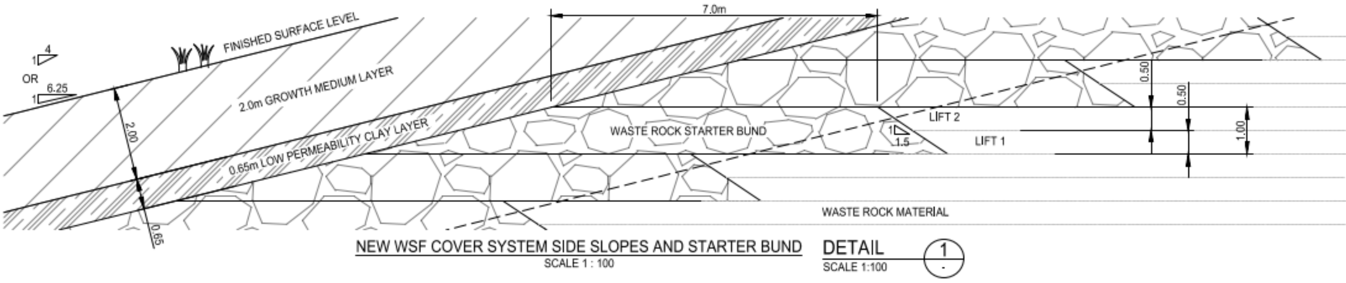


Figure 4 Typical WSF Capping Section, Side Slopes and Starter Bund - Detail 1.

The gradients of the natural topography surrounding the proposed WSFs were measured from the available LiDAR data. The natural gradients appear to be between 5° to 10° and observations on site would show minimal indication of erosion on these slopes over time. The objective of the design of the capping system is therefore to mimic the natural surrounding as practically as possible. This will not only provide more convergence in terms of visual impact but will also replicate as closely as possible the natural site characteristics which appeared to have withstood erosion over a geological timeframe. A comparison of the measured natural slopes and the selected slopes for the WSFs in terms of erosion performance is discussed in **Section 4**.

1.3 Assessment Specific Objectives

The main objectives of this assessment were to:

- Select the most appropriate WSF batter slopes based on long-term erosion performance; and
- Simulate the erosion performance of the WSFs over a period of 500 years including vegetation establishment.

1.4 Erosion Modelling Limitations

There are a number of limitations inherent in the erosion modelling, including:

- All materials are assumed that they are representative of the entire site;
- The compaction and surface roughness of the materials used to perform testing in laboratory setting may be very different to that of the site;
- The author can take no responsibility for any errors that may be the result of inadequacies in the coding or content of the software; and
- It is not possible to guarantee that any prediction or result contained in this report will or might occur.

2 Scope of Work

To address the above assessment objectives, the following scope of work have been completed:

- Collate available data on the cover material and the proposed geometry alternatives of the new WSF landform.
- Use calibrated erosion parameters determined from flume testing and literature for the new WSF cover materials.

- Carry out long term erosion modelling over a period of 500 years to assess the relative performance of the cover materials in terms of sheet and gulley erosion.
- Preparation of this report to document the findings of the erosion assessment.

3 Erosion Assessment Methodology

The erosion assessment for the new WSFs was carried out by adopting a two-stage approach, generally described as follows:

- Stage 1 – This stage involved the selection of the optimal slope or combination of slopes out of three options; and
- Stage 2 – This stage involved modelling of the slope with the optimal erosion performance from Stage 1 with a vegetation cover in various stages of establishment.

The methodology adopted in this assessment is outlined as follows:

1. Review of the proposed slope angles with representative model parameters obtained from the flume testing.
2. Review of the flume testing results carried out using materials extracted from the borrow areas to be used in the landform works to obtain the appropriate erosion parameters. Refer to Appendix A for details on Flume Testing.
3. Using the commercially available software SIBERIA, carry out Stage 1 long-term erosion simulation on three chosen slopes prepared from a 3D digital terrain model. The outcome of this stage is the optimal combination of slopes out of the three. Appendix B provides a more detailed description of SIBERIA.
4. Review a selection of suitable cover materials and vegetation species from literature to cope with local conditions and availability.
5. Using SIBERIA again, carry out Stage 2 long-term erosion simulation on the optimal combination of slopes from Stage 1 with select vegetation cover on it. This stage provides the recommended vegetation that would provide potentially the best long-term outcome against erosion.
6. Assess total erosion and deposition volumes and the locations of the occurrence for input into surface water control design (by others).

3.1 Stage 1 Modelling - Batter Slope Assessment

SLR has developed three alternative landform models (i.e. digital terrain models or DTMs) that would likely satisfy all the specifications and requirements from the agronomical, erosional, geotechnical and hydrological perspectives. The surface water requirements were not considered during this stage.

In order to represent ripping features, construction undulations and irregularities into the surface, the initial DTM was created using a “Random Surface” generating function in which surface irregularities have been simulated by incorporating a typical scatter variation of ±0.1 m in the vertical plane of a 1m × 1m grid.

The analysis-specific objectives of the Stage 1 modelling are as follows:

- To find a suitable slope to comply with agronomical, geotechnical and water surface management requirements;

- To test the erosion performance of the selected material under demanding conditions; and
- To know the locations where erosion is expected.

Specific factors such as batter slope, material types and timeframe implemented in Stage 1 are discussed in the following sections.

3.1.1 Slope

Historically, many reclaimed landforms have adopted linear slope designs. This approach offers simplicity, but the long-term landform performance is often unacceptable. Various studies have demonstrated that concave slopes offer a sediment transport reduction up to three-fold compared to linear ones (Priyashantha, 2009). As one of the main purposes for this assessment is to propose a landform able to minimise erosion, it was decided to test different concave shapes and determine the best option to implement in the final WSF design.

The initial WSF design contemplated the storage of more than 8.5Mm^3 which translated into a landform approximately 40m high accompanied by a trilinear concave slopes of 1:5 to 1:3.5 to 1:2.5 (see **Figure 5)**. According to (O'Kane Consultants Pty Ltd, 2016b), this configuration was designed to maximise long term stability, provided the combination of gradients and climate, vegetation is expected to establish favourably on the lower shallower slopes.

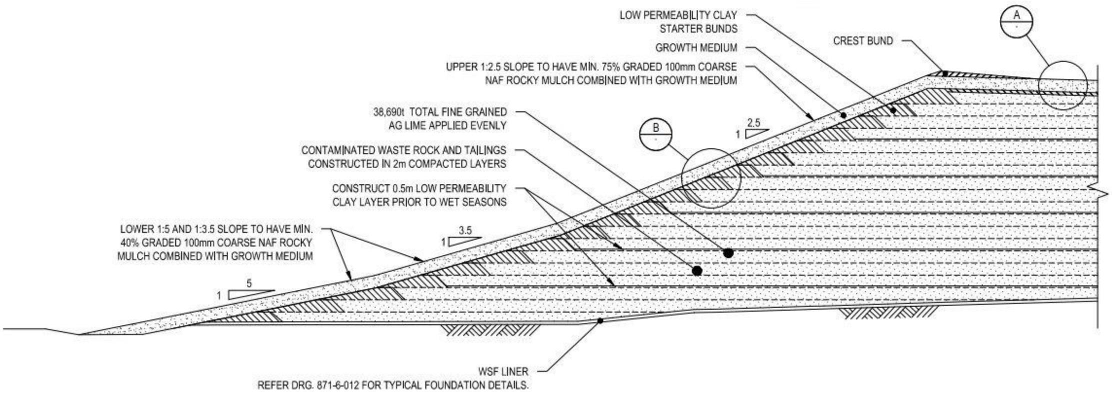
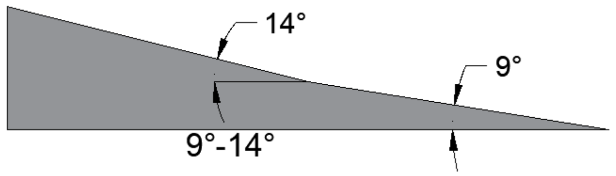
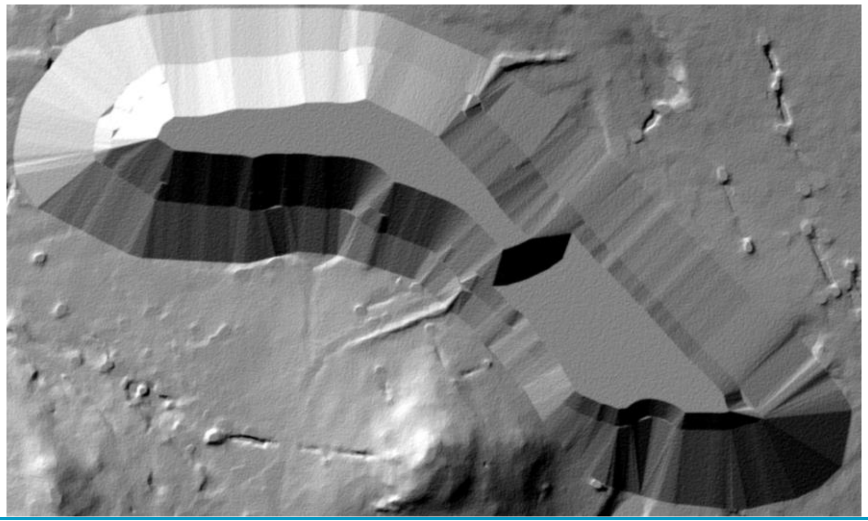
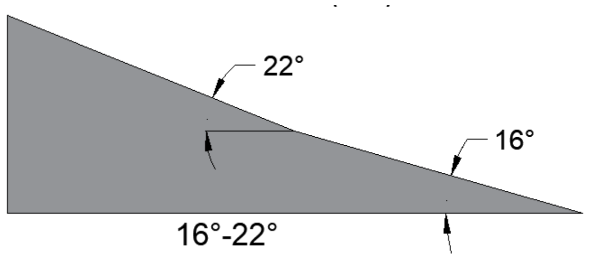
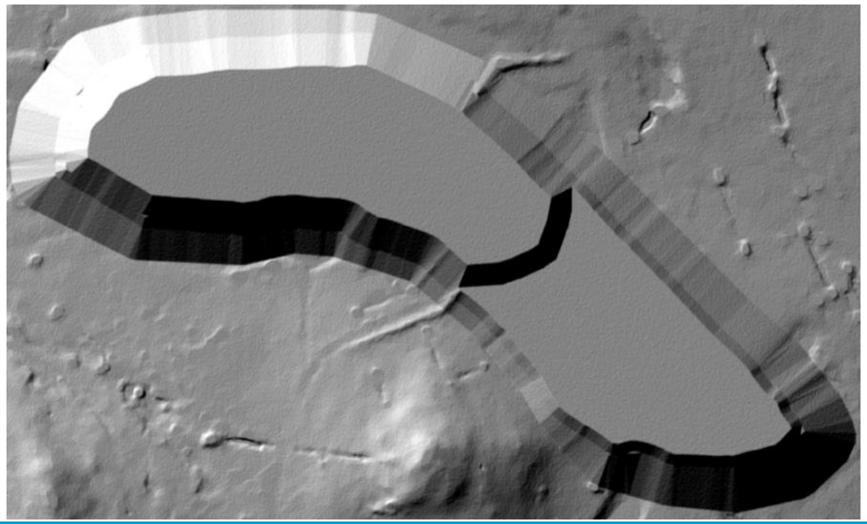
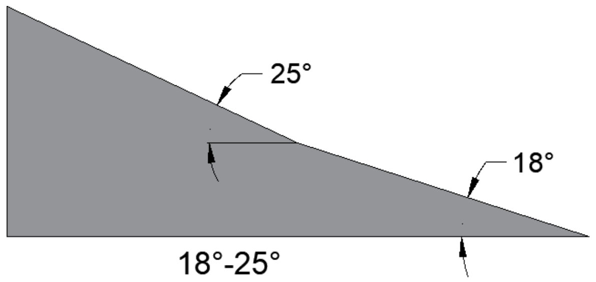
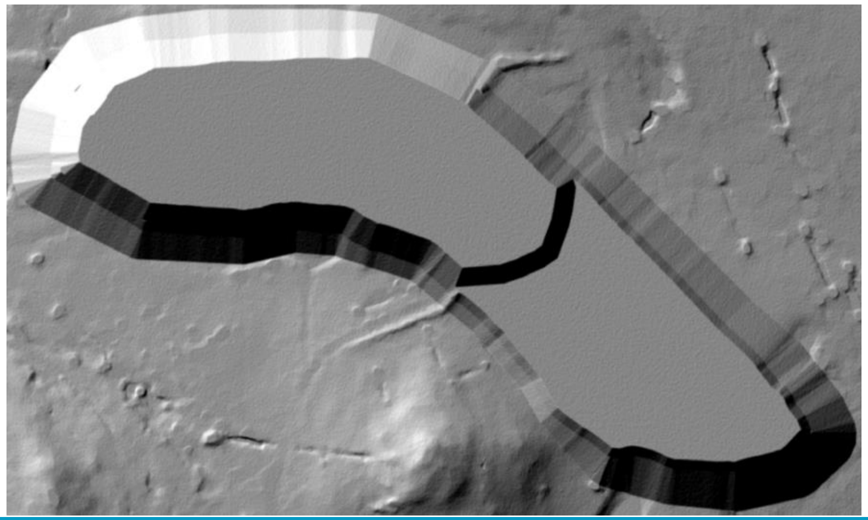


Figure 5 Typical Section, Containing a Trilinear Slope, Source: (O'Kane Consultants Pty Ltd, 2016a).

The updated WSF design would store a smaller volume of around 7Mm^3 and with a lower height. Consequently, the updated proposed slope configuration was decided by removing the flatter lower segment (1:5). Eventually, an option of 1:3.5 to 1:2.5 (or 16° to 22°) was proposed, and subsequently two additional dual-slope options were proposed for assessment, one steeper and one flatter. The change in slope is located at the mid-height of the batter.

The three slope scenarios were modelled using representative soil erosion parameters with no vegetation cover. The East WSF was selected to perform this series of analyses as it has more geometric variety compared to the West WSF. **Table 1** graphically represents the dual slopes that have been considered in these assessments, together with the hillshades of the three concave dual slopes for Stage 1 pre-erosion condition at East WSF.

Table 1 Dual-slope Scenarios and Their Respective Hillshade Representation for EWSF Pre-Erosion.

Dual Slope Scenarios	Hillshades	Description
		**Low Slope** **9° to 14°** (1:6.25 to 1:4 (V:H))
		**Medium Slope** **16° to 22°** (1:3.5 to 1:2.5 (V:H))
		**High Slope** **18° to 25°** (1:3.08 to 1:2.14 (V:H))

3.1.2 Material Parameters

The key input parameters for SIBERIA modelling were developed based on the results of flume testing. The two material types considered for capping are laterite and saprolite, described as follows:

- Laterite material – clayey GRAVEL and/or gravelly/sandy CLAY with zones of COBBLES/BOULDERS found at 0.1 to 0.2m depth; and
- Saprolite material – typically silty/sandy CLAYS of medium to high plasticity and found at 3.00 to 4.00 m depth.

Representative samples of laterite and saprolite were taken from test pit NTP01 at Borrow Area A as part of the geotechnical investigation described in (SLR, 2019). The general location of Borrow Area A is shown in **Figure 6**.

Figure 6 Location of Test Pit NTP01 Where Laterite and Saprolite Materials Were Sampled

In lieu of testing *in situ*, the collected material samples were subjected to flume testing to measure soil erosion performance in a controlled environment. The results of the flume testing are then interpreted for use as input in SIBERIA modelling.

The flume testing of the collected soil samples was completed by Prof. Greg Hancock from the University of Newcastle (NSW, Australia). The samples were obtained by SLR from the test pit NTP01 as part of the geotechnical investigation which took place in July 2019 (SLR, 2019).

SIBERIA parameters were determined from the flume testing results, using a multiple regression for the β1, m1 and n1 values of the fluvial sediment transport equation q_{sf} for runoff, sediment load and each slope until the parameter combination was optimised. **Table 2** provides a summary of the developed parameters and full details of the flume testing are provided in Appendix A.

Table 2 SIBERIA Parameters for the Laterite and Saprolite Materials.

Parameter	Laterite (sample from 0.5m to 1.1m)			Saprolite (sample from 4.9m to 5.3m)		
Slope	5% (3°)	15% (9°)	25% (14°)	5% (3°)	15% (9°)	25% (14°)
β1	0.015	0.01	0.01	0.0015	0.0015	0.015
β3	1	1	1	1	1	1
m1	1.6	1.6	1.5	2.2	2	1.5
m3	1	1	1	1	1	1
n1	2	2	2.6	2.6	2.8	2

The conclusions from the flume testing (Aquaterra International, 2019) are:

- Both the laterite and saprolite are prone to erosion without vegetation cover.
- Revegetation would improve their erosional stability. This is supported by the pH and EC measured in both materials which implies no impediments to plant growth, although nutrient analysis was not undertaken.
- Improvement of both soils requires utilisation of fast-growing cover species such as Japanese Millet, but it is recommended to perform additional flume analyses to ensure this.

Based on the results of the flume testing, a 25% (14°) slope of laterite material was selected for the Stage 1 analyses, based on the following reasons:

- A basic rule of thumb for selecting an adequate material for soil loss resistance is to look for equilibrated contents of silt, clay and sand. The laterite material provides a better distribution than the saprolite (which contains a disproportionate percentage of silt, i.e. 70%).
- The highest slope was selected as this represent the most conservative scenario.
- A 25% (14°) slope with laterite material shows a combined β1, m1 and n1 coefficients of 0.01, 1.5 and 2.6, respectively. This combination typically characterises a material susceptible to rilling and/or gullying which is the more detrimental type of erosion. Thus, the selection of this set of parameters represent a highly conservative scenario.

3.1.3 Timeframe

The selection of the Stage 1 modelling timeframe is based on the following:

- Long-term analyses prevail over short-term ones as long-term performance represents a more demanding scenario.
- Timeframes beyond 500 years require the addition of the diffusivity component, which unnecessarily increases the level of complexity of models, making the prediction less accurate.

Therefore 200 and 500 years were used to undertake Stage 1 analyses.

3.2 Stage 2 Modelling - Cover Material Assessment

The outcome of Stage 1 modelling is then used for the Stage 2 analysis. Stage 2 has an additional degree of complexity by introducing a vegetation cover that will be placed to improve the erosion resistance of the laterite material over time. The selected vegetation cover performance will be predicted over a long-term timeframe.

The analysis-specific objectives of the Stage 2 modelling are as follows:

- Include a long-term vegetation establishment plan, paying special attention to wet and dry seasons;
- Estimate the expected erosion rates and gully depths of the selected slope; and
- Obtain the locations and extent where erosion will occur.

Specific factors such as batter slope, material types and timeframe implemented in Stage 2 are discussed in the following sections.

3.2.1 Slope

The preferred dual slope obtained from Stage 1 modelling is applied to both the East WSF and West WSF.

3.2.2 Material Parameters

As the flume testing did not take into account vegetation, it is necessary to redefine the β1 parameter using the Revised Universal Soil Loss Equation (RUSLE). The process also involves the introduction of the soil erodibility (K) and reduction in the soil loss capacity (C) parameters. K value can be seen as the capacity to erode and C as the ability to minimize it (e.g., by vegetation or rock armoring). In other words, according to RUSLE, β1 is the result of multiplying K and C factors.

The remaining SIBERIA coefficients, i.e. β3, m1, m3 and n1 remain the same as Stage 1 and the processes to determine K and C factors are presented detailed in Appendix C. **Table 3** shows the β1 factors used for the erosion analyses in Stage 2.

Table 3 β1 Factors for the Stage 2 Modelling Over a 500 Year Timeframe.

Year	Time of Year	Total Cover (%)	Estimated C Factor	Estimated K Factor	β1=KxC
1	Start of wet season	≥40	0.22	0.04	0.00880
	Mid-wet season	≥75	0.03	0.04	0.00120
	End of wet season	≥95	0.001	0.04	0.00004
2	End of dry season	≥95	0.001	0.04	0.00004
	End of wet season	≥95	0.001	0.04	0.00004
3	End of dry season	≥95	0.001	0.04	0.00004
	End of wet season	≥95	0.001	0.04	0.00004
4	End of dry season	≥95	0.001	0.04	0.00004
	End of wet season	≥95	0.001	0.04	0.00004
5	End of dry season	≥95	0.005	0.04	0.00020

Year	Time of Year	Total Cover (%)	Estimated C Factor	Estimated K Factor	β1=KxC
	End of wet season	≥95	0.005	0.04	0.00020
10	End of dry season	≥80	0.04	0.04	0.00160
	End of wet season	≥95	0.005	0.04	0.00020
50	End of dry season	≥80	0.04	0.04	0.00160
	End of wet season	≥95	0.005	0.04	0.00020
100	End of dry season	≥80	0.04	0.04	0.00160
	End of wet season	≥95	0.005	0.04	0.00020
500	End of dry season	≥80	0.04	0.04	0.00160
	End of wet season	≥95	0.005	0.04	0.00020

3.2.3 Timeframe

The selection of the Stage 2 modelling timeframe is based on the following:

- Short and long-term performance are important as the former has a direct impact on the latter. It is a considered a concatenated process where simulation of early years is fundamental to improve the accuracy of erosion prediction in the longer term.
- As per Stage 1, timeframes beyond 500 years was not considered.
- Special attention to dry and wet seasons was made. A year by year model from 0 to 5 years was implemented as this timeframe represents the most crucial stage in the vegetation establishment. Then, longer periods of time were included.

Consequently, 5, 50, 200 and 500 years were selected.

4 Results and Discussion

4.1 Stage 1 Results and Analysis

The results from the Stage 1 modelling are summarised in **Table 4** and graphically shown in **Table 5.** The key points are summarised below:

- The lowest dual-slope angles (9° to 14°) provide the lowest erosion rates for all years, with between 1.2 and 1.40 m^3/ha/yr, followed by 16° to 22° with 1.97 to 2.47 m^3/ha/yr and 18° to 25° with 2.29 to 2.87 m^3/ha/yr., respectively.
- Maximum erosion depths at 500 years are 1.45m, 3.13m and 3.74m for the low, medium and high dual-slope angles, respectively.
- The low dual-slope provides the lowest mean erosion depth at 500 years, with 0.13m, followed by medium and high slopes with 0.24 and 0.29m, respectively.

Table 4 Stage 1 SIBERIA Results for Laterite Material on East WSF

Variable	9° to 14° dual-slope		16° to 22° dual-slope		18° to 25° dual-slope	
	200yr	500yr	200yr	500yr	200yr	500yr
Initial Average RL's (m)	86.14		88.32		88.90	
Average RL's (m)	86.12	86.07	88.28	88.19	88.85	88.76
Accumulated Erosion rate (m3/ha/yr.)	-1.20	-1.40	-1.97	-2.47	-2.29	-2.87
Max. Erosion depth (m)	-1.06	-1.45	-1.47	-3.13	-1.95	-3.74
Mean Erosion depth (m)	-0.05	-0.13	-0.10	-0.24	-0.12	-0.29
Max. Deposition height (m)*	0.80	1.08	1.29	1.81	1.42	2.04
Mean Deposition height (m)*	0.07	0.11	0.11	0.20	0.12	0.23

*Note that erosion is expressed as negative to differentiate from deposition at East WSF toe.

- The bar graph in **Figure 7** depicts the erosional rates of each slope scenario in the first 200 years as well as the remaining 300 years of analysis, and generally indicate the erosion rates in the first 200 years compared to the following 300 years increased in all the slope scenarios.
- All slopes present an erosion rate increase of 1.4 times, except for the low slope whose increase is slightly lower at 1.3 times.

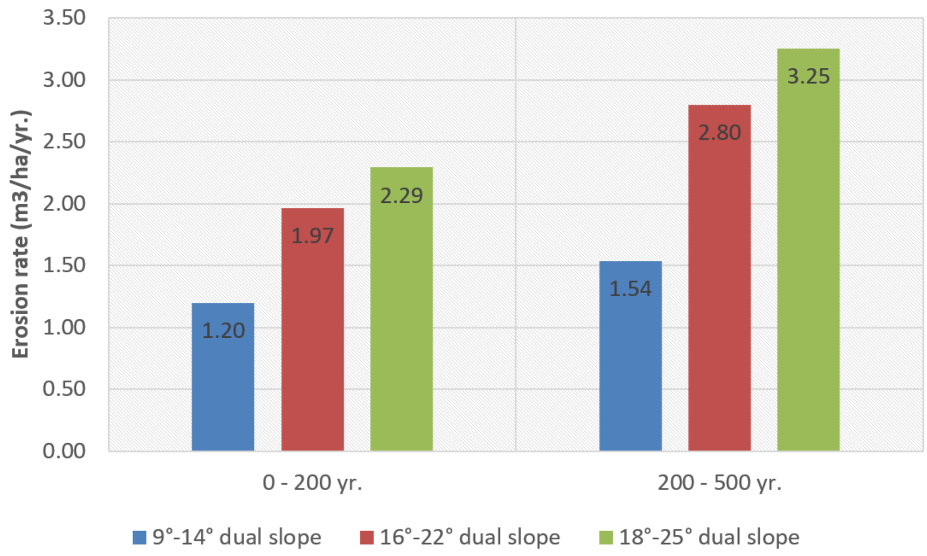


Figure 7 Stage 1 Erosion Rates in the First 500 Years

- Rill and gulley behaviour can be noticed in the several incisions present in the B-B and C-C cross sections in **Table 5** and become more pronounced in the medium and high dual slopes.

- As the modelled landforms used to run SIBERIA were provisional at the time of this analysis, some inaccurate details were allowed. The cross-sectional wrinkles (peaks) observed in the plan view are an example of this. The black line in **Figure 8** illustrates the pre-erosion surface of a typical cross section and the peaks as a result of the wrinkles. In the same figure, orange, blue and green lines show the time-progressive gully formation originated from the marked vertexes acting as seeds for localised erosion. In reality, these inaccuracies are unlikely to occur, therefore, it is likely that the erosion rates and erosion depths predicted in the models are exaggerated. Cross sections in all scenarios show abrupt changes in the original surface, that is a sign that this phenomenon is occurring in the analysed landform.

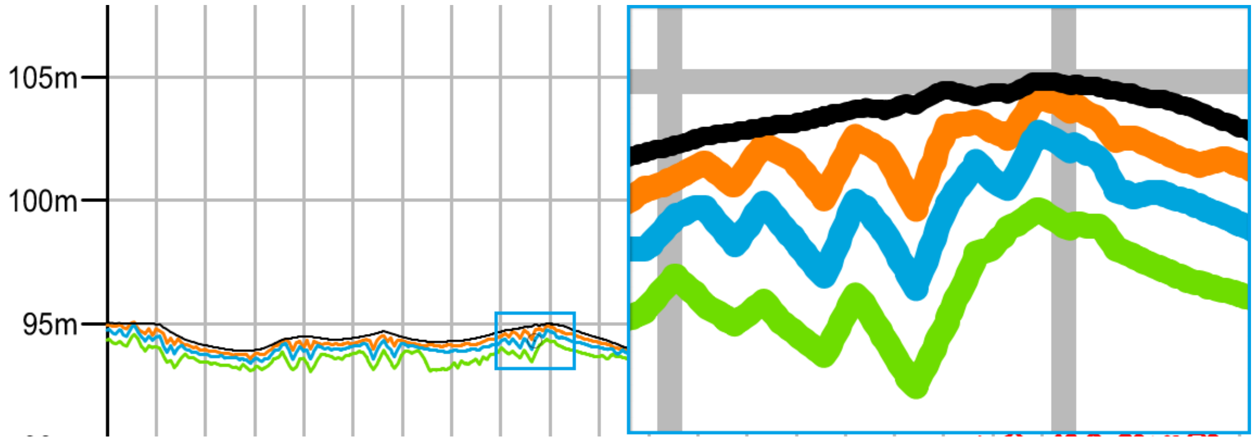


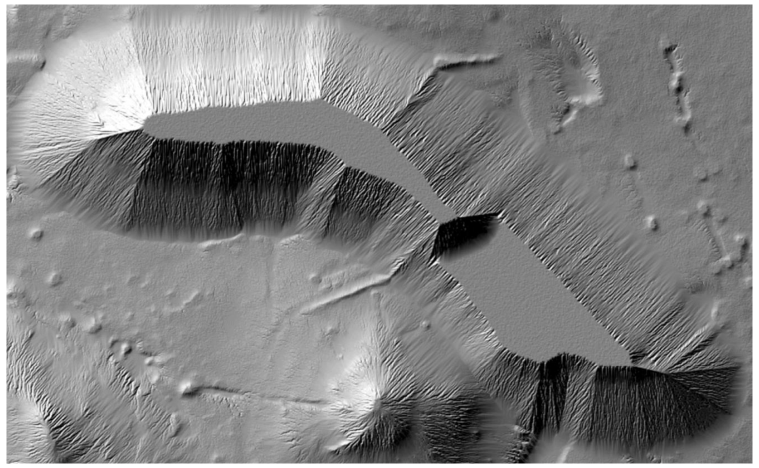
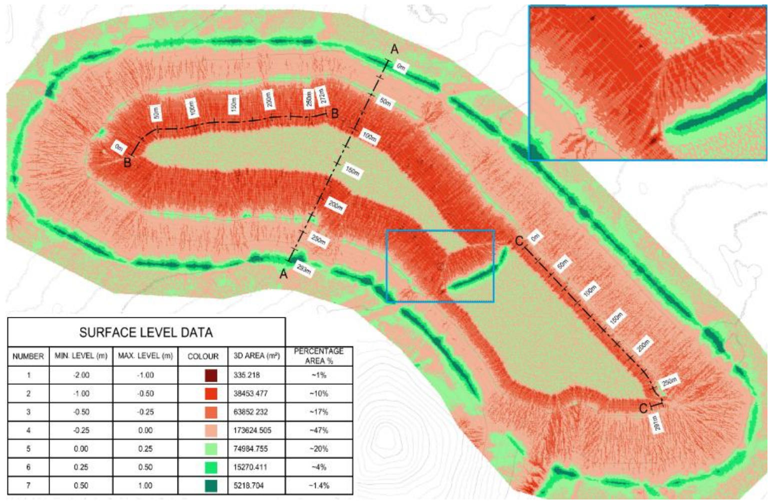
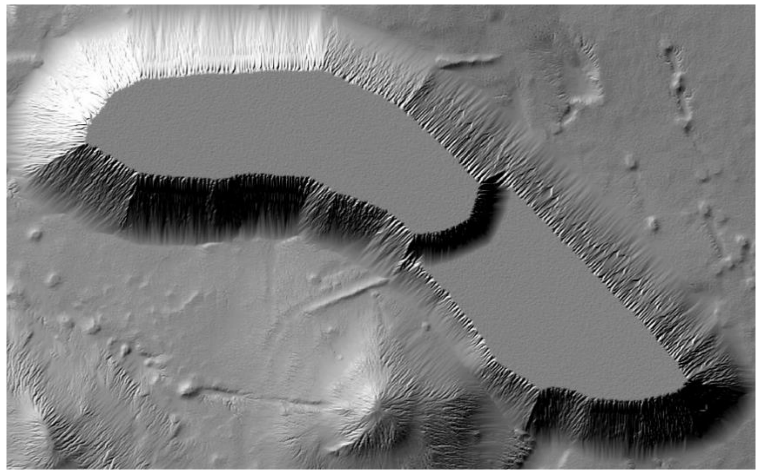
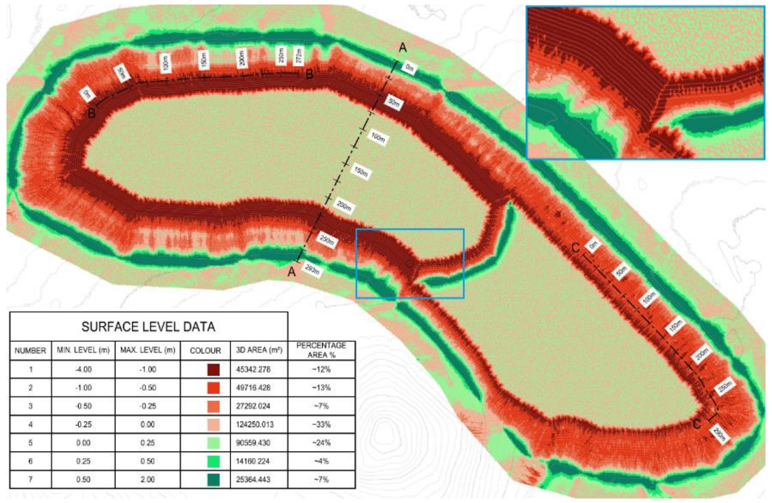
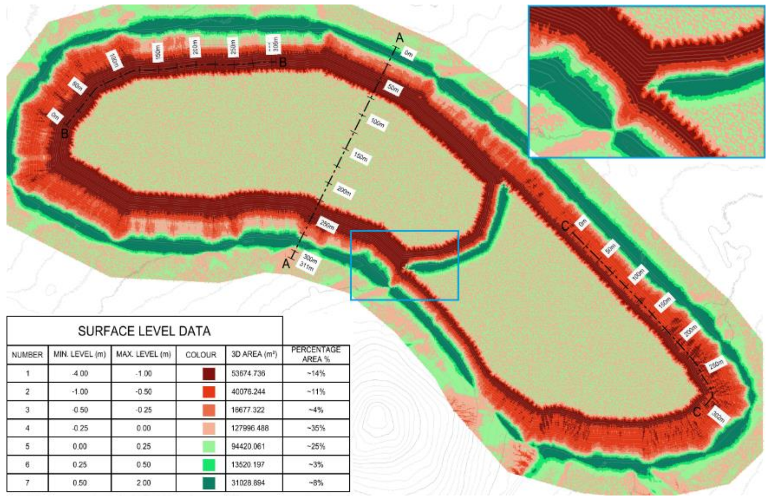
Figure 8 Typical SIBERIA Gully Seeding From Cross Sectional Wrinkles. Black Shows the Initial Profile; Orange, Blue, Green and Red Represent 200, 500 and 1000 Years of Erosion.

- The main purpose for Stage 1 is to select the best dual-slope scenario. This selection was driven by the analysis of erosion rates modelled with SIBERIA. In all points of comparison, the best scenario was the flattest dual slope (9° to 14°).
- Colour maps show that erosion depths larger than 1 m are unlikely in the 9° to 14° dual-slope scenario, only 1% of the total area is predicted to take over this depth. Medium and High slopes have 12 and 14% of total site area where erosion depth can erode further than the 2.0m cover depth.

The portion of the dual slope whose slope is 14° and localised near the top of the batter is the most vulnerable part of the East WSF.

Appendix D show the hillshades for Stage 1 after 500 years for all dual slopes. The erosion produced after 500 years on natural surfaces is similar to the ones produced on East WSF in the same timeframe. Appendix D also illustrates the colour maps and cross sections for the low, medium and high slope scenarios.

Table 5 Stage 1 Hillshades and their respective Soil Loss Maps for East WSF After 500 Years.

Eroded Hillshades	Soil Loss Maps	Description
		**Low Slope** **9° to 14°** (1:6.25 to 1:4 (V:H))
		**Medium Slope** **16° to 22°** (1:3.5 to 1:2.5 (V:H))
		**High Slope** **18° to 25°** (1:3.08 to 1:2.14 (V:H))

4.2 Stage 2 Results and Analysis

The results from the Stage 2 modelling are presented in **Table 6** and graphically illustrated in **Table 7** and key points are summarised as follows:

- In general, West WSF presents larger sheet erosion rates compared to East WSF.
- In terms of the maximum erosion depth at 500 years, East WSF has the larger figure, i.e. 2.10m and West WSF shows a 1.18m depth.
- Regarding mean erosion depth, the results are similar for both facilities, ranging from 0.01 to 0.04 m. Contrary to the Stage 1 results, the most eroded areas are localized and not representative for the whole WSF, only around 2% of erosion depths are larger than 1m, this is especially seen in the colour maps. This is discussed further below.

Table 6 Stage 2 SIBERIA Results for East WSF and West WSF.

Variable	East WSF				West WSF			
	5 yr.	50 yr.	200 yr.	500 yr.	5 yr.	50 yr.	200 yr.	500 yr.
Initial Average elev. (m)	87.67				82.53			
Average elevation (m)	87.67	87.67	87.66	87.66	82.53	82.53	82.52	82.51
Accum. Erosion rate (m3/ha/yr.)	-0.56	-0.24	-0.24	-0.25	-0.79	-0.35	-0.36	-0.37
Max. Erosion depth (m)	-0.29	-0.58	-0.92	-1.18	-0.45	-0.91	-1.42	-2.10
Mean Erosion depth (m)	-0.00	-0.01	-0.02	-0.04	-0.00	-0.01	-0.02	-0.04
Max. Deposition height (m)*	0.18	0.32	0.57	0.79	0.26	0.51	0.86	1.32
Mean Deposition height (m)*	0.01	0.01	0.03	0.07	0.01	0.02	0.03	0.06

*Note that erosion is expressed as negative to differentiate from deposition at East WSF and West WSF toe.

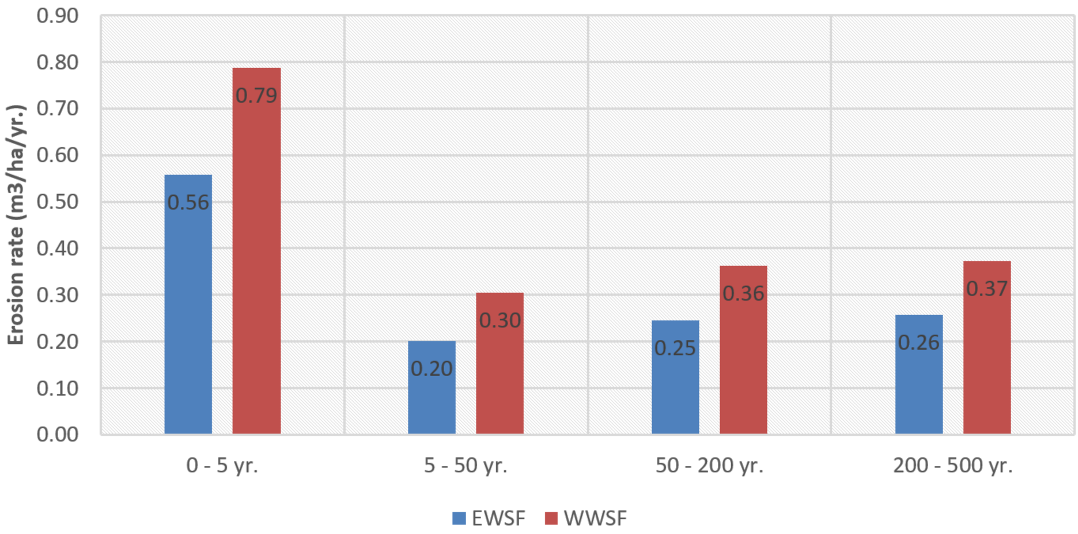


Figure 9 Stage 2, EWSF and WWSF Erosion Rates Comparison in the First 500 Years

- **Figure 9** shows the variability of erosion rates along the 500-year analysis, noting that the highest erosion rates are seen in the first 5 years, where the vegetation establishment takes place, especially in the first 2/3 of year where the total cover is expected to be around 40 to 75%.
- The erosion rates in the 550-year time period is reduced by almost 3-folds to the first 5 years. At least 95% cover is expected in the wet seasons and more than 80% in the dry seasons.
- West WSF erosion rates are in average 1.4 times larger than the ones obtained in the East WSF. This is likely due to:
    - Around 40% of the East WSF perimeter near the small plateau contains a lower portion of the higher slope, i.e. 14°, because of it is truncated by the lower plateau; and
    - East WSF is about 60% of West WSF footprint area, therefore the latter exposes more sloped area to erosion.
- Most of the soil loss is produced by sheet erosion.
- The vegetation inclusion has a direct impact on the reduction of soil loss. This is shown by comparing results from Stage 1 to Stage 2 after 500 years, in particular:
    - In average, the erosion rate is reduced around 4 times, that is 1.4 vs. 0.31 m^3/ha/yr.
    - Maximum erosion depth decreased by 20% and can be reduced further if cross-sectional wrinkles are avoided, i.e. 1.45 vs. 1.18 m.
    - The mean erosion depth is around 3 times smaller, in other words, 0.13 vs. 0.04 m.
    - Even though maximum erosion depths are still large in stage 2, the colour maps show that their significance is vastly reduced from 10 to 1%. This clearly indicates that after 500 years this is a negligible value.
- **Figure 10** shows a comparison of soil loss after 500 years for the East WSF compared to the natural surroundings. Although the model assumed one material for the whole site, the slopes for the natural landform present generally different values for slope as input parameter to the model. The erosional behaviour of both the capping and natural slopes are similar in terms of soil loss which lends to the overarching concept of the WSF slopes matching the natural surroundings. This is mainly driven by the fact that the chosen dual-slope of 9° to 14° which is similar to the surrounding natural slopes ranging between 5° and 10°.
- **Figure 11** illustrates a portion of the WWSF. It can be seen that at the change in concave slope interface there will be some deposition (shown in green). To mitigate this, an abrupt change in angle should be avoided, and a continuous and soft concave interface constructed.
- **Figure 12** shows the maximum deposition depth of 0.25m which needs to be taken into account in designing surface water management.
- Comparing Stage 1 and 2 cross sections, it is evident that the vegetation reduces the impact of erosion on the surfaces. The rill and gully behaviour persist; however, the scale of incisions is reduced.
- Under vegetated conditions both WSF's are unlikely to experience incision depths of more than 2.5m.

Presented in Appendix E are the hillshades for Stage 2 after 500 years for all both East WSF and West WDF.

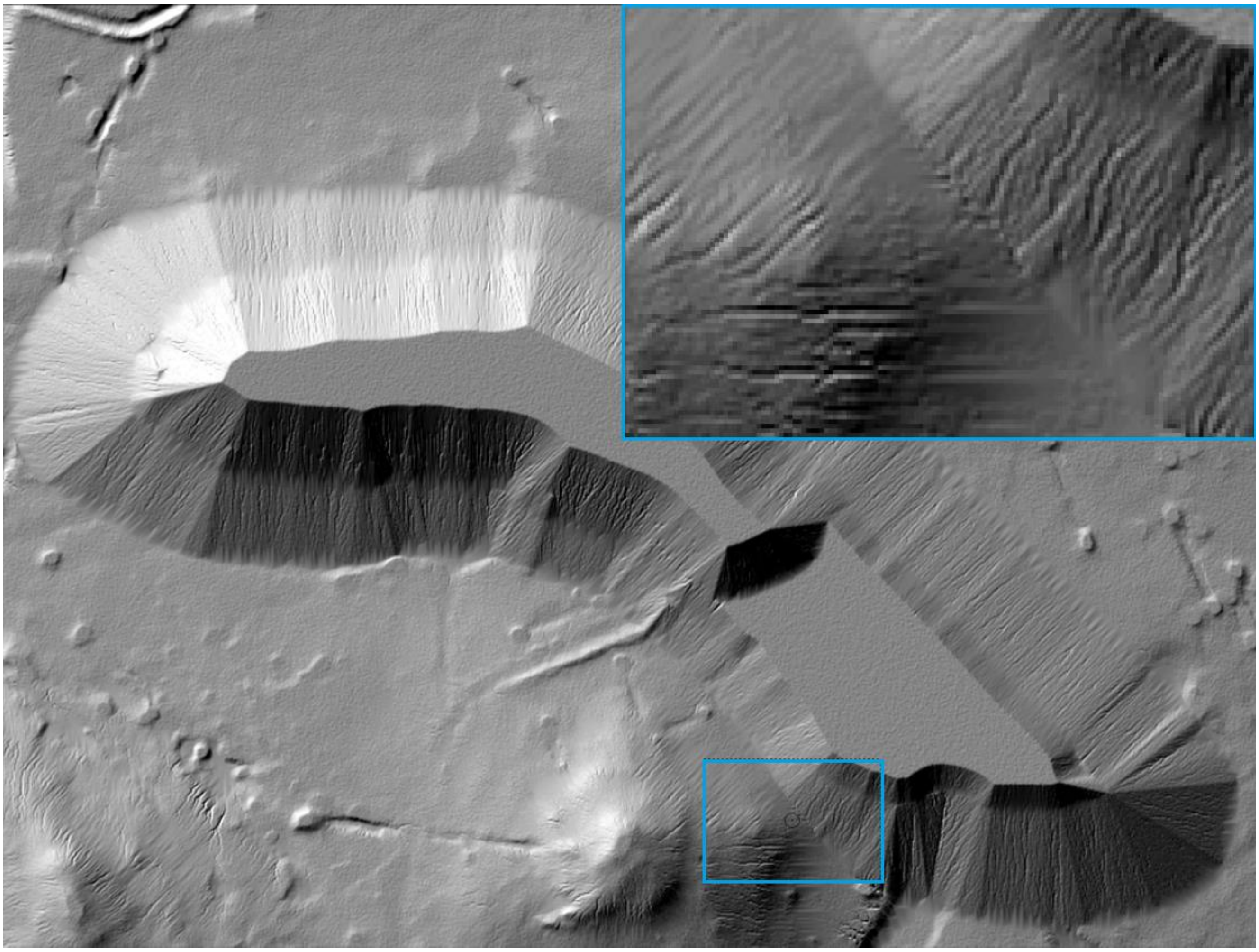


Figure 10 Soil Loss Comparison of Adjacent Natural and Manmade Volumes After 500 Years.

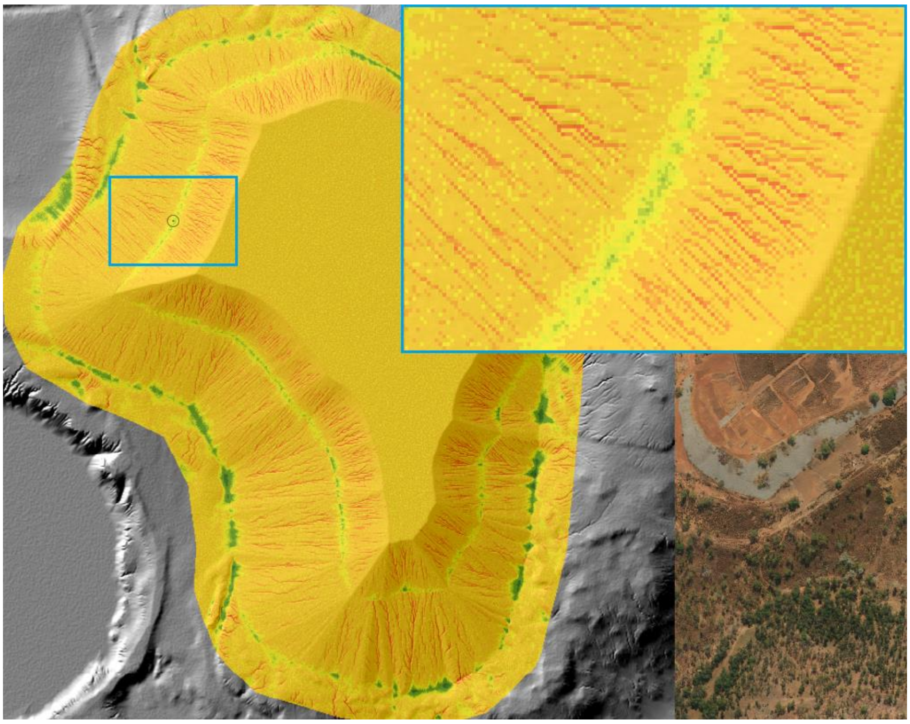


Figure 11 WWSF Zoom-in 1

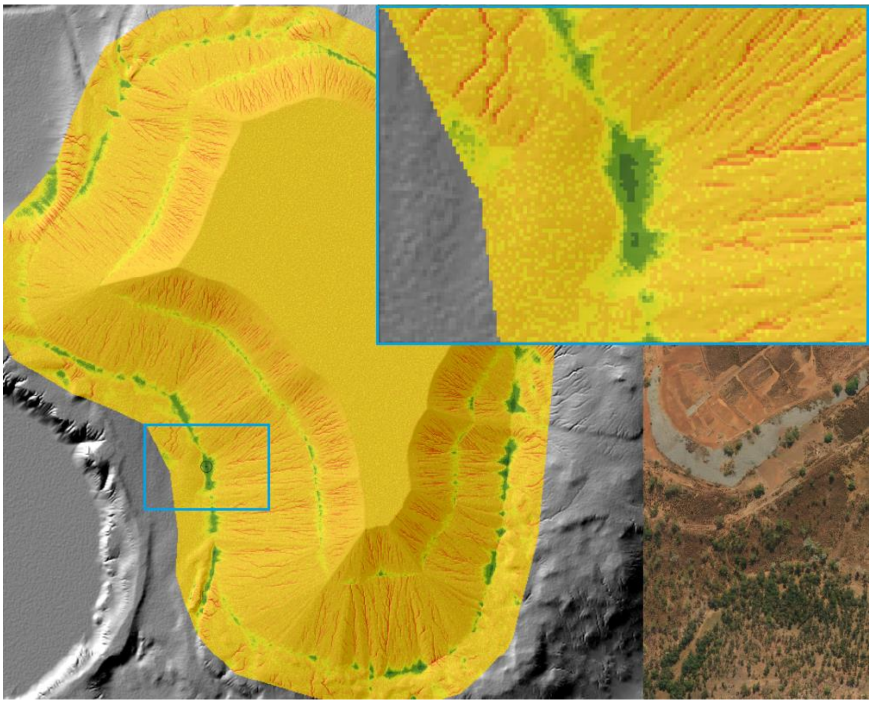
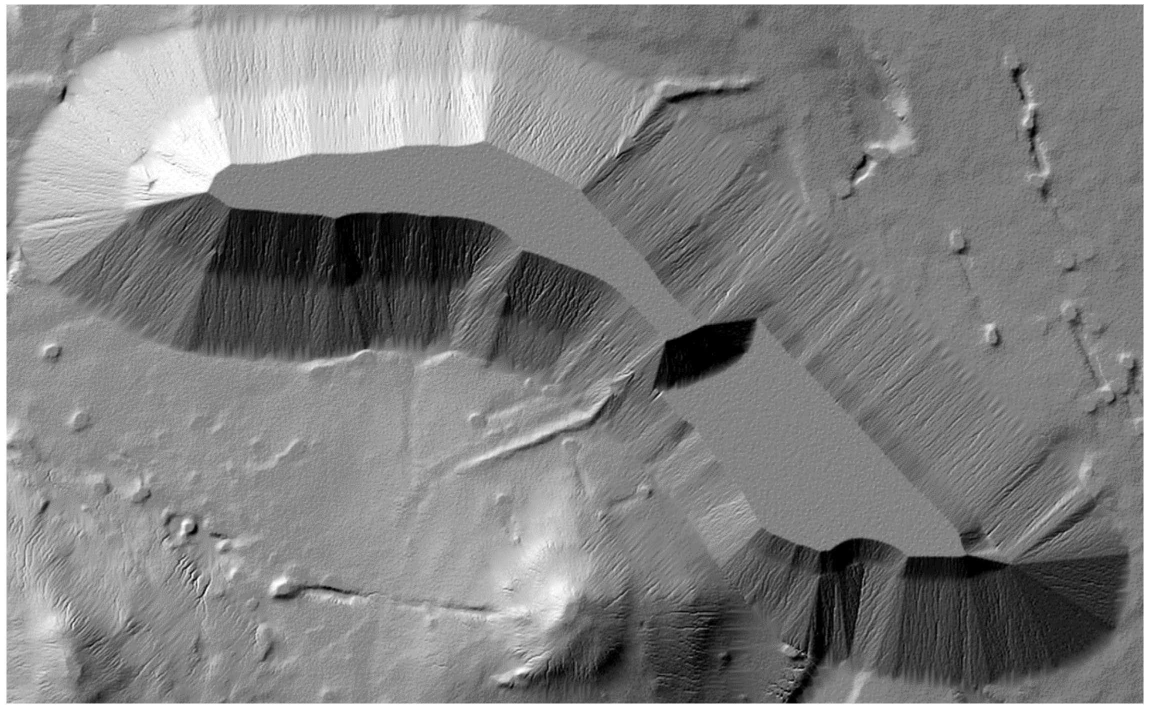
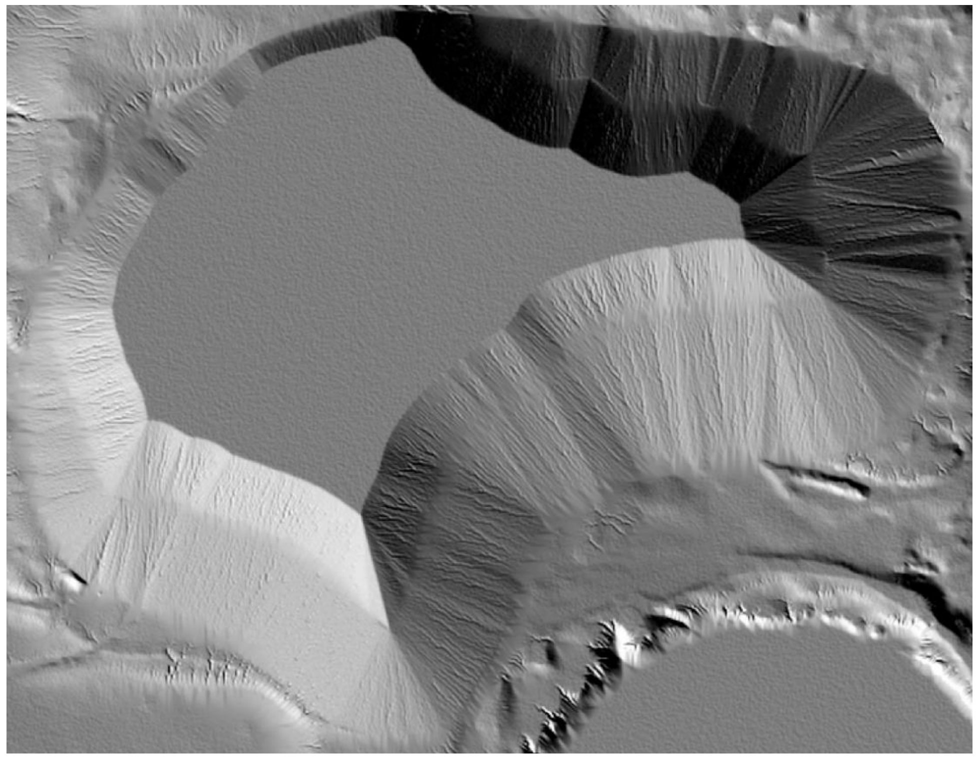


Figure 12 WWSF Zoom-in 2

Table 7 Stage 2 Hillshades and their respective Soil Loss Maps for EWSF and WWSF After 500 Years.

<table>
<tr><th>Eroded Hillshades</th><th>Soil Loss Maps</th><th>Description</th></tr>
<tr><td></td><td>
</td><td>East Waste Storage Facility

9° to 14° Dual Slope
(1:6.25 to 1:4 (V:H))</td></tr>
<tr><td></td><td>
</td><td>West Waste Storage Facility

9° to 14° Dual Slope
(1:6.25 to 1:4 (V:H))</td></tr>
</table>

5 Conclusions

Based on the results presented in this report it is conclude that:

- The recommended batter slope to prevent excessive erosion/gully incision into the capping materials is 9°to 14° dual-slope.
- Vegetated cover models predict that the proposed cover depth of 2.50 m is not likely to be reached after 500 years.
- The maximum gully depths are localised and represent a minor percentage in terms of area.
- Although the models show a good performance in terms of erosion, it is recommended that:
    - The portion of the dual slope whose slope is 14° and localised near the top of the batter is the most vulnerable part of the East WSF, so a different vegetation configuration should be prescribed, using species able to withstand larger runoff speed compared to the plateau;
    - The change in slope needs to be smoothed in the construction phase (refer Section 6), so the abrupt change does not become an erosion seeding feature;
    - A rapid and consistent vegetation cover should be chosen to minimise the chance to cause early deterioration of the bare soil; and
    - Rock armouring is a good option to prevent erosion, however, direct sun exposition can lead to hot temperatures that may 'cook' the vegetation in contact. Therefore, this solution should only be adopted under specific circumstances where the associated risk can be overcome.
- There is currently no wide agreement on what can be considered as 'acceptable' rate of erosion on a mine site. However, the Queensland Department of Minerals and Energy (QDME) 'target erosion rate' for rehabilitated spoil is 12 to 40 t/ha/yr (Society for Mining, Metallurgy, and Exploration, Inc., 2000). The proposed vegetation establishment shows that after 500 years the erosion rate is around 0.4 m^3/ha/yr. Considering a material bulk density of 1.25 t/m^3 the erosion rate can be expressed as 0.5 t/ha/yr. This value is significantly lower than the specified by QDME.
- The selected slope provides a landform able to accommodate the volume within the desired footprint. In addition, it offers a similar visual scenario compared to the existing surrounding natural features.

6 Recommendations for Construction Stage

As outlined in Section 1.2.3, it is important to note that the WSF landforms that have been used were in draft at the time of initial modelling. Although the results indicate that the erosional performance is acceptable, it is important to understand that modelling relies on assumptions and/or simplification in order to obtain results. These assumptions relate to shape (plan and elevation geometry) and material (soil and vegetation) and it is recommended that these be assessed or refined further before the design is ready for construction.

Recommendations for finalising the design relate to activities that can be undertaken during the construction phase, include:

- All borrow materials tested and modelled are assumed to be representative of all borrow materials. Geotechnical parameters should be reassessed via flume testing and/or field tests prior to construction to ensure that the they comply with specification envelopes; alternatively, materials can be conditioned to meet the values required here and/or modelling could be updated.
- The type and rate of revegetation is critical to controlling erosion. The Project revegetation plan (which is to be developed by DPIR prior to construction) should be representative of the data provided within this report; alternatively modelling to estimate likely erosion under the proposed revegetation plan should be undertaken.
- Sharp edges at crests, change of batter slope and the toe should be avoided as these act as seeds for localised gully erosion. A continuous and soft concave interface should be developed as shown in **Figure 13**.

  Smoothing the WSF's in these three aspects will result in a more natural, visually pleasant geometry which combined with the 9° to 14° dual-slope will blend with the natural surroundings.

Figure 13 Final expected concave shape including vegetation

- The final landform should be based on the DTMs that have been provided by SLR as part of the final design package (SLR, 2020a). However, it is acknowledged that the WSFs landform may change from the final design due to changes in material assumptions during construction (i.e. bulking factors, compaction factors etc.) or unexpected finds on site. Therefore, ongoing updates to the WSF design, including consideration of erosion requirements, will be required during design.
- Quality control is crucial in terms of material placement such as foundation preparation, density and compaction, layer thickness, organic material content or any other specification need to be among the desirable limits to assure integrity and stability. Failure to provide this will translate in failure of the designed facilities even at a small scale, where a simple settlement will act as an initial state to deteriorate a whole capping system.

7 Erosion monitoring

The *Australian Soil and Land Survey Field Handbook* (National Committee on Soil and Terrain, 2009) is the accepted soil science standard guide for soil and land assessment, including surveying accelerated erosion (this is separate from detailed scientific research of erosion). Reference should be made to pp 133-138 of the handbook. Erosion monitoring is conducted by recording field data onto the recognised Australian soil science standard log sheet, referred to as the "green sheet", as developed and updated by the Queensland DPI/DNRM, or some similar customised log sheet that provides for recording all criteria associated with each erosion mode. Photographs should also be taken of each erosion area with examples of the different modes associated with it.

Where the handbook does not provide for rating measurements, such as scale of tunnel erosion, a standardised approach should be developed, reviewed, and adopted, and remain consistent throughout the monitoring program, once agreed by all parties. For example, assessment of tunnel erosion, inclusive of a rating scale that is not currently present in the handbook, could include the scale parameters nominated in **Table 8**. Similarly, a scale rating system could be developed for any of the other erosion types where one does not currently exist in the handbook, e.g. mass movement, otherwise other published standards could be adopted to support the monitoring. **Appendix F** provides an example form containing the recommended information to be consistently collected on site at the time of each field visit.

Additional data/methods to support monitoring for erosion and quantifying its extent and severity are highly recommended. This includes detailed terrain LiDAR to assess changes in terrain/problem areas (e.g. erosion, ponding, etc), multi-spectral, high-resolution aerial imagery by drone/light aircraft or from Landsat 8 to derive a normalized difference vegetation index (NDVI) output, differential GPS coordinates of the boundaries of the dominant erosion type in a given area (there could be multiple definable sub-areas within a single eroded area), permanent transect survey markers (e.g. star pickets with final surface level and depth marks from final surface level to measure soil loss or deposit), pit traps, etc. It will be critical to establish background sites to compare against as well as comparing with previous years' data for each site.

Table 8 Example of Rating Scale for Assessment of Tunnel Erosion

Type	State	Degree	Location	Scale
T (for tunnel erosion)	A – Active S – Stabilised P – Partly stabilised	X – Not apparent 0 – No tunnel erosion 1 – Present	I – Inlet O – Outlet M – Middle J – Junction	For each tunnel, record for each inlet and outlet their actual diameter but also rate them as follows: 1 – <0.1 m 2 – ≥0.1 - <0.5 m 3 – ≥0.5 m And record their actual length from inlet to outlet but also rate them as follows: 1 – <5 m 2 – ≥5 - <15 m 3 – ≥15 m Where there is potential branching, e.g. multiple inlets to a single outlet, use professional judgement to determine where the confluence between the tunnels occurs and record the GPS location of this and measure the lengths to and from the junction. From this data, an estimate of soil volume eroded can be calculated.

The first 20 years after construction of the WSF's are vital to ensure that erosion performs according to the modelled predictions. Thus, it is recommended to develop a monitoring program for the first 7 years until vegetation establishment has achieved a minimum of 90% soil cover, with field checks every 6 month and/or after any storm event that produces runoff. In parallel, two DEM (LiDAR) checks are also required to assess whether there are any signs of deviation from the modelled predictions/normality developing that may not be readily visible in the field. These are required at the following frequency: one at 3.5 years and the second at 7 years.

From 7 to 20 years, provided vegetation has established to provide a soil cover greater than 90%, the majority of monitoring will be performed by DEM (LiDAR) monitoring in parallel with ground-truthing in the field. One DEM (LiDAR) check every 4 years and field checks every 12 months.

Should the aforementioned monitoring activities indicate the WSF's are presenting dissimilar behaviour compared to the modelled predictions, it is critical that immediate investigations are undertaken to identify the root causes of failure to design and implement appropriate maintenance works as early as possible.

The procedure to follow in order to determine possible issues, their causes and the corrective actions, if required, are shown in **Table 9**. The table is a categorisation of typical changes in the WSF's surface and the actions needed to return stability and integrity to the cover system as early and efficiently possible.

Table 9 Actions Required to Determine the Cause of Possible Issues After Monitoring Activities

Issue	Activities to Determine the Cause	Action Required
Lack of soil cover from poor/impeded vegetative growth to provide adequate foliage projective cover and/or lack/loss of mulch cover	Undertake soil analyses in accordance with the soil monitoring specifications for the growth medium and compare to the design specifications	Ameliorate as required to bring soil chemical and physical conditions into line with design specification and monitor for response demonstrating improved vegetative growth and mulch generation to provide for greater soil cover.
Sheet flow down slope has changed to concentrated flow via rills/gullies (minor mass movement events)	Undertake site assessment to understand reason for change from sheet flow to concentrated flow. This may include measuring/looking for areas that are depressed below or raised above the surrounding areas through settlement, animal diggings, fallen timber, monitoring stations, etc that are causing concentration of surface waters	Re-shape landform to remove depressions/mounds/obstructions causing concentrated flow to reinstate sheet flow. This could include filling with additional soil, moving soil from mounds to depressions, re-positioning fallen timber or cutting up fallen timber
Sheet flow down slope has changed to concentrated flow via land slips, slumps, etc (major mass movement events)	Undertake site assessment to understand reason for change from sheet flow to concentrated flow. This may include trench excavation to inspect subsurface conditions and sample for laboratory analysis to understand reason for change in conditions	Soil replacement according to desired physical and chemical composition (e.g. degree of compaction, moisture content, pH, dispersion, etc) as per design specification
Other land management practices, such as maintenance of designated access tracks, burning practices, etc	Undertake desktop and site assessment to understand reason.	Design and implement appropriate solution

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APPENDIX A

Flume Erosion Report

Material characteristics and erosion parameter determination for Rum Jungle materials

Cover image. Flow over the NPT01 material.

1 Introduction

SLR plan to employ the SIBERIA landscape evolution model (LEM) to assess rehabilitation designs for the Rum Jungle site. Before use, the SIBERIA LEM requires calibration for the surface materials.

Aquaterra International has been engaged by SLR to determine parameters for two materials that may be used at the site.

This report presents results for a flume assessment on erodibility and parameter derivation for two different potential surface materials. A basic characterisation and assessment was also conducted to assist in this.

The information here was used to determine input parameters for the SIBERIA landscape evolution model.

2 Methods

2.1 Basic material analysis

Basic material analysis was conducted – Electrical Conductivity, pH, % sand, silt and clay by hydrometer, sieve analysis (<2mm and >2mm size fraction) and bulk density.

Infiltration rate here was calculated from quantifying the groundwater leaving the flume (see below).

2.2 The use of laboratory scale flumes for the testing of soil and the calculation of erosion rates

The flume was constructed of a box 2.4m long, 0.2m wide and 0.3m deep. In the base a galvanised mesh frame was placed 0.05m above the base which was covered in geotextile material. 50mm of river sand was placed on top of this base which was then covered in geotextile material. This provided a free-flowing porous base which did not impede the infiltration of soil water and through which any groundwater could exit. At the base of the box at the lower end a 20mm diameter pipe allowed any groundwater to exit.

A header tank at the top of the box supplied runoff across the width of the flume (0.2m) at a constant rate.

The design of the flume was such that a specified discharge could be applied at the top of the slope and all water and sediment can be measured including groundwater (collected) at the outlet. As discussed above, water was also free to infiltrate through the material and be collected and quantified. A water balance is therefore able to be calculated.

The flume was mounted in a steel frame. Slope of the flume was able to be adjusted to any angle between 0 and 30%.

Water to the flume was provided by a header tank which provided an even distribution of water across the full width. Flow was adjusted by a valve which allowed discharge to be regulated from 0 to 20 l/min. Flow was quantified (checked) twice. Once by checking the flow entering the header tank (pre-test) and also by measuring what exited the flume both by surface water and groundwater flow at the outlet. For all experiments potable water was used.

2.3 Material placement

Depending on the material, this is a multistep process with a layer being placed, it then gently being compacted by a flat plate. Depending on the material and its water content, water may need to be added for each layer.

Once the maximum depth had been reached the surface is smoothed with a straight edge to provide a uniform surface.

Once placed in the flume, the material is packed with a flat plate, with particular emphasis along the edges so that there were no preferential flow paths or unevenness and resmoothed.

For multiple runs (i.e. different slopes), the surface material was removed and a layer of fresh material added (i.e. to a depth of 20-40mm) depending on the type of erosion and how deep (i.e. rilling) it was.

No attempt here has been made to simulate compaction generated by a bulldozer or other earth moving equipment. This can be done upon rrequest. Here it has been assumed that the surface would be ripped and any compaction would be minimal.

2.4 Flume operation

Once the material was placed in the flume, the surface was wet until it was saturated but not generating runoff. This was done several times and could take several days before the material was fully packed and was at field capacity.

Once packed and wet, the material was allowed to sit for at least 24 hours. This ensured that the material was wet to field capacity, fully settled as well as providing a consistent soil moisture and starting conditions for all experiments.

Each run was commenced with a low flow so to allow the material to slowly wet up and runoff commence. This was continued until a constant runoff and groundwater discharge occurred. Flows were increased to represent different rainfall/runoff rates. An adjustment period of at least 5 minutes for each new flow allowed runoff and groundwater to equilibrate for the new input flow.

For each flow rate between one and three water samples were collected with both time of sample collected the number of seconds to fill the container recorded. Surface flow and groundwater exiting the flume was therefore independently measured for each flow rate.

Each water/sediment sample was collected in pre-weighed containers which were then weighed when full (~2000ml in volume). These samples were then placed in an oven at 70 Celsius to drive off all water (for approximately 7 days) with the bottles containing the dried sediment then reweighed. Using the gravimetric method allowed both volume of runoff and mass of sediment to be calculated. This data was then used to determine SIBERIA model parameters.

3 Supplied samples

Samples were supplied from the positions displayed in Figure 1.

Test pit data supplied by SLR is displayed in Figures 2 and 3.

3.1 Materials for testing

Materials for testing were supplied in 20 litre containers (Figure 4).

These were labelled:

1. NPT01 0.5m-1.1m (3 x 20 litre)
2. NPT01 4.9m-5.3m (3 x 20 litre)

3.2 Material preparation

All material was removed from their containers and mixed before use (Figure 5). A sample was randomly selected for basic material analysis. Results area displayed in Table 1.

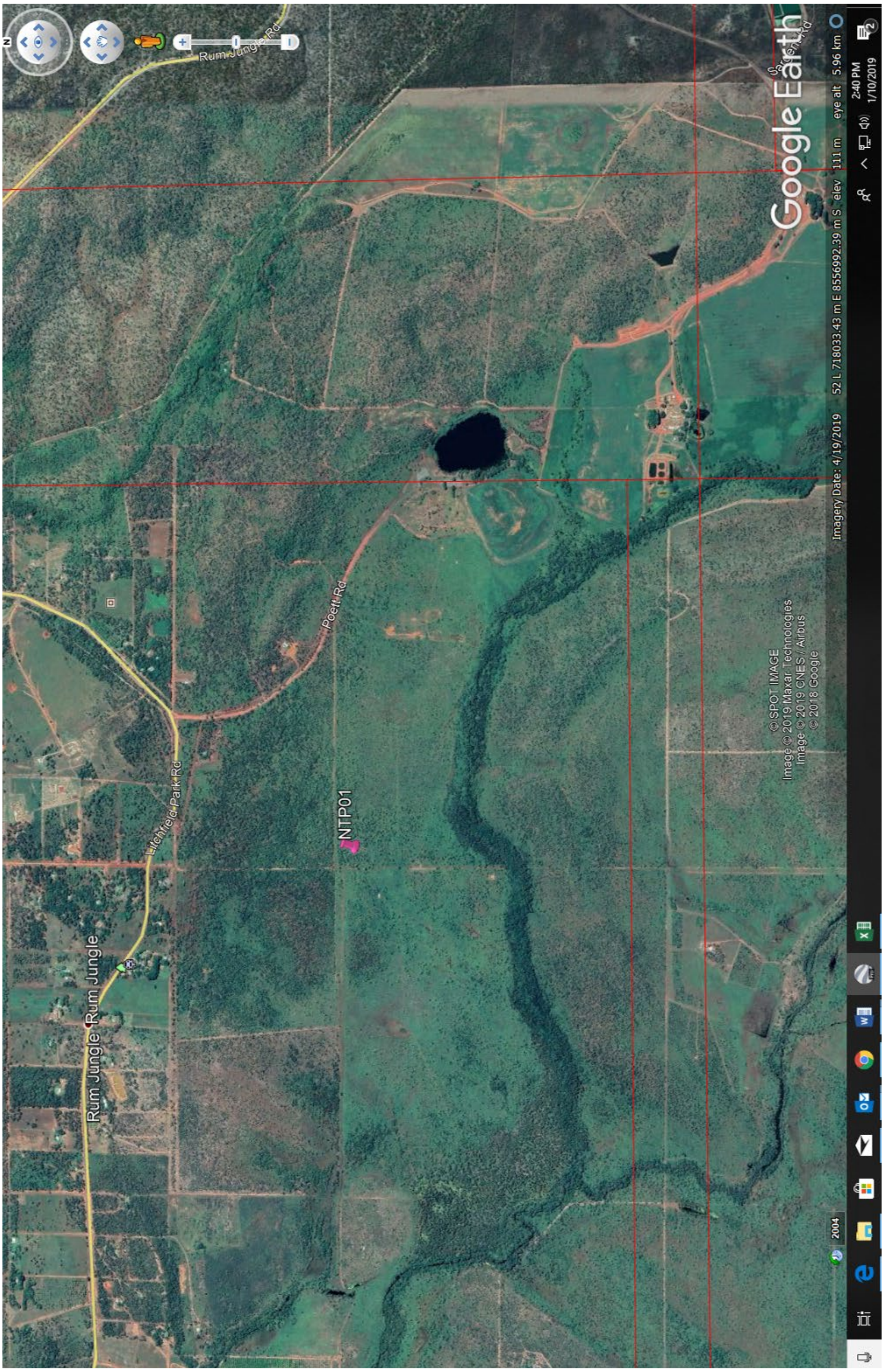
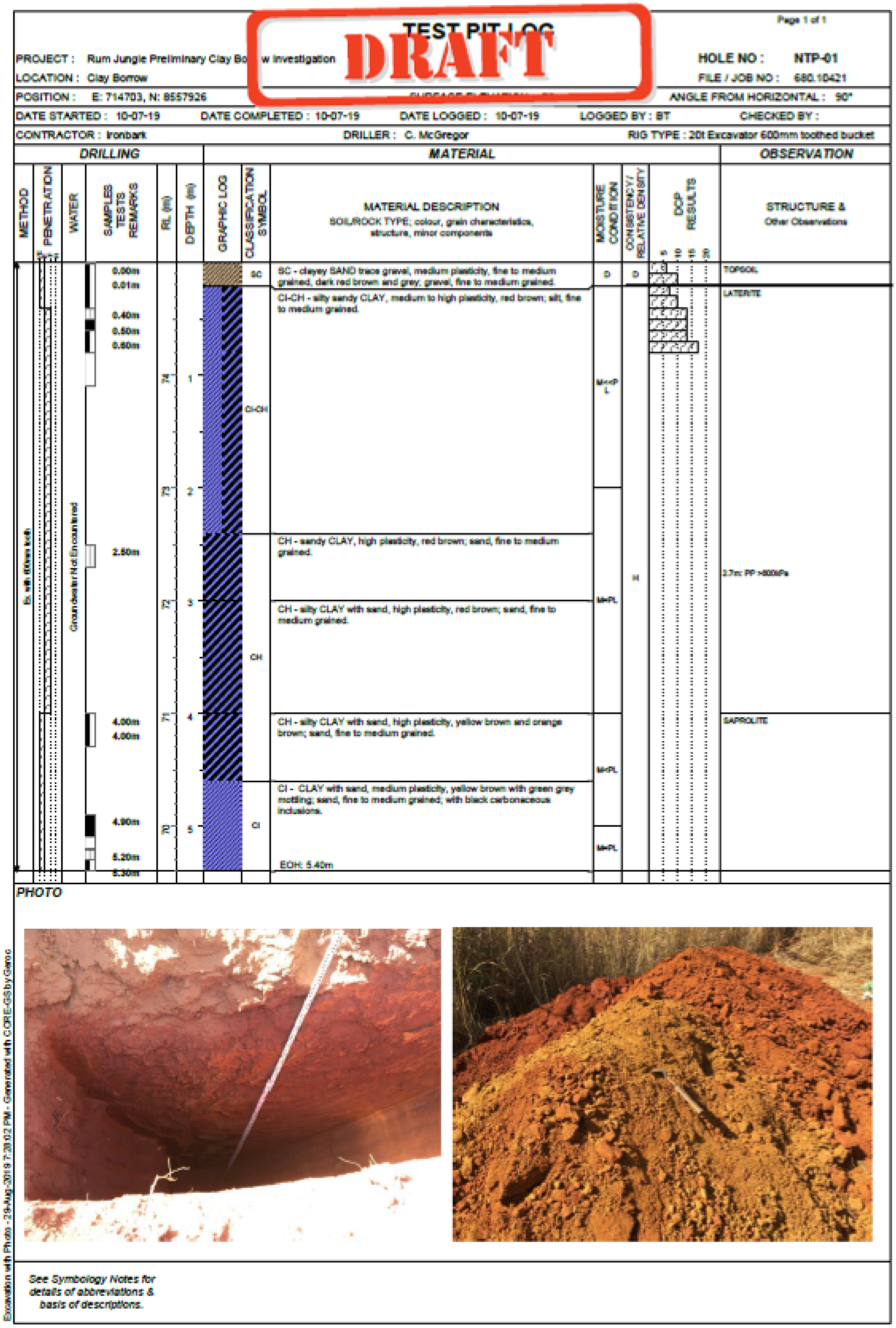


Figure 1. Location of material sampled (google earth). Coordinates supplied by SLR.

Figure 2. NPTO1 soil pit photo log (supplied by SLR).



TEST PIT LOG — DRAFT

Page 1 of 1

PROJECT : Rum Jungle Preliminary Clay Bo[...]w Investigation — HOLE NO : NTP-01
LOCATION : Clay Borrow — FILE / JOB NO : 680.10421
POSITION : E: 714703, N: 8557926 — ANGLE FROM HORIZONTAL : 90°
DATE STARTED : 10-07-19 — DATE COMPLETED : 10-07-19 — DATE LOGGED : 10-07-19 — LOGGED BY : BT — CHECKED BY :
CONTRACTOR : Ironbark — DRILLER : C. McGregor — RIG TYPE : 20t Excavator 600mm toothed bucket

Method: Ex. with 600mm tooth; Water: Groundwater Not Encountered

Samples / tests / remarks: 0.00m, 0.01m, 0.40m, 0.50m, 0.60m, 2.50m, 4.00m, 4.00m, 4.90m, 5.20m, 5.30m

Classification symbol	Material description	Moisture condition	Consistency / relative density	Structure & other observations
SC	SC - clayey SAND trace gravel, medium plasticity, fine to medium grained, dark red brown and grey; gravel, fine to medium grained.	D	D	TOPSOIL
CI-CH	CI-CH - silty sandy CLAY, medium to high plasticity, red brown; silt, fine to medium grained.	M<<PL	H	LATERITE
CH	CH - sandy CLAY, high plasticity, red brown; sand, fine to medium grained.	M≈PL		2.7m: PP >600kPa
CH	CH - silty CLAY with sand, high plasticity, red brown; sand, fine to medium grained.			
CH	CH - silty CLAY with sand, high plasticity, yellow brown and orange brown; sand, fine to medium grained.	M≈PL		SAPROLITE
CI	CI - CLAY with sand, medium plasticity, yellow brown with green grey mottling; sand, fine to medium grained; with black carbonaceous inclusions.	M≈PL		
	EOH: 5.40m			

PHOTO

See Symbology Notes for details of abbreviations & basis of descriptions.

Excavation with Photo - 29-Aug-2019 7:28:02 PM - Generated with CORE-GS by Geroc

Figure 3. NPTO1 soil pit/drill log (supplied by SLR).

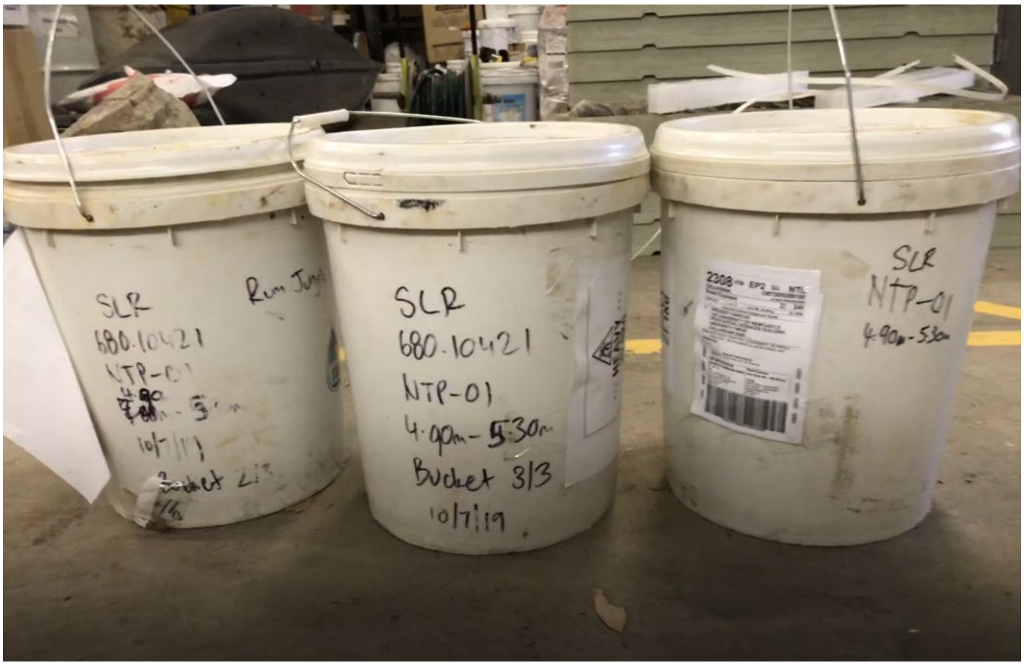


Figure 4. NPT01 0.5m-1.1m (Red) (top) and NPT01 4.9m-5.3m (Tan) (bottom) as received.

Figure 5. NPT01 0.5m-1.1m (Red) (top) and NPT01 4.9m-5.3m (Tan) (bottom) after removal from containers.

3.3 Material general characteristics

Table 1. Rum Jungle material properties

	NPT01 0.5m-1.1m (Red)	**NPT01 4.9m-5.3m (Tan)**
EC Soln (µS)	18.4	23.4
pH Soln	6.1	6.2
Moisture (%)	13.1	22.5
<2mm (%)	90	88
>2mm (%)	10	12
%Sand	29	16
%Silt	18	70
%Clay	53	13
Bulk density (<2mm)	1.25t/m^3	1.27t/m^3
Infiltration*	<5mm/hr	<5mm/hr
Material classification	silty clay	silty loam
K (RUSLE)**	0.025	0.055

*calculated from groundwater flow rates from base of flume
**K values from Hazelton and Murphy (2007)

3.3.1 NPT01 0.5m-1.1m (Red)

Description
Upon removal from the containers material was quite moist (13.1%). Colour was deep red/brown (and was named 'Red' for easy identification). This suggests an oxidised soil with a high iron content (Table 1). The material has a pedal structure with a clay peds present, some of which were quite large (Figure 5). These were broken and included in the mix. Small plant roots were present. Silty clay in texture. Quite sticky to work/mix.

pH (6.1) and EC suggests that there are no major impediments to plant growth (Table 1) however nutrient or elemental analysis was not undertaken. Infiltration was low and the soil texture suggests a high water holding potential.

The contents of the drums were mixed together and used as one material (Figure 5).

3.3.2 NPT01 4.9m-5.3m (Tan)

Description
Upon removal from the containers material was quite moist (23.4%) (Table 1).Colour was a tan with brown mottles (and was named 'Tan' for easy identification) suggestive of anaerobic conditions and having its origins at depth. The soil has a pedal structure with large peds present (Figure 5). These were broken and included in the mix. Silty loam in texture. Quite sticky to work/mix.

pH (6.2) and EC suggests that there are no major impediments to plant growth (Table 1) however nutrient or elemental analysis was not undertaken. Infiltration was low and the soil texture suggests a high water holding potential.

The contents of the drums were mixed together and used as one material (Figure 5).

4 Flume runs

Each material was packed in a series of layers, wet, and compacted and smoothed before the start of each run as described above.

For compaction and to ensure a complete wetting, each material was allowed to sit for at least 24hrs before the start of the run.

A number of flume runs at different slope angle were performed for each material. These were:

NPT01 0.5m-1.1m (Red)	5%, 15%, 25% slope
NPT01 4.9m-5.3m (Tan)	5%, 15%, 25% slope

5 Parameter calculation

The SIBERIA fluvial sediment transport equation is (q_{sf}):

$$q_{sf} = \beta_1 Q^{m_1} S^{n_1} \quad (1)$$

where Q represents the discharge per unit width (m^3/s/m width), S is the slope in the steepest downslope direction (m/m) while n_1, β_1 (soil erodibility) and m_1 are calibrated parameters which in combination will represent sheetwash, rilling or gullying.

The SIBERIA parameter determination was a multiple regression for the β_1, m_1 and n_1 for runoff, sediment load and each slope until the parameter combination was optimised.

The RUSLE K factor was used as the starting point for the determination of β_1 as it is a well-recognised measure of erodibility.

It is well known that the values of m_1 and n_1 (Equation 1) vary widely but for most fluvial systems they both range between 1 and 3 (Kirkby, 1971; Willgoose, 2005). However, n_1 has been measured to be as low as 0.5 in mining applications due to surface armouring (Willgoose and Riley, 1998; Willgoose and Sharmeen, 2006) with, everything else being equal, steeper slopes developing coarser, less erodible, surfaces than flatter slopes (Cohen et al., 2009 and Welivitiya et al., 2016).

SIBERIA operates using the 1:2 year storm as the most geomorphically active rainfall event. This is the storm that on average does the most geomorphic work (Willgoose, 2005). Here we use the Bureau of Meteorology Intensity-Frequency Duration data for Rum Jungle to determine this storm (Figure 6).

Rainfall and resultant runoff for the flume is based on this data and for each slope runoff starts from low intensity longer duration and progresses to higher intensity shorter duration. The higher intensity data also represents concentrated flow over the surface.

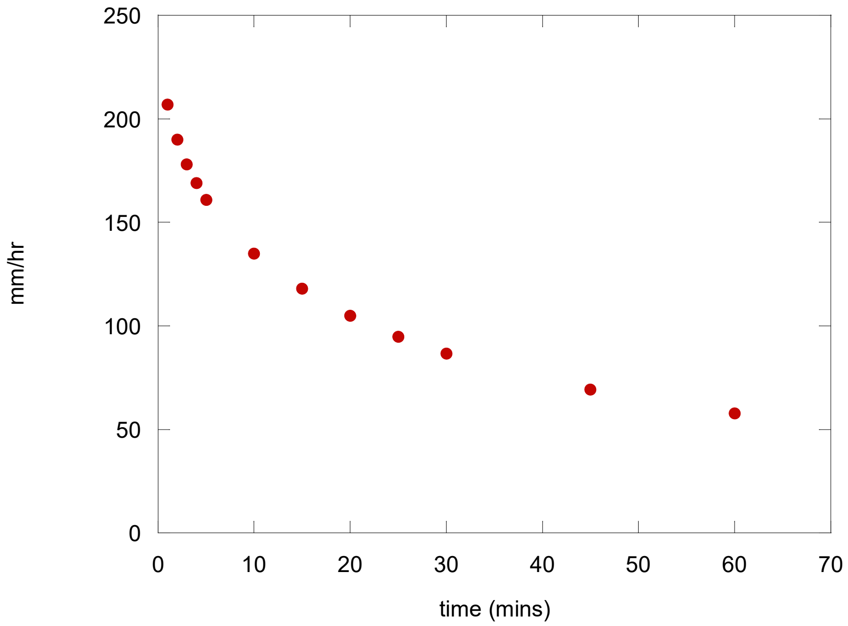


Figure 6. Intensity Frequency Duration curve for a 1:2 year storm for Rum Jungle (www.bom.gov.au).

6 Results

6.1 Erosion results and process – NPT01 0.5m-1.1m (Red)

The material was fully wet upon packing and allowed to settle for 24hours before the commencement of the run. The material had a very smooth texture but was difficult to finish to a smooth surface due to the high clay content. However, upon initial wetting a smooth surface resulted (Figure 7).

It is best to have a material thickness of at least 120mm (150mm optimal) to ensure sufficient depth of material to erode (i.e. severe erosion) and also to ensure a reliable infiltration rate and therefore runoff over the surface. Sufficient material is also needed to produce a good seal along the flume walls. Here, material was placed in the flume to a maximum depth of 80-100mm as this was the maximum depth allowed by the supplied material. This is the bare minimum for analysis.

Upon initiation of runoff the material immediately had a high erosion rate as evidenced by a high sediment discharge (Figure 8). Small rills appeared almost immediately. As runoff increased 'pot holes' developed in conjunction with the sheetwash and rilling (Figures 9-11). The pot holes were up to 40mm deep at the end of the run.

At the higher slopes and flow rates sediment output was erratic as clay peds were removed creating a knickpoint and more erodible material was exposed to be transported. This pulse like delivery of sediment made it difficult to sample as any result depended on when the sample was collected in the cycle of the pulses.

Fines were removed and the surface became armoured with more resistant peds for each flow. However, an increase in flow quickly increased shear stress until the fines again were washed through again leaving a coarse armour which was easily disturbed upon increased flow. Without vegetation or a surface cover this surface will be high erodible.

The material produced no groundwater. Therefore all rainfall will become runoff unless vegetation is present.

Sediment output (Figure 12) and fitted parameters are described below (Table 2)

The model parameters here are representative of a material which has a combination of both sheetwash and gullying due to its clay content. The clay binds the material for low flows but at higher flow the shear creates knickpoints at positions of concentrated flow. The material has thresholds that generate different erosion mechanisms as flow increases.

Revegetation will be key if this material is to be used. Given the chemically benign nature of the material, there is no reason why a rapid and consistent vegetation cover could not be established. Alternatively, a rock armour would reduce erosion.

This is a highly erodible material that will erode at low slopes (Figure 7).

Other material properties: The material was allowed to sit for several days before commencement of the runs. During this time the material was subject to several hot days (>30C) and dried. The material readily cracked. Given the seasonal nature of rainfall at the site, it can be expected that this material will crack with the potential for the cracks to act as points initiation for erosion.

Figure 7. NPT01 0.5m-1.1m (Red) material starting conditions.

Figure 8. NPT01 0.5m-1.1m (Red) material with eroded material deposited at the outlet of the flume at the end of the 5% run.

Figure 9. Eroded surface at the end of the 15% run for NPT01 0.5m-1.1m (Red) material.

Figure 10. Eroded surface at the end of the 15% run for NPT01 0.5m-1.1m (Red) material.

Figure 11. Head of rill 40mm deep after termination of the 25% run.

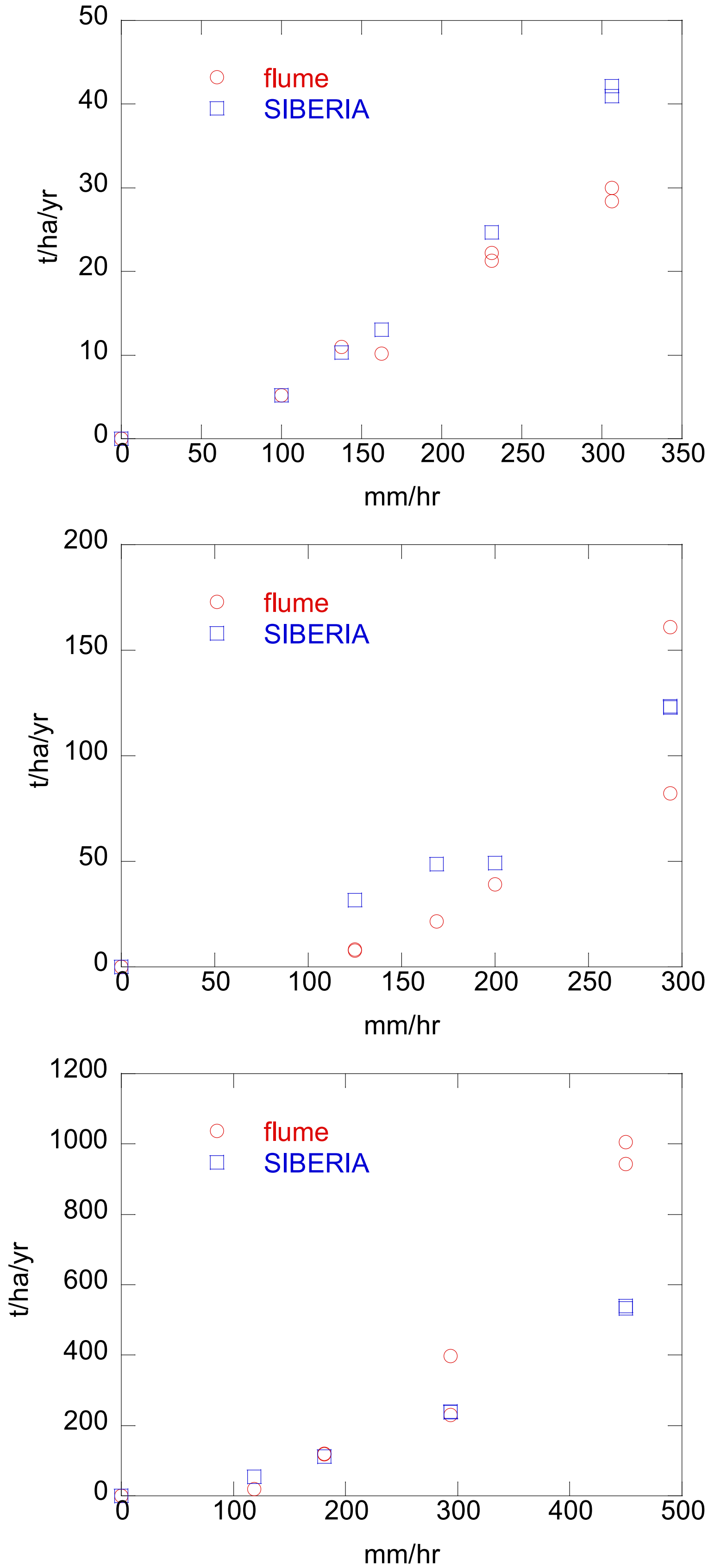


Figure 12. NPT01 0.5m-1.1m (Red) flume sediment output and SIBERIA predicted sediment output from 5%, 15% and 25 % slopes.

Table 2. SIBERIA parameters for the NPT01 0.5m-1.1m (Red) material.

	5%	**15%**	**25%**
β_1	0.015	0.01	0.01
β_3	1	1	1
m_1	1.6	1.6	1.5
m_3	1	1	1
n_1	2	2	2.6

6.2 Erosion results and process – NPT01 4.9m-5.3m (Tan)

The material was fully wet upon packing and allowed to settle for 24hours before the commencement of the run. The material had a very smooth texture and was difficult to finish to a smooth surface. However, upon initial wetting a smooth surface resulted (Figure 13).

It is best to have a material thickness of at least 120mm (150mm optimal) to ensure sufficient depth of material to erode (i.e. severe erosion) and also to ensure a reliable infiltration rate and therefore runoff over the surface. Sufficient material is also needed to produce a good seal along the flume walls. Here, material was placed in the flume to a maximum depth of 80-100mm as this was the maximum depth allowed by the supplied material. This is the bare minimum for analysis.

Upon initiation of runoff the material immediately had a high erosion rate as evidenced by a high sediment discharge. Small rills (~5mm deep) appeared almost immediately (Figure 14).

At the higher slopes and flow rates sediment output was erratic as peds were removed creating a knickpoint and more erodible material was exposed to be transported. This pulse like delivery of sediment made it difficult to sample as any result depended on when the sample was collected in the cycle of the pulses.

Fines were removed and the surface became armoured with more resistant peds for each flow. However an increase in flow quickly increased erosion until the fines again were washed through again leaving a coarse armour which was easily disturbed upon increased flow. Without vegetation this surface will be high erodible (Figure 15).

The material produced no groundwater. Therefore all rainfall will become runoff unless vegetation is present.

At the end of the runs there was both sheetflow erosion and rilling and the potholes suggest the potential for gullies (Figures 16 and 17). Erosionally, this material is very unusual. The parameters at 5% suggest the material will gully, however as slope increases the material erodes more by rilling and sheetwash. A point to note is the order of magnitude difference in β_1 between the 5% and 15% slopes with that of the 25% slope.

These properties are likely a result of the high silt content of this subsoil where a lack of clay results in loss of material cohesiveness at high flows.

Revegetation will be key if this material is to be used. Given the chemically benign nature of the material, there is no reason why a rapid and consistent vegetation cover could not be established. Alternatively, a rock armour would reduce erosion.

This is a highly erodible material that will erode at low slopes (Figure 7).

Sediment output (Figure 18) and fitted parameters are described below (Table 3).

Other material properties: The material was allowed to sit for several days after completion of the runs. During this time the material was subject to several hot days

(>30C) and dried. The material readily cracked (Figure 19). Given the seasonal nature of rainfall at the site, it can be expected that this material will crack with the potential for the cracks to act as points initiation for erosion.

Figure 13. NPT01 4.9m-5.3m (Tan) material starting conditions.

Figure 14. NPT01 4.9m-5.3m (Tan) 5% slope at the end run. Note the rill running the length of the flume.

Figure 15. NPT01 4.9m-5.3m (Tan) 15% slope at the end run. Note the rill running the length of the flume.

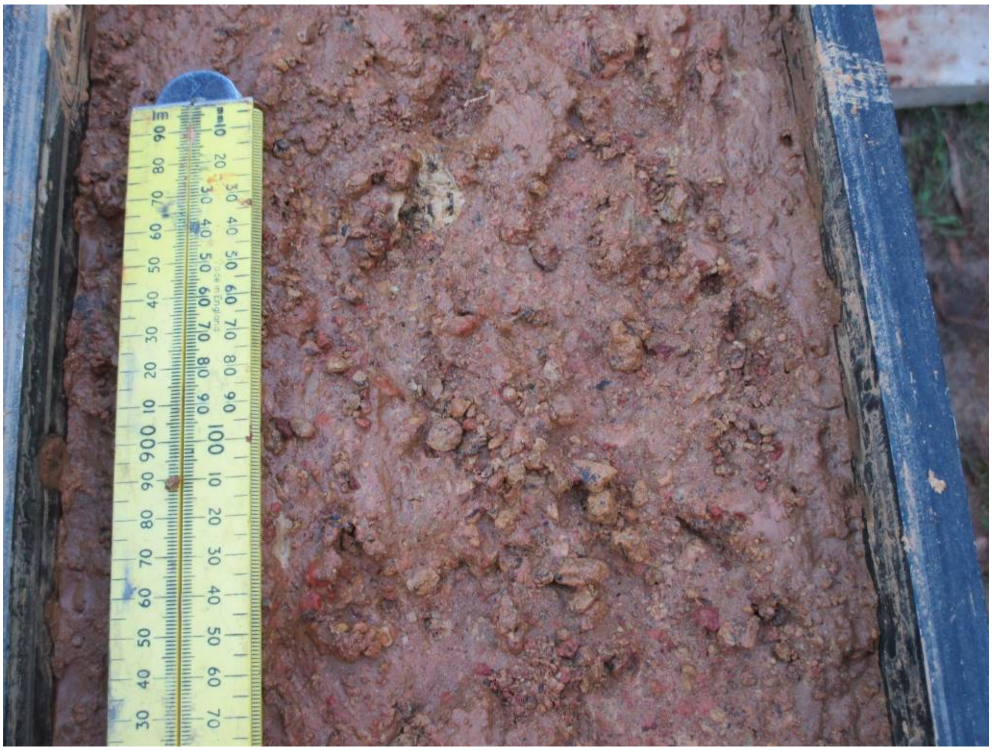


Figure 16. NPT01 4.9m-5.3m (Tan) material at the start (top) and end run (bottom).

Figure 17. NPT01 4.9m-5.3m (Tan) 25% slope at the end run. Note the rill running the length of the flume.

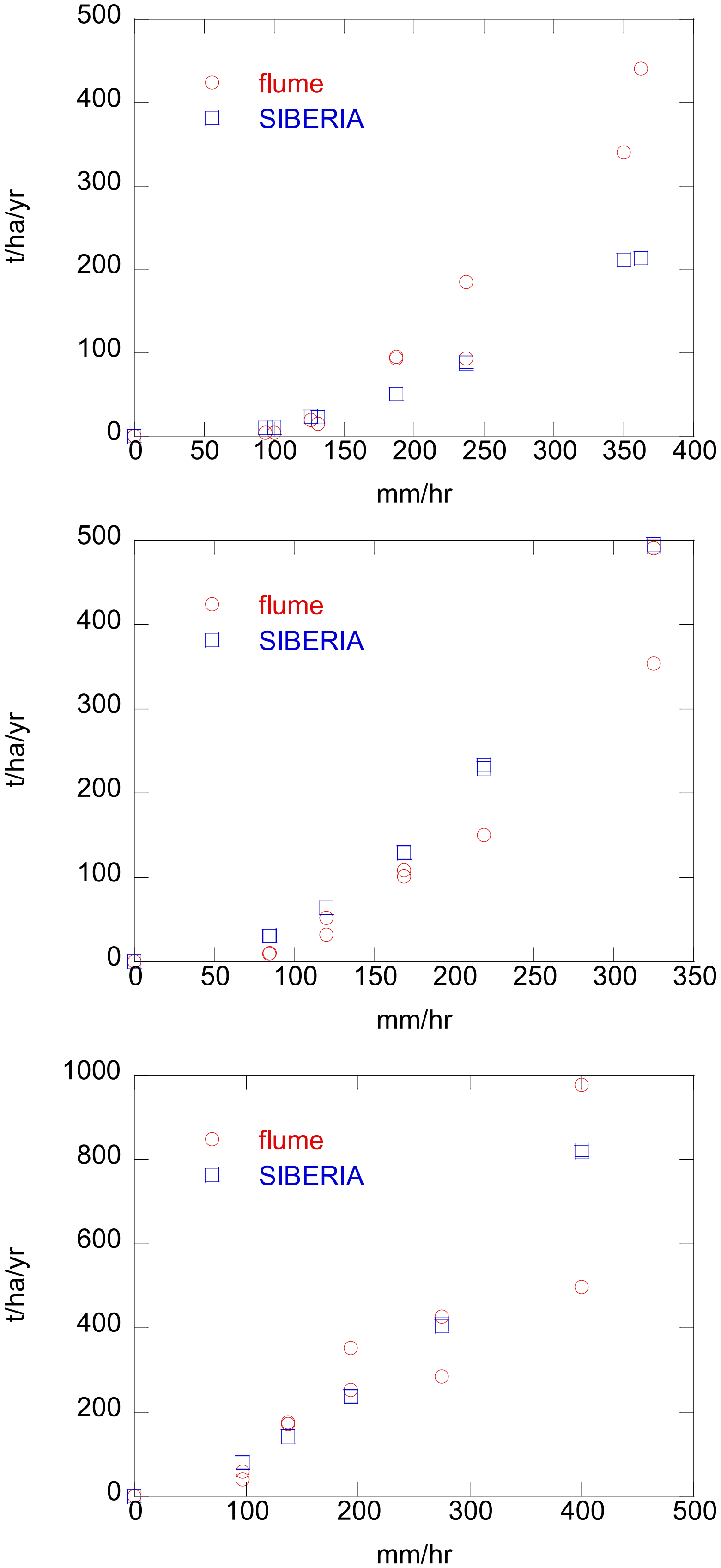


Figure 18. NPT01 4.9m-5.3m (Tan) flume sediment output and SIBERIA predicted sediment output from 5% (top), 15% (middle) and 25 % slope (bottom).

Table 3. SIBERIA parameters for the NPT01 4.9m-5.3m (Tan) material.

	5%	**15%**	**25%**
β_1	0.0015	0.0015	0.015
β_3	1	1	1
m_1	2.2	2.0	1.5
m_3	1	1	1
n_1	2.6	2.8	2

Figure 19. NPT01 4.9m-5.3m (Tan) material one week after the completion of the flume runs. Extensive cracking is evident.

6 Study limitations

1. All materials were supplied by SLR. There can be no guarantee that they are representative of the entire site.
2. The erosion parameters obtained represent bare materials with no vegetation or long-term environmental exposure. There is no way to guarantee that the parameters will or will not change if exposed for longer periods.
3. The compaction and surface roughness of the materials in the flume may be very different to that of the mine site. There is no guarantee that the erosion parameters will be the same or different under mine site conditions.

7 Summary

Here two different surface material were tested for their erosion properties. From this data parameters for the SIBERIA Landscape Evolution Model were developed.

The β_1 values for all materials are high indicating high erodibility. The values of m_1 and n_1 are all within the range expected for similar material at other sites and observed erosion behaviour matches that of the derived parameters (Willgoose and Riley, 1998; Willgoose and Sharmeen, 2006).

The results demonstrate that NPT01 0.5m-1.1m (Red) and NPT01 4.9m-5.3m (Tan) are erodible and revegetation would improve their erosional stability.

Revegetation could be tested by further flume analysis. This requires growing a fast growing cover species such as Jap Millet in the flume and then running the flume for different slopes and flows.

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APPENDIX B

SIBERIA Erosion Modelling Description

Description of SIBERIA

SIBERIA is a long-term erosion model developed by Willgoose et al. in 1989 to model the interaction of the time evolving geomorphic form of natural landscapes with the hydrology and erosion processes taking place, and how these processes, dictate the shape of a natural landform. This piece of software utilises a digital terrain model (DTM) as a starting point, which evolves in time under the imposed runoff and erosion parameters extracted from erosion models.

These models are based on commonly accepted erosion physics, specifically relationships between catchment area and runoff rate such as that typically used in regional flood frequency analysis:

$$Q = \beta_3 A^{m_3} \qquad (1)$$

Where Q is the characteristic discharge out of the catchment, β_3 is the runoff rate, *A* is the catchment area and m_3 is a coefficient. The characteristic discharge is the mean peak discharge.

The erosion model is similar to that used in traditional agricultural sediment transport models where the rate of sediment transport is related to discharge, slope and a transport threshold:

$$Q_s = \beta_1 Q^{m_1} S^{n_1} - \textit{threshold} \qquad (2)$$

Q_s is the mean annual sedimentation rate, β_1 is the erodibility (including the material erodibility, vegetation cover factor and any cropping practice factors (USLE terminology), S the slope, and m_1 and n_1 are parameters to be calibrated for the erosion process. The erosion is relatively insensitive to the exponent n_1 which is commonly taken as 2. The exponent m_1 is modified during calibration to ensure that the concavity of the modelled slope is like the prototype. According to (Kirkby, 1971) (Willgoose, 2005) the values of m1 and n1 (Equation 1) vary widely but for most fluvial systems they both range between 1 and 3.

Equations (1) and (2) may be combined to yield equation 3 below:

$$Q_s = \beta_1 \ \ {\beta_3}^{m_3} \ \ A^{m_1 m_3} S^{n_1} \qquad (3)$$

Solution of the above two equations by finite elements at each grid point is affected by SIBERIA to derive the eroded position of the grid point at the end of each time step. The eroded topography is therefore being continuously updated thus enabling the simulation of gulley formation.

Over an extended period, the parameters β_3 and m_3 remain essentially constant. It is therefore possible to write equation (3) as:

$$Q_s = \beta_1{}' A^{m_1 m_3} S^{n_1} \qquad (4)$$

Where

$$\beta_1{}' = \beta_1 \ \ {\beta_3}^{m_3} \qquad (5)$$

Where calibrations are conducted using surveys of dumps over an extended period, and where the rainfall that occurred over that period can be regarded as representative of the long term average and incorporates unseasonably high as well as low rainfall periods, it is possible to carry out the calibration to determine $\beta_1{}'$ directly without the need to consider and specifically account for the rainfall-related parameters β_3 and m_3.

APPENDIX C

Development of K and C Factors for Stage 2

K Factor

The upper capping layer proposed for the waste rock capping is described in detail in the Waste Storage Facility, Clay and Sand Borrow Areas, Geotechnical Investigation report (SLR, 2019). From this description, the dominant soil profiles within the broader landscape are identified as Kandosols under the Australian Soil Classification (ASC) system. Kandosols are soils that lack strong texture contrast, have massive or only weakly structured B horizons, and are not calcareous throughout. More specifically, these soils have all of the following characteristics:

- B2 horizons in which the major part is massive or has only weak grade of structure;
- A maximum clay content in some part of the B2 horizon which exceeds 15% (i.e. heavy sandy loam, SL+);
- Do not have a tenic B horizon;
- Do not have a clear or abrupt textural B horizon; and
- Are not calcareous throughout the solum, or below the A1 or Ap horizon or a depth of 0.2 m if the A1 horizon is only weakly developed.

These soils have been selected to replicate on the waste rock capping (heavy clay) not only because they are the dominant soils within the broader landscape, but they have the following characteristics that make them ideal for a growth medium on a constructed hill of waste rock and capping:

- Tend to be deeply weathered profiles, which are suitable for a growth medium in the tropics;
- Have a sandier texture and good humus content in the surface horizon that provide for moderately rapid stormwater infiltration due to lack of surface crusting or hard setting properties;
- Have gradually increasing clay contents that provide for good water retention and cation exchange capacity;
- Have deep, less consolidated (massive to weak structure) profiles suitable for deep root penetration by grasses and shrubs (but not so deep as to penetrate a clay capping) and are moderately permeable; and
- Have moderately high humus and organic carbon levels as a result of good vegetation growth that in turn improves surface horizon texture and structure.

Should replication of the Kandosol soil prove problematic, the alternative preference would be to replicate a Dermosol soil, which has a fraction more clay throughout the profile, a structured B2 horizon that is more developed than weak and lacks strong texture contrast between the A and B horizons.

The growth material profile proposed to replicate a Kandosol (or Dermosol) and associated K factors for erosivity are shown in the table contained in the next page. Based on the respective soil textures and as recommended by the soil scientist the potentially worst K factor is 0.04 in the A2 to B21 horizons of the Kandosol, because it represents the material with the highest capacity to erode, so this value has been used for the erosion modelling as a worst scenario.

Growth Material Profile for Kandosol (or Dermosol) and Associated K Factors

Approx. Depth (cm)	Kandosol					Dermosol				
	Horizon	Texture	PSD (%)	Structure	K Factor Range	Horizon	Type of Soil (USDA)	PSD (%)	Structure	K Factor Range
0-20	A1	Sandy Loam to Sandy Clay Loam	Clay: 8-20 Silt: 2-10 Sand: 71-91 Clay: 18-33 Silt: 2-8 Sand: 65-82	Massive	0.030 to 0.025	A1	Sandy Clay Loam to Clay Loam, Sandy	Clay: 18-33 Silt: 2-8 Sand: 65-82 Clay: 21-35 Silt: 6-15 Sand: 50-70	Massive	0.02 to 0.03
20-60	A2	Sandy Clay Loam to Clay Loam, Sandy	Clay: 18-33 Silt: 2-8 Sand: 65-82 Clay: 21-35 Silt: 6-15 Sand: 50-70	Massive	0.025 to 0.04	A2 to B21	Clay Loam, Sandy, to Sandy Light Clay	Clay: 21-35 Silt: 6-15 Sand: 50-70 Clay: 27-40 Silt: 2-20 Sand: 40-71	Massive to Weak	0.0 to 0.025
60-120	B21	Clay Loam, Sandy, to Sandy Light Clay	Clay: 21-35 Silt: 6-15 Sand: 50-70 Clay: 27-40 Silt: 2-20 Sand: 40-71	Massive to Weak	0.04 to 0.025	B21 to B22	Sandy Light Clay to Sandy Light Medium Clay	Clay: 27-40 Silt: 2-20 Sand: 40-71 Clay: 40-45 Silt: 2-20 Sand: 35-58	Weak to Moderate	0.025- 0.018
120-200	B22	Sandy Light Clay to Sandy Light Medium Clay	Clay: 27-40 Silt: 2-20 Sand: 40-71 Clay: 40-45 Silt: 2-20 Sand: 35-58	Weak to Moderate	0.025 to 0.018	B22 to B23	Sandy Light Medium Clay to Sandy Medium Clay	Clay: 40-45 Silt: 2-20 Sand: 35-58 Clay: 45-55 Silt: 2-20 Sand: 25-53	Moderate	0.018- 0.015

C Factor

The upper capping layer proposed for the WSFs is described in detail in the Waste Storage Facility, Clay and Sand Borrow Areas, Geotechnical Investigation report (SLR, 2019). From the detailed description, the dominant vegetation communities within the broader landscape are identified as *Eucalyptus tetrodonta, E. miniata, Erythrophleum chlorostachys* woodland to open forest and *E. tetrodonta, E. miniata, Corymbia polysciada open woodland.*

Components of these vegetation communities have been selected to replicate on the WSFs not only because they are the dominant vegetation communities within the broader landscape, but they are also best suited to the proposed landform, slopes and growth material.

The proposed capping material vegetation cover will be established by broadcast seeding (hand spreading of seed) supplemented with infill planting of tubestock and follow-up broadcast seed. This is DPIF's preferred method of establishment based on past project experience.

There will be a four-year program of planting with an emphasis initially on establishing erosion protection with native annual grasses, with later focus shifting to developing a suitable final vegetation community. The vegetation community will comprise native annual and perennial grasses, ground cover shrubs, and possibly shallow rooted trees, which is DPIF's preferred species mix, with the final species mix to be decided in consultation with Traditional Owners.

In consultation with DPIF and their experience with previous similar projects, SLR proposed success criteria for the growth material cover design throughout the establishment phase and, subsequently, out to 500 years. The culmination of these proposed success criteria was predicted C factors for each year and major season with reference to section E3.5 C-factor of Book 2, Volume E of the IECA guidelines (IECA, 2008).

The growth material cover design, establishment method, success criteria, which are based on previous rehabilitation success using this approach, and resultant C factors are shown in the table contained in the following pagesError! Reference source not found..

Achievement of the success criteria for every year is based on the following general assumptions:

- Wet season starts as predicted, average wet season, minimal destructive rainfall events (e.g. intense storm cells, cyclones) to damage revegetation/wash away surface materials.
- Dry season starts as predicted, average dry season, not prolonged or excessively hot thereby killing off seedlings.

Soil Cover Program and Associated C Factors

Year	Soil Cover Description	Construction Complete By	Monitoring and Success Criteria								Total Cover %	C Factor (IECA, 2008)
			Time of Year	Shrub Foliage Cover (%)[1]	Grass Foliage Cover (%)[1]	Stems[2] /m²	Ground Foliage Cover (%)[1]	Mulch Cover[3] %	Mulch Cover[3] Depth (mm)	Bare Ground (%)		
1	• Broadcast seeding with preferred seed mix including native grasses, ground cover, shrubs, • Fire excluded	Prior to end of dry season	Start of wet season	0	≥40	0	0	0	0	≤60	≥40	0.22
			Mid-wet season	0	≥75	>0.25	0	≥2.5	≥1	≤25	≥75	0.03
			End of wet season	≥1	≥95	≥0.5	≥1	≥5	≥2	≤5	≥95	0.001
2	• Ground cover and shrub growth started (seedlings germinated) • Native annual grass cover 100%, now dying off • Perennial native grasses seedlings germinated • Infill planting with additional native shrub tubestock • A1 horizon meets soil specifications • Fire excluded	NA	End of dry season	≥1	≥75	≥0.5	≥1	≥25	≥5	≤5	≥95	0.001
			End of wet season	≥5	≥95	≥2	≥5	≥75	≥5	≤5	≥95	0.001
3	• Ground cover and shrub growth progressing (some flowering and seeding) • Native annual grass cover 5% • Perennial native grasses progressing (flowering and seeding) • Infill with broadcast grass and tubestock shrub as required	NA	End of dry season	≥7.5	≥75	≥2	≥7.5	≥90	≥10	≤5	≥95	0.001
			End of wet season	≥10%	≥95	≥2	≥20%	≥75%	≥20	≤5	≥95	0.001

Year	Soil Cover Description	Construction Complete By	Monitoring and Success Criteria								Total Cover %	C Factor (IECA, 2008)
			Time of Year	Shrub Foliage Cover (%)[1]	Grass Foliage Cover (%)[1]	Stems[2] /m^2	Ground Foliage Cover (%)[1]	Mulch Cover[3] %	Mulch Cover[3] Depth (mm)	Bare Ground (%)		
	• A1 horizon meets soil specifications • Fire excluded											
4	• Shrub growth progressing (flowering and seeding, some secondary regeneration) • Native annual grass cover 0% • Perennial native grasses reached maturity (secondary regeneration) • Ground cover reached maturity (flowering and seeding, some secondary regeneration) • Infill with broadcast grass and tubestock shrub as required • A1 horizon meets soil specifications • Fire excluded	NA	End of dry season	≥10	≥75	≥2	≥10	≥95	≥20	≤5	≥95	0.001
			End of wet season	≥20%	≥95%	≥2	≥20%	≥95	≥40	≤5	≥95	0.001
5	• Second generation of shrub growth reached maturity • Second generation of perennial native grasses seedlings • Second generation of ground cover seedlings • Infill with broadcast grass and tubestock shrub as required	NA	End of dry season	≥20	≥75	≥1	≥10	≥95	≥40	≤5	≥95	0.005
			End of wet season	≥50%	≥95%	≥1	≥20%	≥95	≥50	≤5	≥95	0.005

Year	Soil Cover Description	Construction Complete By	Monitoring and Success Criteria								Total Cover %	C Factor (IECA, 2008)
			Time of Year	Shrub Foliage Cover (%)[1]	Grass Foliage Cover (%)[1]	Stems[2] /m^2	Ground Foliage Cover (%)[1]	Mulch Cover[3] %	Mulch Cover[3] Depth (mm)	Bare Ground (%)		
	• A1 horizon meets soil specifications • Fire excluded											
10	• Mature shrub layer • Mature perennial native grasses • Mature ground layer • >75 mm native mulch layer • A1 horizon meets soil specifications • Controlled fire introduced	NA	End of dry season	≥25	≥60	≥0.5	≥15	0	0	≤20	≥80	0.04
			End of wet season	≥50%	≥95%	≥0.5	≥20%	≥5	≥2	≤5	≥95	0.005
50	• Mature shrub layer • Mature perennial native grasses • Mature ground layer • >75 mm native mulch layer • A1 horizon meets soil specifications • Controlled fire	NA	End of dry season	≥25	≥60	≥0.5	≥15	0	0	≤20	≥80	0.04
			End of wet season	≥50%	≥95%	≥0.5	≥20%	≥5	≥2	≤5	≥95	0.005
100	• Mature shrub layer • Mature perennial native grasses • Mature ground layer • >75 mm native mulch layer • A1 horizon meets soil specifications	NA	End of dry season	≥25	≥60	≥0.5	≥15	0	0	≤20	≥80	0.04
			End of wet season	≥50%	≥95%	≥0.5	≥20%	≥5	≥2	≤5	≥95	0.005

Year	Soil Cover Description	Construction Complete By	Monitoring and Success Criteria								Total Cover %	C Factor (IECA, 2008)
			Time of Year	Shrub Foliage Cover (%)[1]	Grass Foliage Cover (%)[1]	Stems[2] /m²	Ground Foliage Cover (%)[1]	Mulch Cover[3] %	Mulch Cover[3] Depth (mm)	Bare Ground (%)		
	• Controlled fire											
500	• Mature shrub layer • Mature perennial native grasses • Mature ground layer • >75 mm native mulch layer • A1 horizon meets soil specifications • Controlled fire	NA	End of dry season	≥25	≥60	≥0.5	≥15	0	0	≤20	≥80	0.04
			End of wet season	≥50%	≥95%	≥0.5	≥20%	≥5	≥2	≤5	≥95	0.005

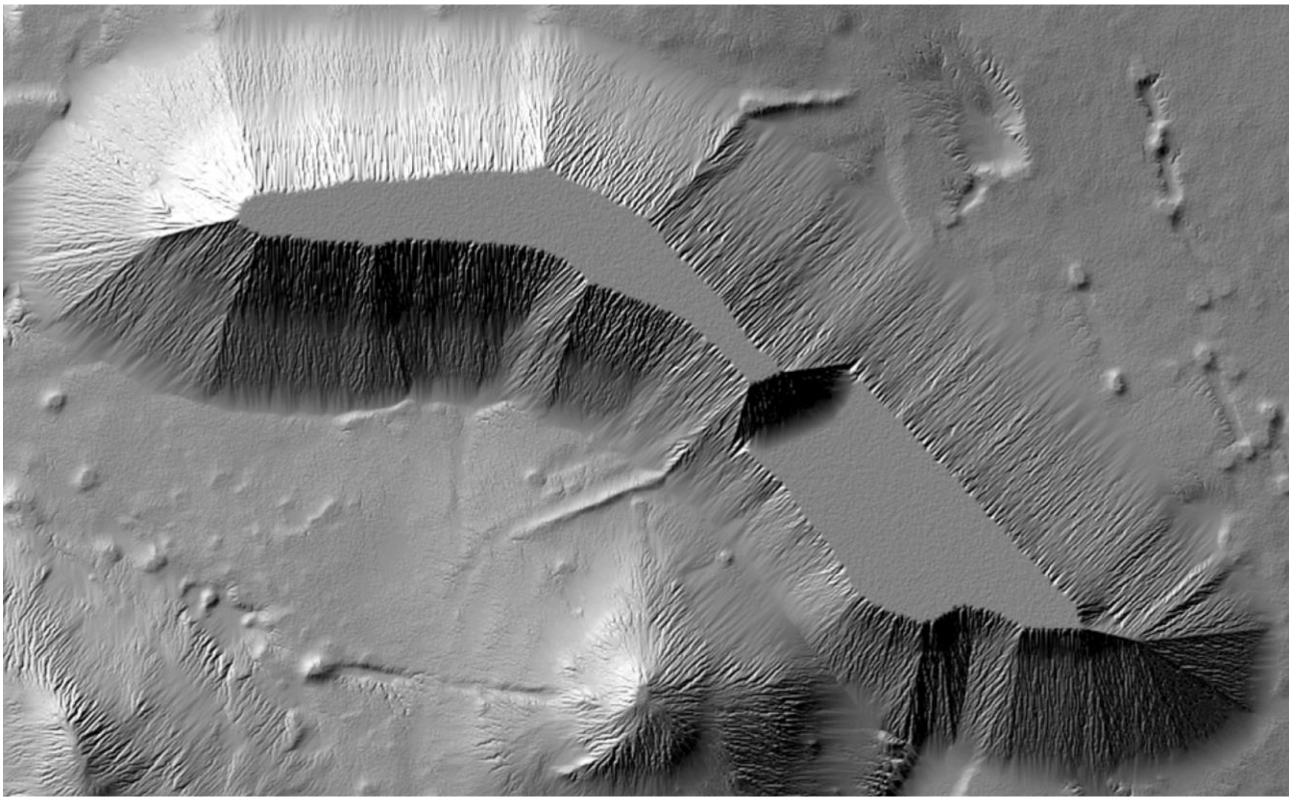
Notes:
1 Foliage cover includes live and dead standing vegetative material
2 Individual stems of shrubs only
3 Mulch cover includes and live or dead material that has detached from a plant and is laying on the ground

APPENDIX D

Stage 1 Hillshades and Erosion Colour Maps

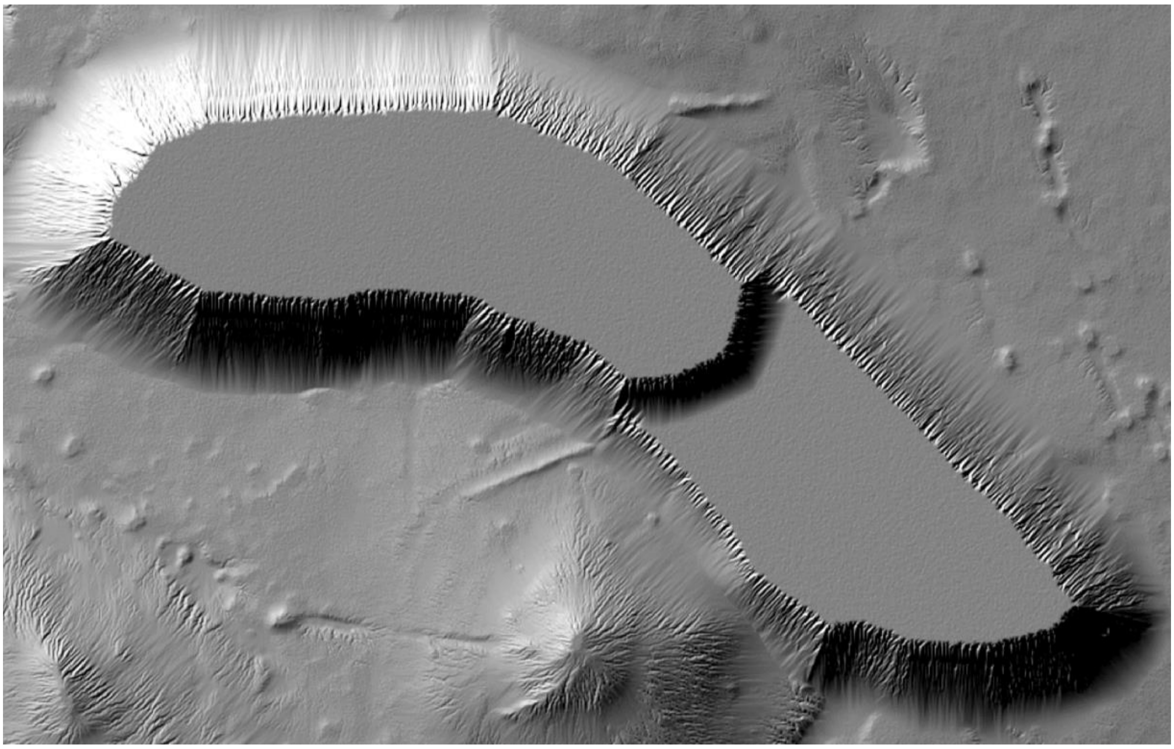
In general, the following can be observed:

- Predicted erosion profiles at 0, 200 and 500 years, showing increasing erosion depth with time.
- The majority of soil loss in all scenarios is evidenced in the -0.00 to -0.25 m bracket, where 47%, 33% and 35% of the EWSF area correspond to the low, medium and high slopes. Similarly, the deposition bracket of 0.00 to 0.25 m contains the larger portion of soil deposition at the WSF's toe.
- The colour maps for all scenarios show that deep erosion depths i.e. >1m are around 1%, 12% and 14% of total site area for the low, medium and high dual slopes, respectively.

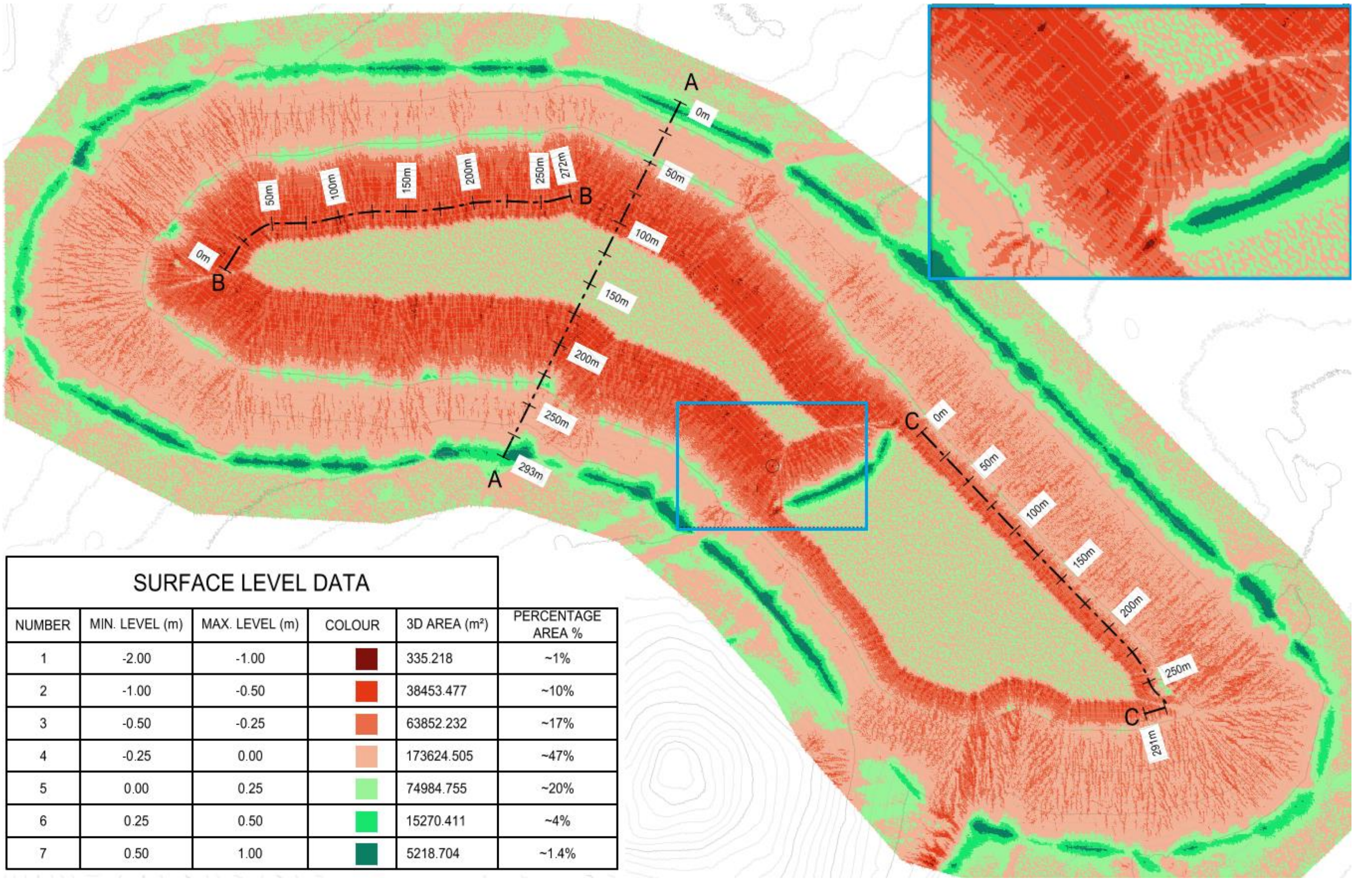


Stage 1 EWSF Hillshade After 500 Years, 9°-14° Dual-slope

Stage 1, EWSF Hillshade After 500 Years, 16°-22° Dual-slope



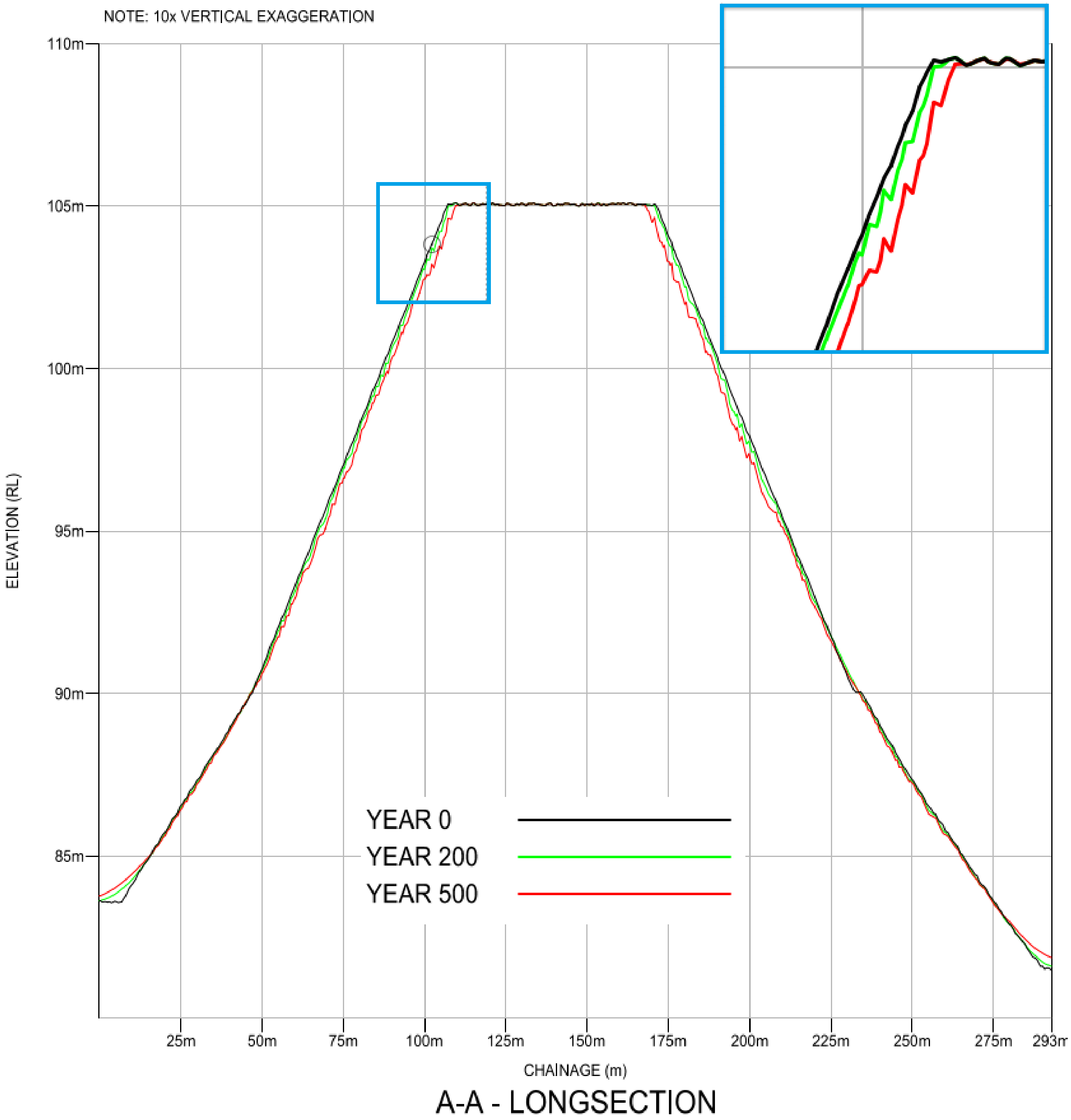
Stage 1, EWSF Hillshade After 500 Years, 18°-25° Dual-slope



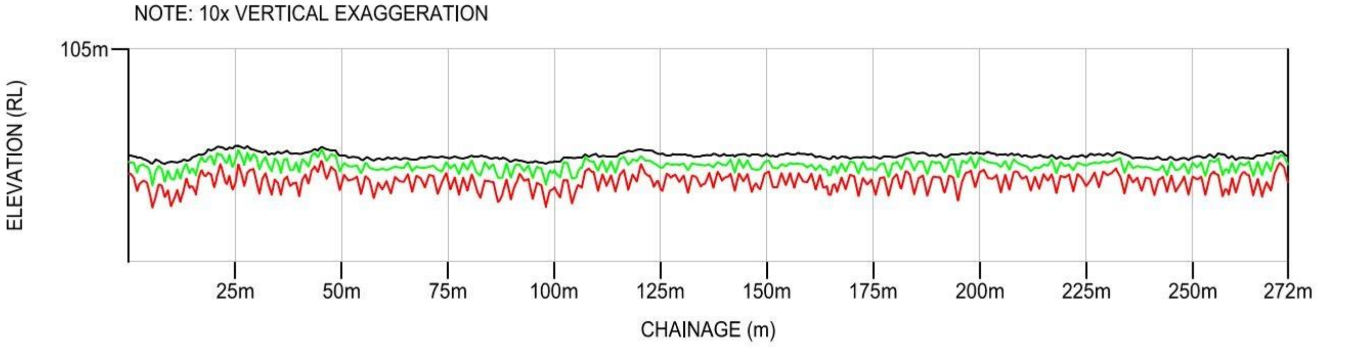
SURFACE LEVEL DATA

NUMBER	MIN. LEVEL (m)	MAX. LEVEL (m)	COLOUR	3D AREA (m^2)	PERCENTAGE AREA %
1	-2.00	-1.00		335.218	~1%
2	-1.00	-0.50		38453.477	~10%
3	-0.50	-0.25		63852.232	~17%
4	-0.25	0.00		173624.505	~47%
5	0.00	0.25		74984.755	~20%
6	0.25	0.50		15270.411	~4%
7	0.50	1.00		5218.704	~1.4%

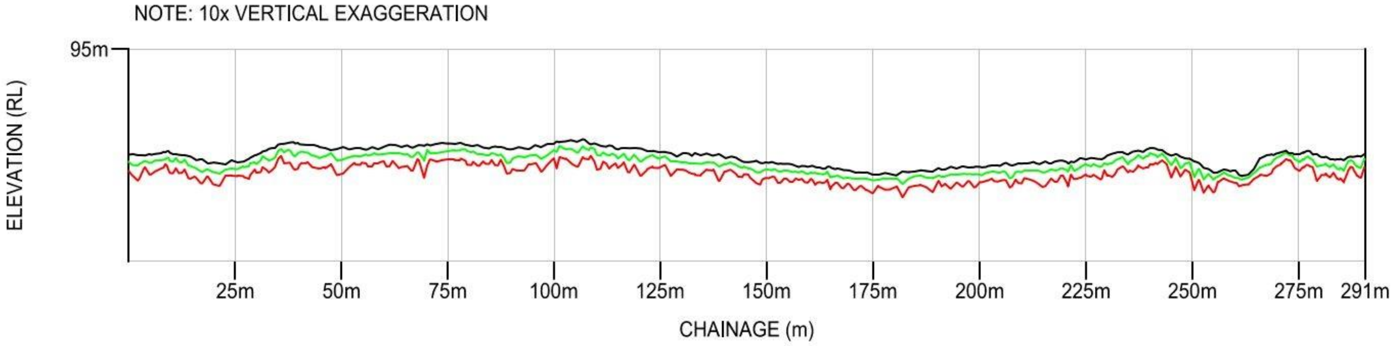
Stage 1, Soil Loss Map, Bare Soil, 500-year Scenario, EWSF, 9°-14° Dual-slope



Stage 1, Cross Section A, 9°-14° Dual-slope, EWSF

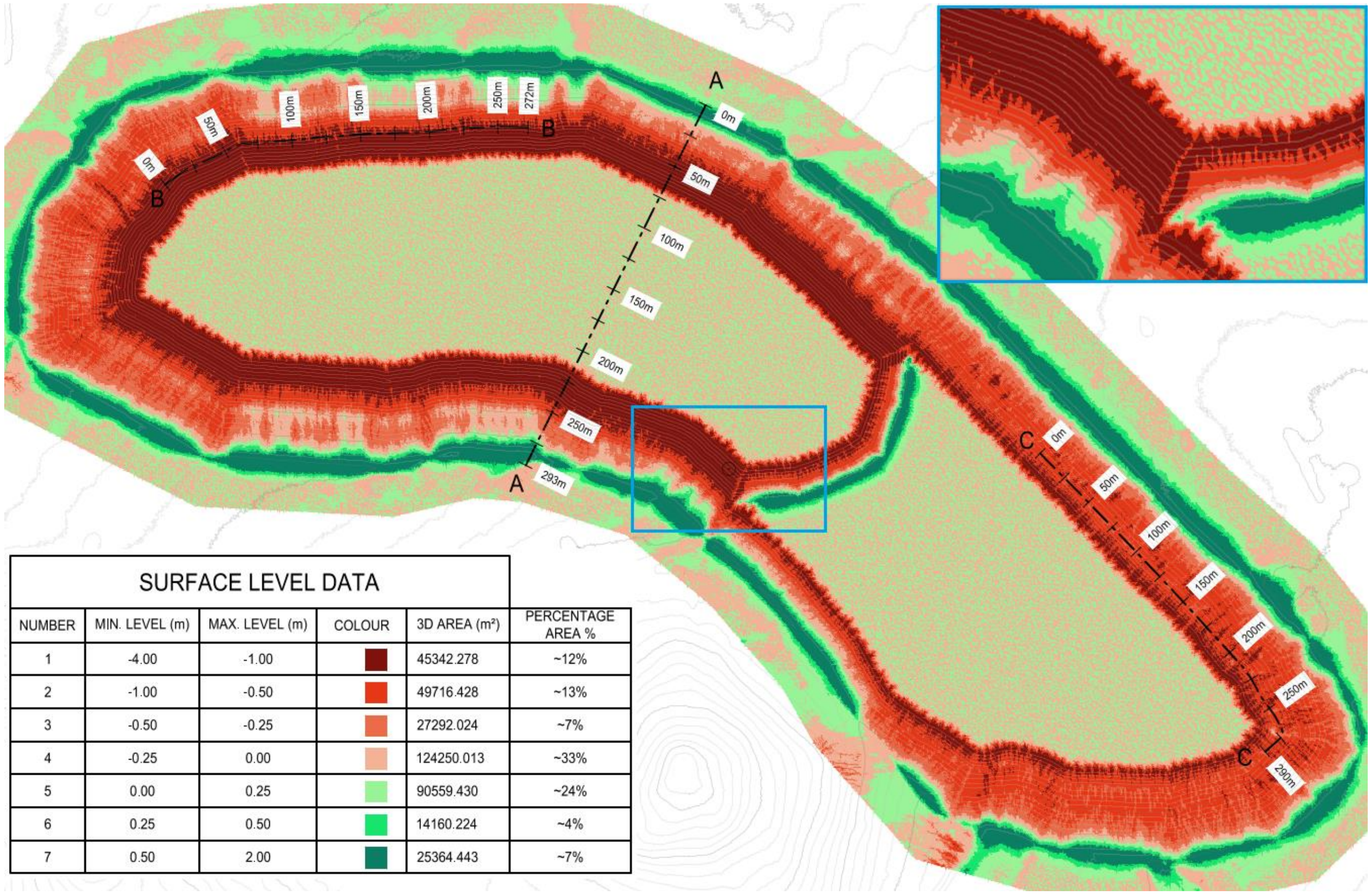


B-B - LONGSECTION



C-C - LONGSECTION

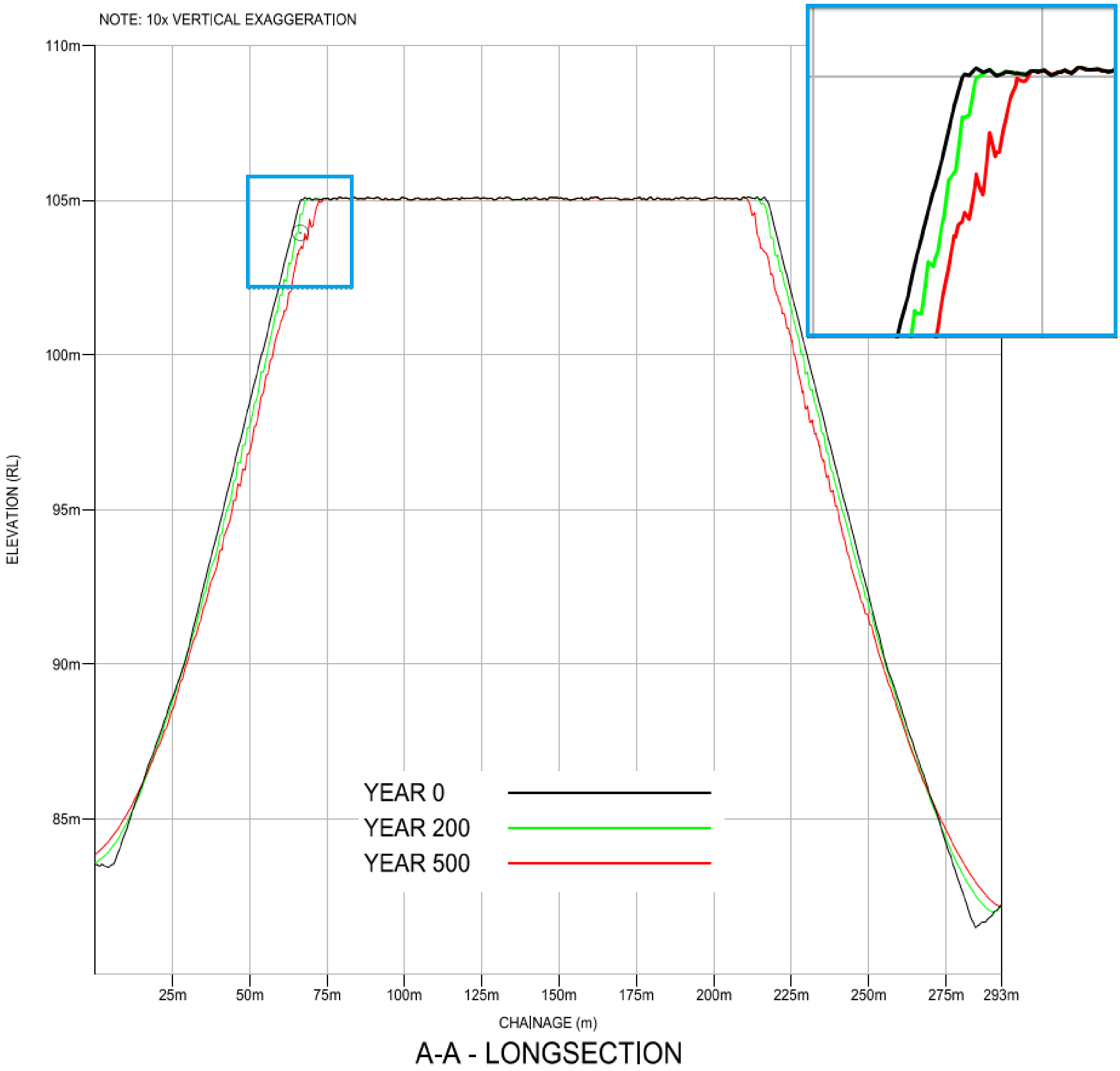
Stage 1, Cross Sections B and C, 9°-14° Dual-slope, EWSF



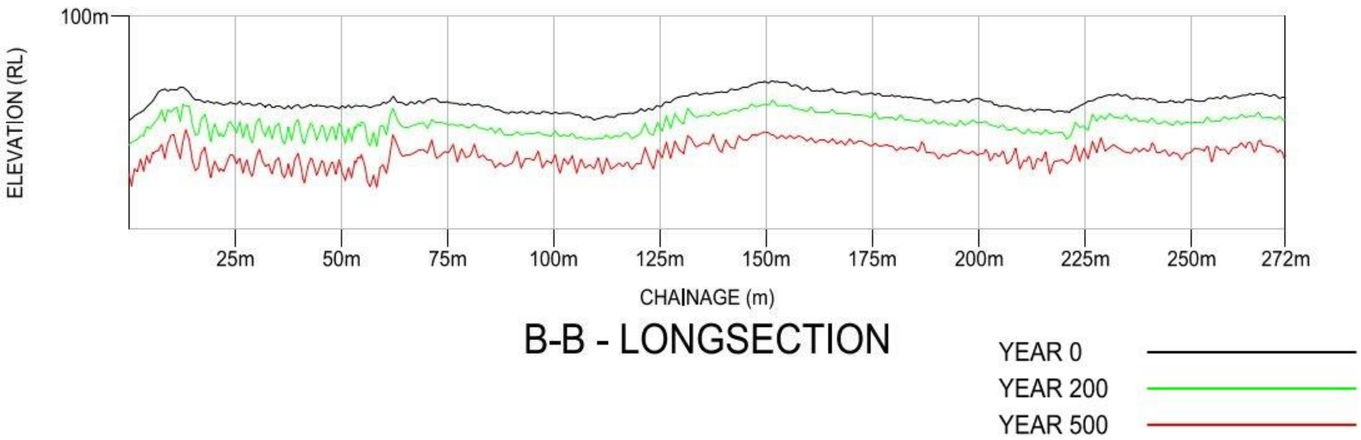
SURFACE LEVEL DATA

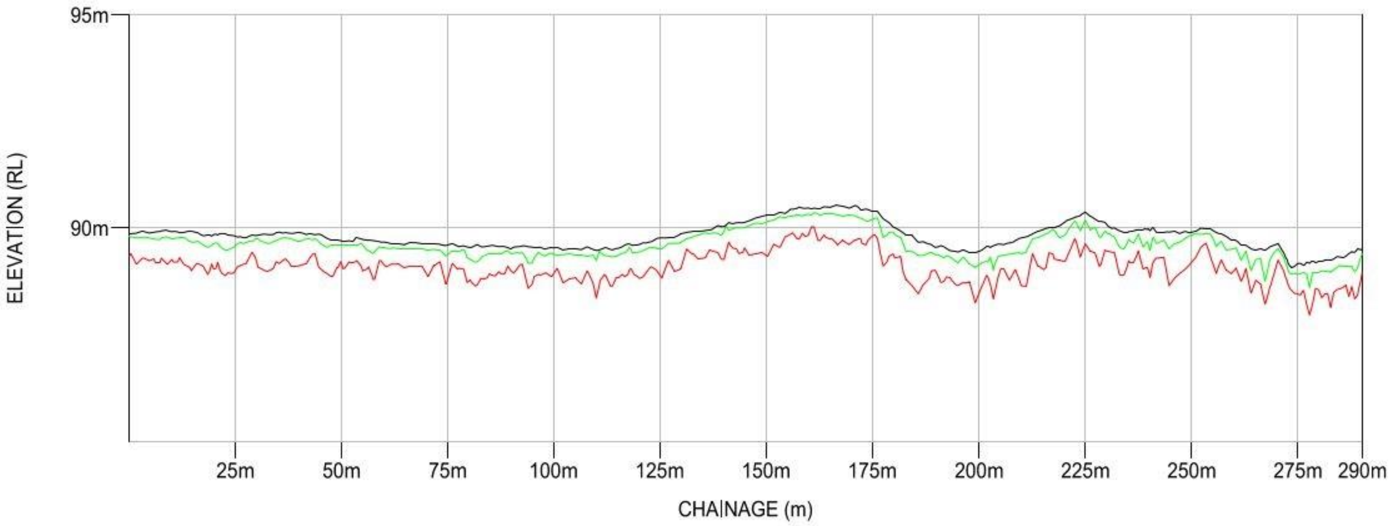
NUMBER	MIN. LEVEL (m)	MAX. LEVEL (m)	COLOUR	3D AREA (m²)	PERCENTAGE AREA %
1	-4.00	-1.00		45342.278	~12%
2	-1.00	-0.50		49716.428	~13%
3	-0.50	-0.25		27292.024	~7%
4	-0.25	0.00		124250.013	~33%
5	0.00	0.25		90559.430	~24%
6	0.25	0.50		14160.224	~4%
7	0.50	2.00		25364.443	~7%

Stage 1, Soil Loss Map, Bare Soil, 500-year Scenario, EWSF, 16°- 22° Dual-slope

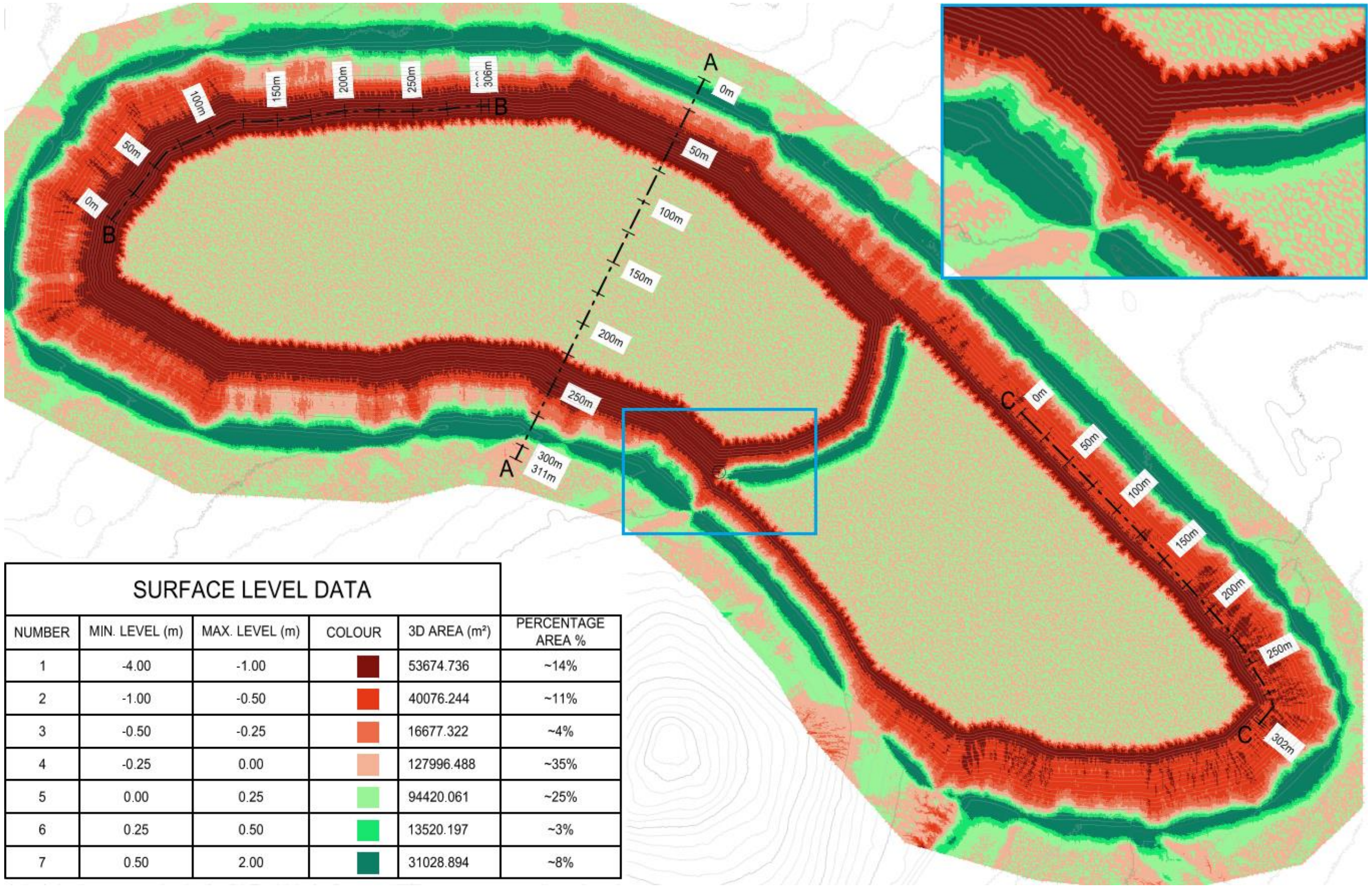


Stage 1, Cross Section A, 16°- 22° Dual-slope, EWSF





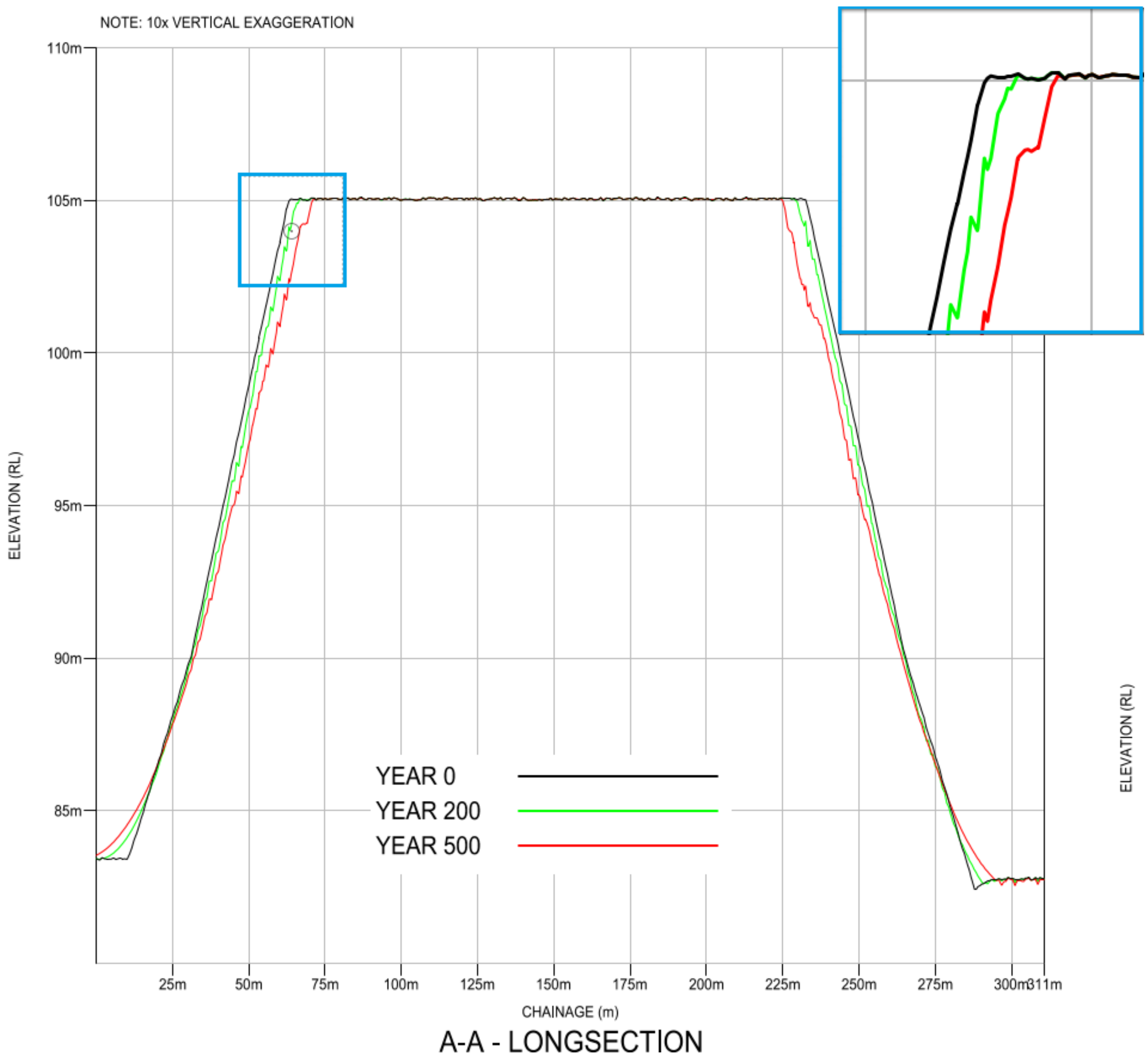
Stage 1, Cross Sections B and C, 16°- 22° Dual-slope, EWSF



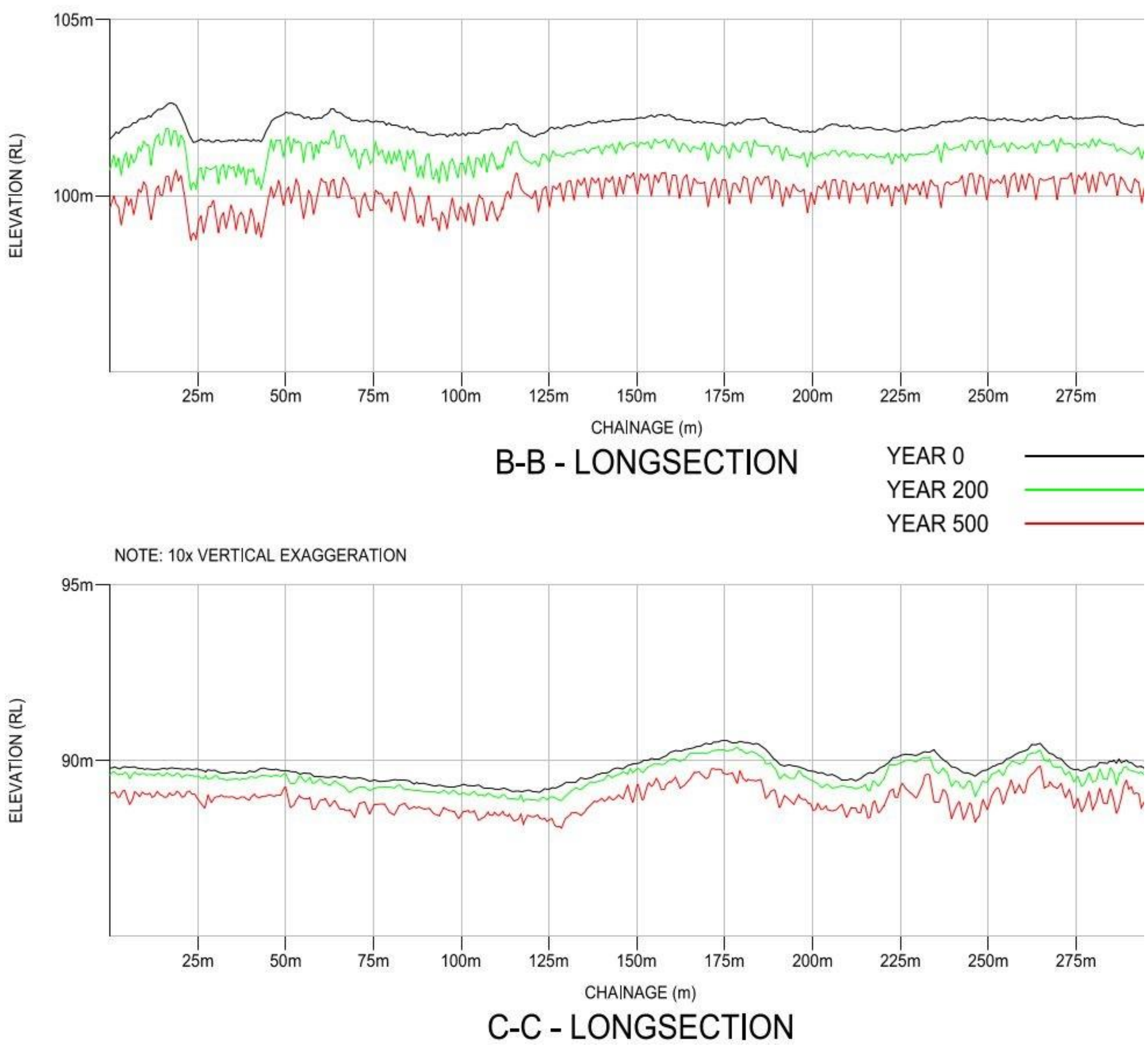
SURFACE LEVEL DATA

NUMBER	MIN. LEVEL (m)	MAX. LEVEL (m)	COLOUR	3D AREA (m²)	PERCENTAGE AREA %
1	-4.00	-1.00		53674.736	~14%
2	-1.00	-0.50		40076.244	~11%
3	-0.50	-0.25		16677.322	~4%
4	-0.25	0.00		127996.488	~35%
5	0.00	0.25		94420.061	~25%
6	0.25	0.50		13520.197	~3%
7	0.50	2.00		31028.894	~8%

Stage 1, Soil Loss Map, Bare Soil, 500-year Scenario, EWSF, 18°- 25° Dual-slope



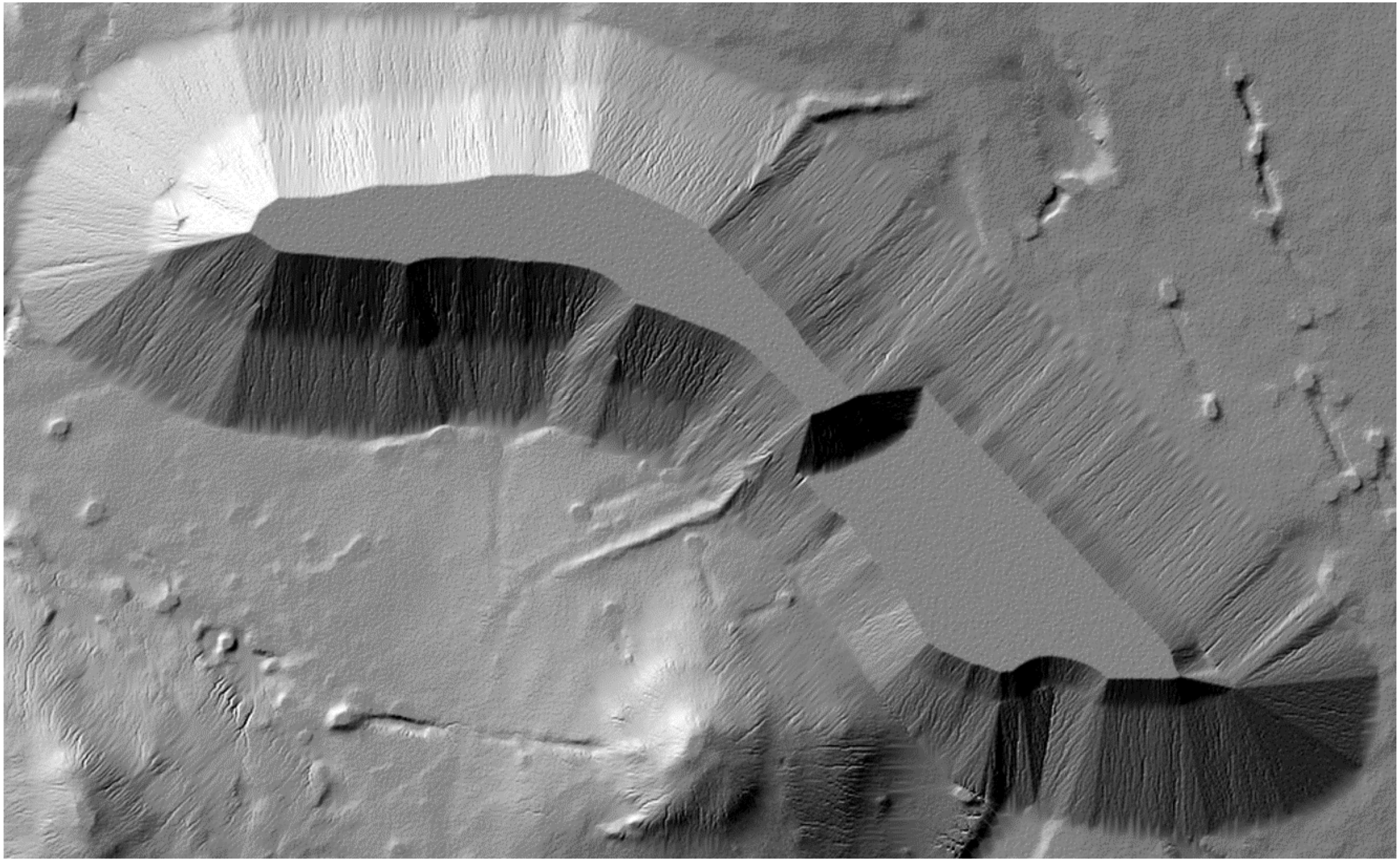
Stage 1, Cross Section A, 18°- 25° Dual-Slope, EWSF



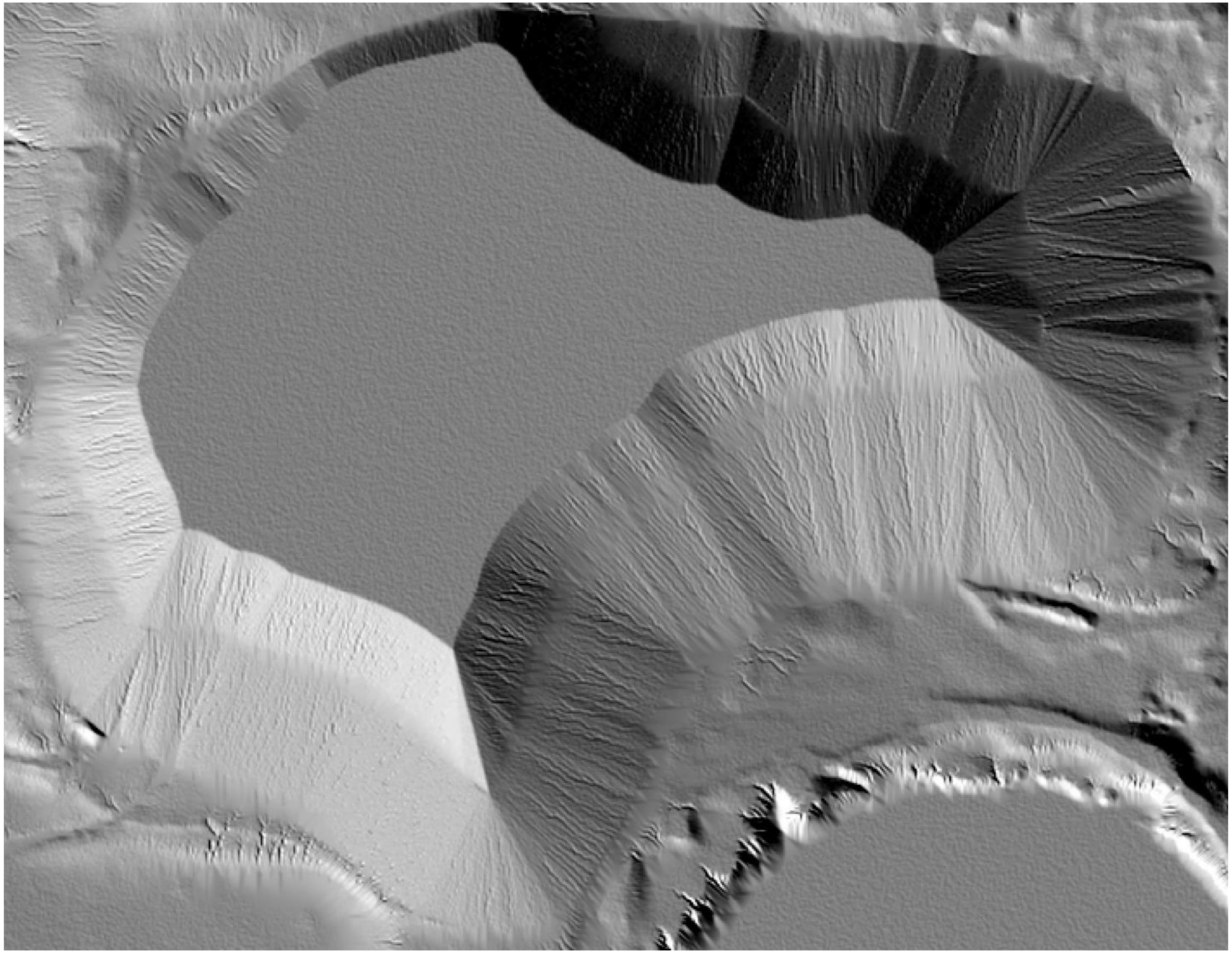
Stage 1, Cross Section B and C, 18°- 25° Dual-Slope, EWSF

APPENDIX E

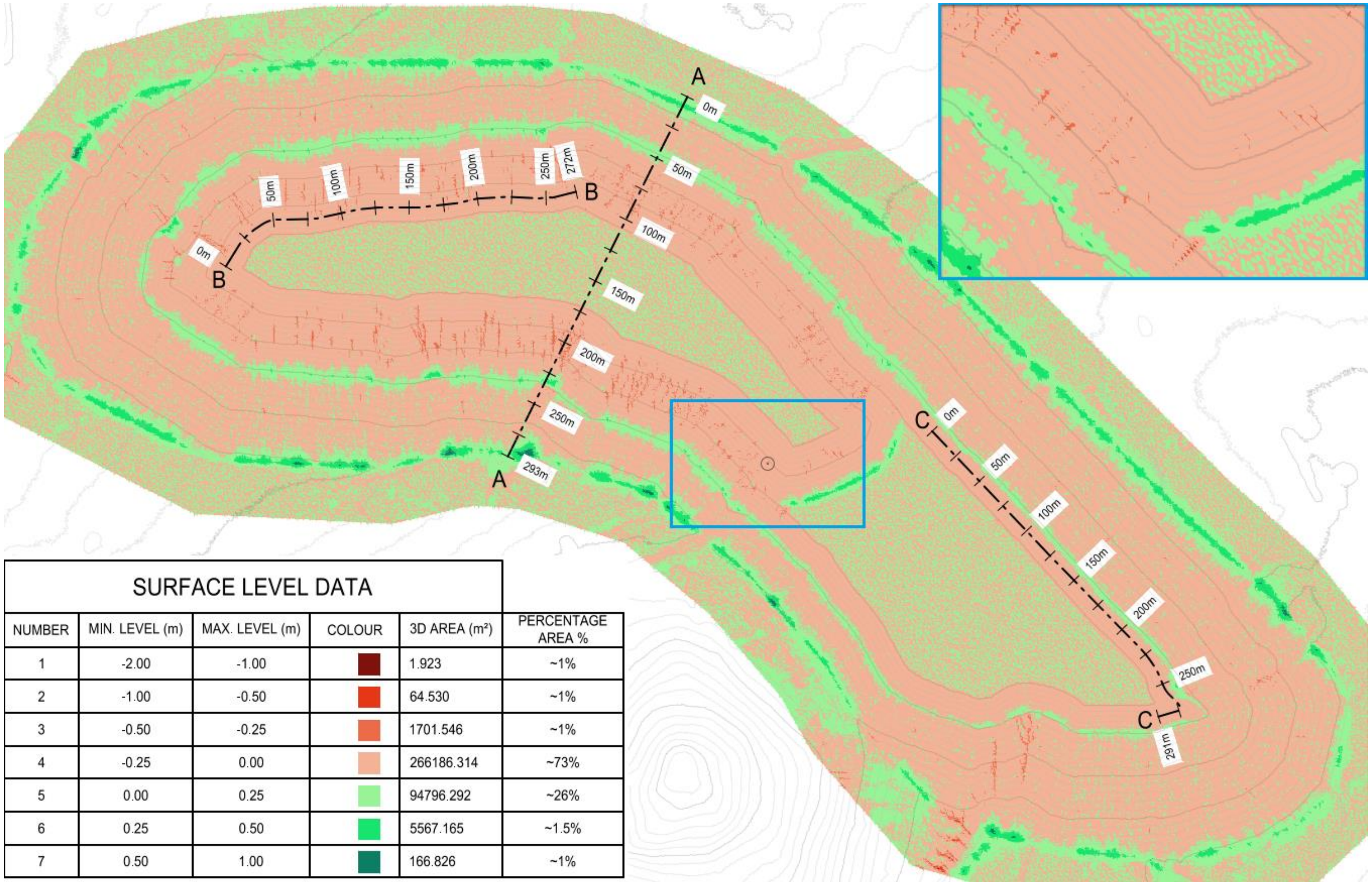
Stage 2 Hillshades and Erosion Colour Maps



Stage 2, EWSF Hillshade After 500 Years

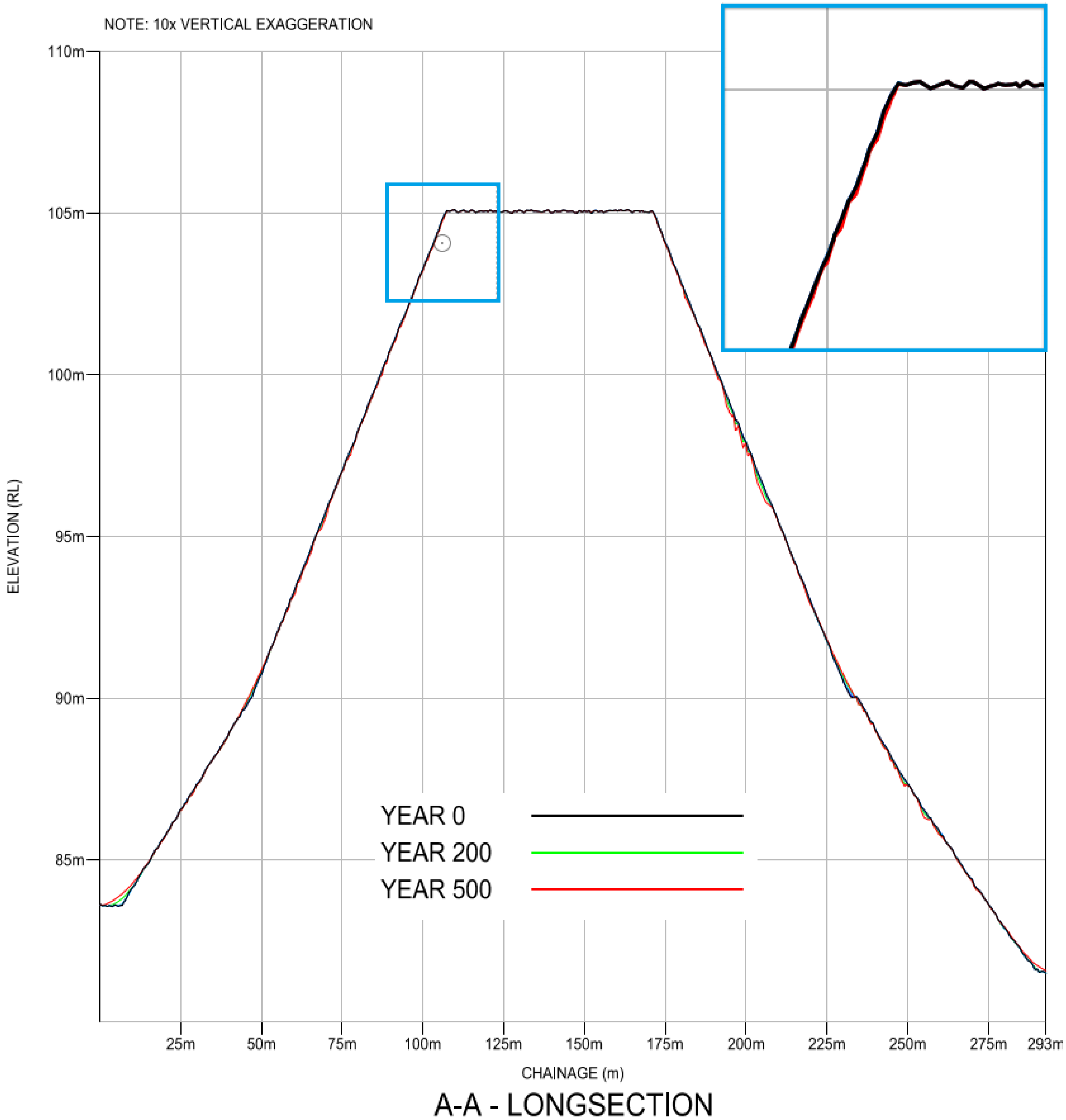


Stage 2, WWSF Hillshade After 500 Years

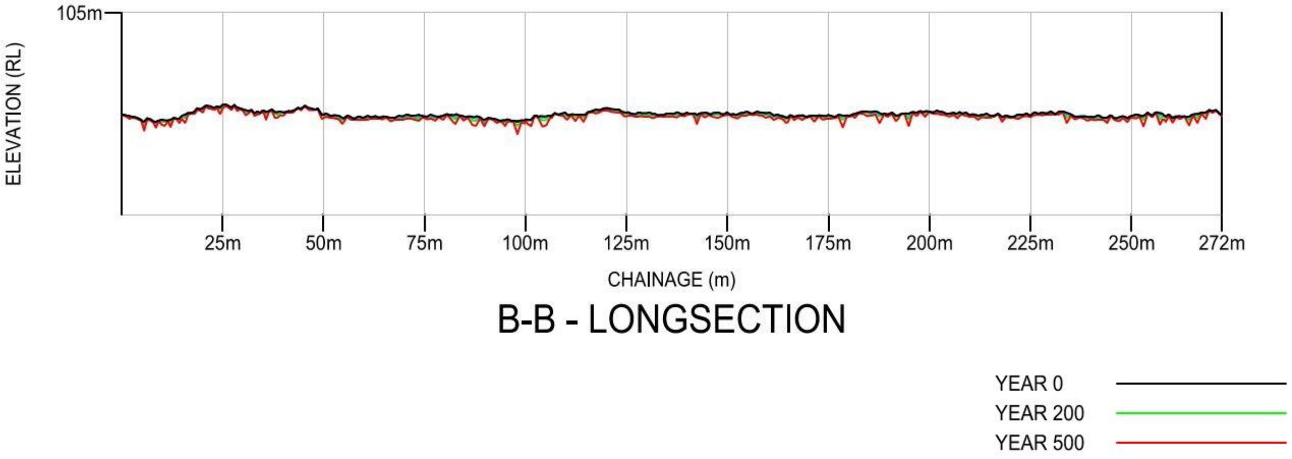


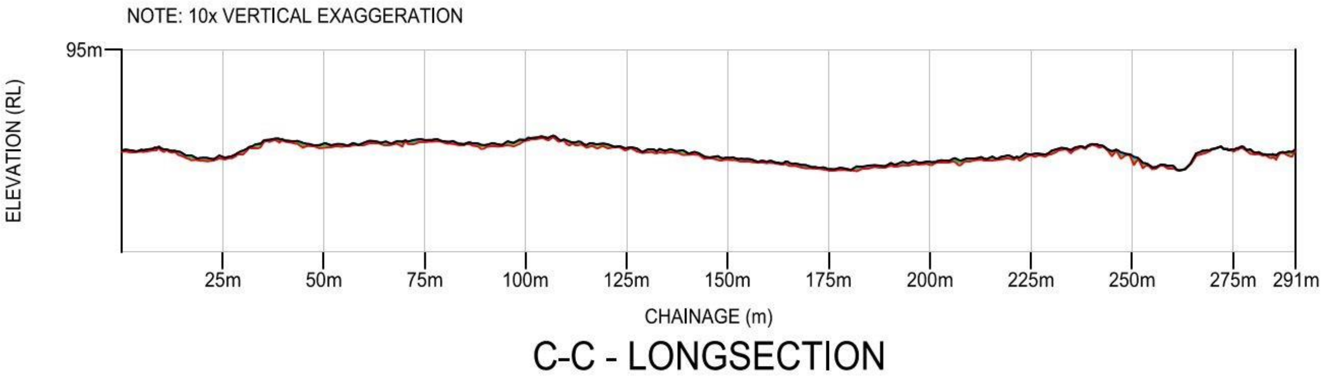
SURFACE LEVEL DATA					
NUMBER	MIN. LEVEL (m)	MAX. LEVEL (m)	COLOUR	3D AREA (m²)	PERCENTAGE AREA %
1	-2.00	-1.00		1.923	~1%
2	-1.00	-0.50		64.530	~1%
3	-0.50	-0.25		1701.546	~1%
4	-0.25	0.00		266186.314	~73%
5	0.00	0.25		94796.292	~26%
6	0.25	0.50		5567.165	~1.5%
7	0.50	1.00		166.826	~1%

Stage 2, Soil Loss Map, Vegetated 500-year Scenario, EWSF



Stage 2, Cross Section A, EWSF



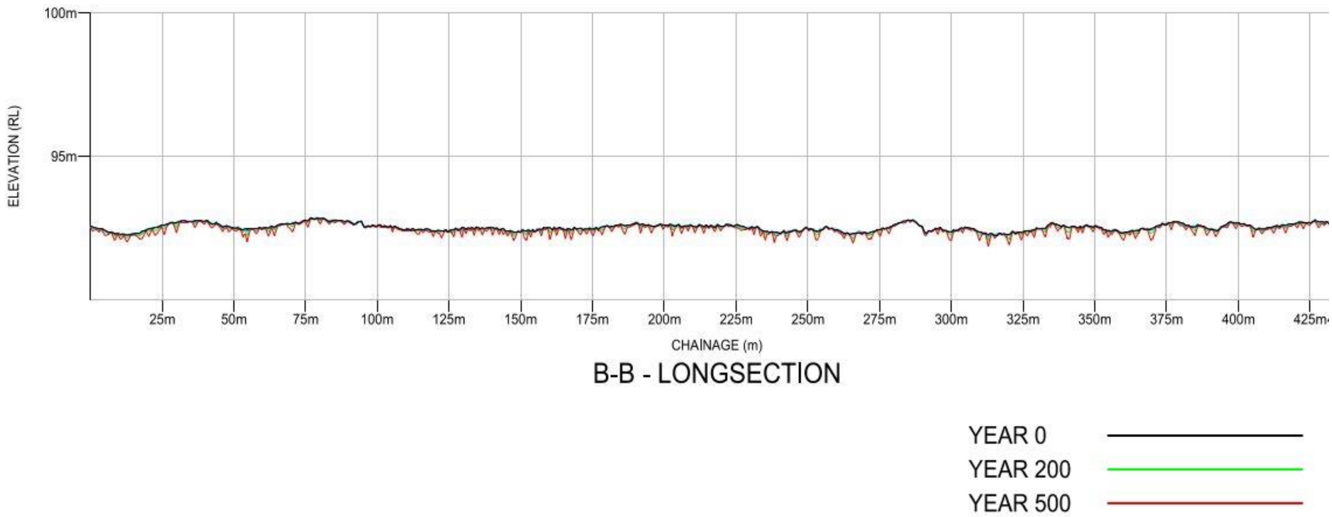


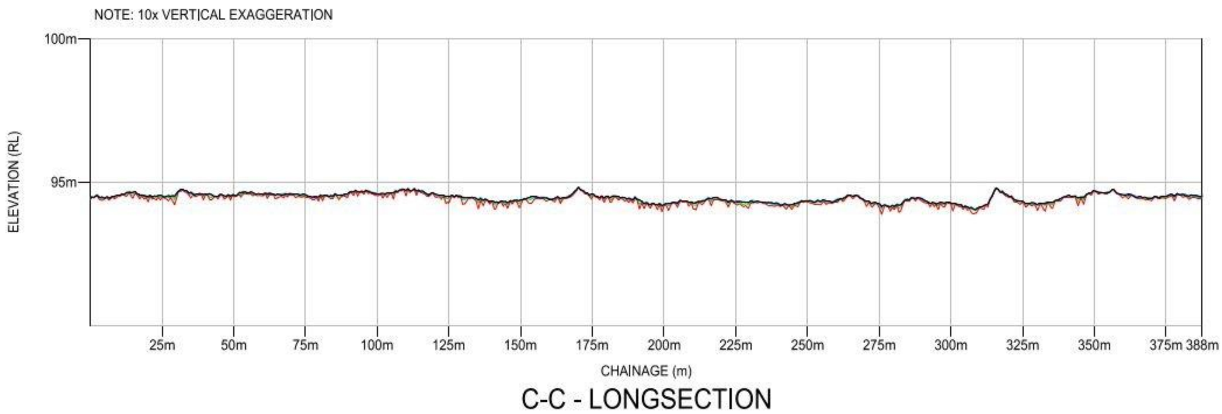
Stage 2, Cross Sections B and C, EWSF

SURFACE LEVEL DATA					
NUMBER	MIN. LEVEL (m)	MAX. LEVEL (m)	COLOUR	3D AREA (m²)	PERCENTAGE AREA %
1	-2.00	-1.00		0.000	~1%
2	-1.00	-0.50		188.841	~1%
3	-0.50	-0.25		2468.143	~1%
4	-0.25	0.00		244588.726	~75%
5	0.00	0.25		78646.050	~24%
6	0.25	0.50		3329.402	~1%
7	0.50	1.00		369.828	~1%

Stage 2, Soil Loss Map, Vegetated 500-year Scenario, WWSF

Stage 2, Cross Section A, WWSF





Stage 2, Cross Sections B and C, WWSF

APPENDIX F

Erosion Monitoring Form

Erosion Monitoring

Described By			

Date (ddmmyy)					

Project					

Site			

General Location

Zone		Easting/Latitude						Northing/Longitude						

Slope, Landform Element & Pattern

Percent			Class		MT	Type			Pattern			Class	RMS	

Water

Runoff	Perm	Drainage

Surface Coarse Fragments

Abun	Size	Shape		Lith		Str	

Microrelief

Type	Agent	Cmpt	Prop	VI		HI	

Erosion

Type	State	Deg	Location	Scale	Length	Easting/Latitude						Northing/Longitude							Comments

Notes:

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APPENDIX D

Growth Medium Design

Memorandum

To:	Danielle O'Toole	**At:**	SLR
From:	Cameron Trail	**At:**	SLR Consulting Australia Pty Ltd
Date:	20 March 2020	**Ref:**	680.10421.900010 M06 Growth Ma Capping v1.docx
Subject:	Rum Jungle Rehabilitation - Stage 2A Detailed Engineering Design Growth Medium for WSF Capping		

This memo has been prepared to support the capping design, in particular the erosion modelling, for the WSFs. It is recommended that a detailed Growth Medium Management Plan be developed as part of the Projects Revegetation Management Plan.

1 Growth Material for Waste Storage Facility Capping

A purpose-designed growth material has been designed to cover the new WSFs. The growth material is to provide a long-term, sustainable growing medium for selected native revegetation species. It is also to provide a reduced likelihood of, equal to or better than baseline for the area, sheet, rill, and gully erosion over the proposed life of the WSFs capping. The growth material will need to provide for moderately rapid stormwater infiltration and be moderately permeable to reach field capacity but also have sufficient clay content to provide some structure, water holding capacity, and mineral exchange and nutrient adsorption capacity to support revegetation with, and long-term sustainability of, native shrubs and grasses.

1.1 Historical Soil and Land Resource Information

1.1.1 Land Systems of the Northern Part of the Northern Territory

The *Land Systems of the Northern Part of the Northern Territory* (Lynch, 2010) is an amalgamation of some 16 existing land system surveys covering the northern portion of the Northern Territory. The land system approach provides a broad-scale representation of the main features of the landscape, which are based on detailed information collected at specific field sites.

The Project site and specific areas are located across the land systems described in **Table 1** and shown on **Figure 1**.

These land systems provide an indication of the geology, terrain, soils and vegetation characteristics and associations that may guide design and characterization of the WSFs capping growth material.

1.1.2 Soil and Land Information Soil Profile Descriptions

The Northern Territory Department of Environment and Natural Resources maintains a database of soil profile information from all soil surveys, which is referred to as the Soil and Land Information (SALI) database. Accessing this database provided representative soil profile descriptions within and immediately surrounding the Project site in the dominant land systems described in **Table 1** and shown on **Figure 1** that the Project site is primarily located in. These being Woodcutter (Wdc) and Gully (Gly) land systems.

Table 1 Land Systems of the Project Site

Land System	Geological Zone	Landscape Class	Landscape Class Description	Landform Description	Original Soil Description	Australian Soil Classification	Vegetation Description	Specific Areas
Baker (Bkr)	Pine Creek	Sandstone hills	Low hills, hills and stony plateaus on sandstone, siltstone, quartzite and conglomerate (deeply weathered in places); outcrop with shallow stony soils	Rugged hills and strike ridges with intervening narrow valleys and short lower slopes on folded Burrels Creek greywacke, sandstone and siltstone	Skeletal soils and outcrop with minor sandy red and yellow gradational soils	Leptic Rudosols, shallow Yellow and Brown Kandosols	Mid-high woodland of *C. dichromophloia*, *E. miniata*, *C. bleeseri*, *E. tectifica* and *C. terminalis* over *Sorghum* spp, *Themeda triandra* and *Chrysopogon* spp	Very thin margin of southwestern edge of Borrow Area B Very thin margin of northeastern edge of Borrow Area A
Bend (Bnd)	Pine Creek	Sandstone plains and rises	Plains, rises and plateaus on mostly on sandstone, siltstone, claystone, shale and some limestone; commonly shallow soils with surface stone and rock outcrop	Undulating low strike ridges and rises on folded Burrels Creek greywacke, sandstone and siltstone	Skeletal soils and shallow gravelly loams	Shallow Yellow and Brown Kandosols and Leptic Rudosols	Mid-high woodland of *C. latifolia*, *C. foelscheana*, *E. polysciadia*, *E. tectifica*, *Erythrophleum chlorostachys* over tropical tall grass (*Sorghum* spp, *Heteropogon* spp, *Chrysopogon* spp)	Northwestern portion of Eastern WSF
Gully (Gly)	Pine Creek	Granite plains and rises	Gently undulating to undulating plains with rises and low hills on granite, schist, gneiss (deeply weathered in places); coarse grained sandy, earthy and texture contrast soils	Undulating terrain developed on granite, schist, and gneiss	Red massive earths and mottled yellow duplex soils	Red Kandosols and Yellow Chromosols	Woodland of *C. confertiflora*, *C. foelscheana*, *Erythrophleum chlorostachys*, *Terminalia canescens*, *Petalostigma* spp over perennial grasses (*Heteropogon triticeus*, *Themeda australis*, *Sorghum plumosum*)	Northeastern half of Borrow Area B Far southeastern portion of Eastern WSF
Woodcutter (Wdc)	Pine Creek	Sandstone plains and rises	Plains, rises and plateaus on mostly on sandstone, siltstone, claystone, shale and some limestone; commonly	Very gently [rising] upland surface; probably developed on Tertiary sediments	Deep red massive earths and yellow massive earths	Deep Red and Yellow Kandosols	Mid-high woodland of *Erythrophleum chlorostachys*, *E. miniata*, *C. confertiflora*, *C. papuana*, *Petalostigma*	Majority of Eastern WSF All of Western WSF

			shallow soils with surface stone and rock outcrop	overlying carbonate-rich Lower Proterozoic rocks			spp over perennial grasses (*Heteropogon triticeus*, *Chrysopogon latifolius*, *Imperata cylindricus*)	Most of southwestern half of Borrow Area B Majority of Borrow Area

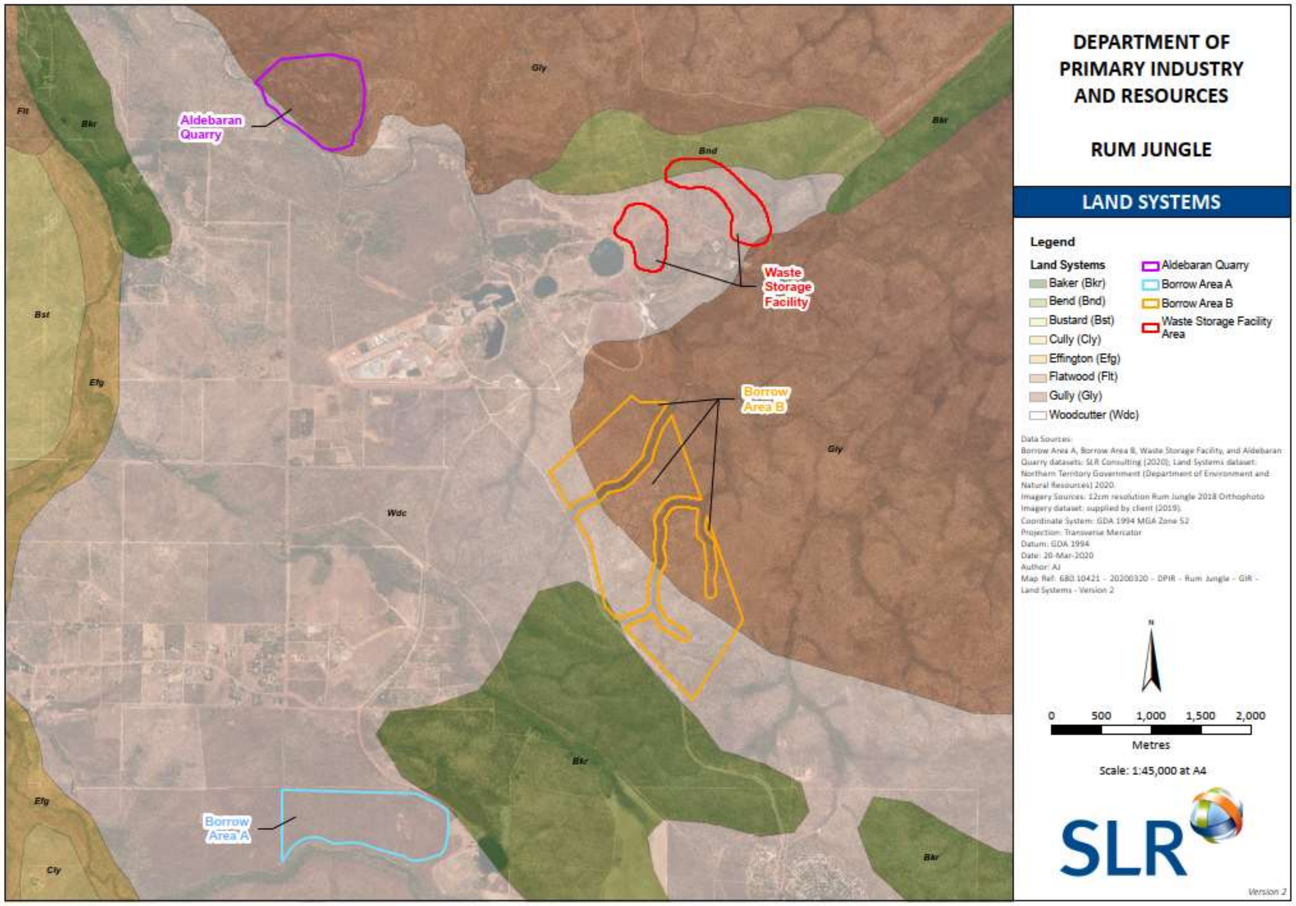

Figure 1 Land Systems of the Project Site

The dominant soils across these land systems appear to be Kandosols that tend to occur on very gently undulating plains, rises and plateaus. The final landforms proposed for the WSFs should be consistent with these landforms and, therefore, these soils should be most suitable to replicate for the growing medium over the capping on the WSFs. Representative profile examples of Kandosols from the surrounding landscape are shown in **Appendix 1** with available historical laboratory data shown in **Appendix 2**.

Aside from being dominant soils in the general landscape, Kandosols are considered a suitable growth medium for the following reasons:

- They tend to be deeply weathered profiles, which are suitable for the tropics
- They have a sandier texture and good humus content in the surface horizon that provide for moderately rapid stormwater infiltration due to lack of surface crusting or hard setting properties
- They have gradually increasing clay contents that provide for good water retention and cation exchange capacity
- They have deep, less consolidated (massive to weak structure) profiles suitable for deep root penetration by grasses and shrubs (but not so deep as to penetrate a clay capping) and are moderately permeable
- They have moderately high humus and organic carbon levels as a result of good vegetation growth that in turn improves surface horizon texture and structure.

Should replication of the Kandosol soil prove problematic, the preference would be to replicate a Dermosol soil, which has a fraction more clay throughout the profile and a structure that is weak to moderate.

1.1 Characteristics of Landforms

Landforms surrounding the Project site are strongly influenced by surface geology, faulting and folding, and climate (typically, a monsoonal wet season from November to March and dry season from May to September). Based on the land systems and SALI database information, landforms surrounding the Project site appear to largely comprise:

- Plateaus with relatively flat (<9 m relief, 0-1% slopes) to gently undulating (<30 m relief, 1-3% slopes) surfaces that abruptly downslope become either short, cliffed (>300%), precipitous (100-200%) and/or very steep (56-100%) slopes, usually rocky, or steep (32-56%) and/or moderately inclined (10-32%) slopes, that grade to gently inclined (3-10%) followed by very gently inclined (1-3%) slopes that level off on flat (0-1%) to very gently undulating (1-3%) plains. Slopes are intersected by shallow and relatively level drainage depressions on the plateaus that become steep gullies, as they drop off the plateaus, that gradually flatten with the concave landform to become streams, creeks and rivers meandering through the landscape.
- Ridges with cliffed (>300%), precipitous (100-200%) and/or very steep (56-100%) slopes, usually rocky, concavely grading to steep (32-56%) and/or moderately inclined (10-32%) slopes, that grade to gently inclined (3-10%) followed by very gently inclined (1-3%) slopes that level off on flat (0-1%) to very gently undulating (1-3%) plains. Slopes are intersected by steep gullies from ridges that gradually flatten with the concave landform to become streams, creeks and rivers meandering through the landscape.

- Gently undulating to rolling low hills (<30 m relief, <10% slopes) with crests that are smoothly convex, flat (0-1% slopes) to very gently inclined (1-3% slopes) convexly grading into gently inclined (3-10%) slopes and terminating on the bank of a drainage feature.

Based on the above, the preferred landform for the new WSFs would be a plateau to low hill with relatively flat (0-1%) grading to gently inclined (1-3%) slopes (convex crest) that relatively rapidly increases to a moderately inclined (10-32%) slope that grades to gently inclined (3-10%) followed by very gently inclined (1-3%) slopes (concave slope) as it grades into natural ground landform conditions.

Drainage off the preferred landform would be sheet flow as much as is practicably possible to minimise concentrated flows creating rills and gullies.

1.2 Characteristics of Kandosols

In accordance with the *Australian Soil Classification* (ASC) (Isbell & NCST, 2016), Kandosols are soils that lack strong texture contrast, have massive or only weakly structured B horizons, and are not calcareous throughout. More specifically, these soils have all of the following characteristics:

- B2 horizons in which the major part is massive or has only weak grade of structure
- A maximum clay content in some part of the B2 horizon which exceeds 15% (i.e. heavy sandy loam, SL+)
- Do not have a tenic B horizon
- Do not have a clear or abrupt textural B horizon
- Are not calcareous throughout the solum, or below the A1 or Ap horizon or a depth of 0.2 m if the A1 horizon is only weakly developed.

Based on the representative profile examples of Kandosols from the surrounding landscape, as shown in **Appendix 1**, and the available historical laboratory data, as shown in **Appendix 2**, the general characteristics of a Kandosol for the growth material should be similar to those detailed in **Table 2**.

Table 2 Generalised Characteristics of Kandosol Soil Profile

Attribute	Description
Slope:	<2% (but can be considerably steeper depending on specific surface texture, depth, vegetative cover and other factors)
Runoff:	Slow to moderate
Permeability:	Moderately to highly permeable
Drainage:	Imperfectly to well-drained
Surface rock:	0%
Horizon:	A1
Depth:	From 0 to 0.1-0.2 m
Texture:	Sandy loam to sandy clay loam (refer to NCST, 2009, pp164-166)
Colour:	Dark brown (may tend reddish or yellowish)
Fabric:	Earthy
Pedality:	Massive
pH:	Range from 4.5 to 5.5
EC:	At least 10 µS/cm
Chloride:	<10 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic

Attribute	Description
Ca:Mg ratio:	>1
Total P:	At least 50 mg/kg
Bicarb Extr. P:	At least 20-40 mg/kg
Total Kjeldahl N:	At least 150-250 mg/kg
Total Organic Carbon:	At least 1.5-2.5%
Sulfur:	<10 mg/kg
Horizon:	A2
Depth:	From 0.1-0.2 to 0.2-0.6 m
Texture:	Loam to clay loam, sandy (refer to NCST, 2009, pp164-166)
Colour:	Brown (may tend reddish or yellowish)
Fabric:	Earthy
Pedality:	Massive
pH:	Range from 5.0 to 6.0
EC:	At least 10 µS/cm
Chloride:	<10 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1
Total P:	At least 50 mg/kg
Bicarb Extr. P:	At least 20-40 mg/kg
Total Kjeldahl N:	At least 150-250 mg/kg
Total Organic Carbon:	At least 1.5-2.5%
Sulfur:	<10 mg/kg
Horizon:	B21
Depth:	From 0.2-0.6 to 0.4-1.0 m
Texture:	Sandy clay loam to light clay (refer to NCST, 2009, pp164-166)
Colour:	Strong brown (may tend red or yellow)
Fabric:	Earthy
Pedality:	Massive to weak
pH:	Range from 5.0 to 6.0
EC:	At least 2 µS/cm
Chloride:	<20 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1
Horizon:	B22
Depth:	From 0.4-1.0 to 0.8-1.6 m
Texture:	Clay loam, sandy to light medium clay (refer to NCST, 2009, pp164-166)
Colour:	Strong brown (may tend dark red or yellow)
Fabric:	Earthy
Pedality:	Massive to moderate
pH:	Range from 5.0 to 6.0
EC:	At least 5 µS/cm
Chloride:	<50 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1

1.3 Identification of Suitable Materials for the Growth Material

Although a Kandosol replication is proposed for the growth material, the soil profile will be classified as an Anthroposol, in accordance with the ASC (Isbell & NCST, 2016). Anthroposols are described under the ASC as soils that result from human activities that have caused a profound modification, mixing, truncation or burial of the original soil horizons, or the creation of new soil parent materials.

The intent of the design is to utilize naturally occurring layers of material that are inherently suitable for specific horizons of the growth material. Where this is not possible to source in the first instance to the maximum volume required, the deficit may be made up by combining appropriate proportions of other naturally occurring layers of material to meet the desired horizon texture specifications.

Geotechnical field logs within the Borrow Areas A and B were referenced to identify the potentially most suitable layers to form the growth material. Laboratory analytical results for selected samples collected from representative test pits were also referenced to further inform the identification of suitable layers. As the geotechnical field logs were based on the Unified Soil Classification System (USCS) for classifying the proportions of clay, silt, sand and gravel present in each pit layer, interpretation of the data was approximated to the Australian field texture classes described in the *Australian Soil and Land Survey Field Handbook* (NCST, 2009) based on clay, silt and sand fractions only and excluding the gravel fraction. These approximate interpretations were supported by the physical laboratory analytical results for the selected samples that were analysed for most of the following agronomical parameters for each sample:

- pH $_{(1:5\ water)}$ and pH $_{(CaCl2)}$
- Electrical conductivity
- Chloride
- Acid neutralizing capacity
- Cation exchange capacity, exchangeable cations and acidity, calcium: magnesium ratio and exchangeable sodium percentage (ESP)
- Emerson aggregate test
- Particle size distribution
- Bicarbonate extractable potassium
- Sulfur
- Silicon
- Boron
- Extractable metals (Cu, Fe, Mn, Zn)
- Trace metals (arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, nickel, selenium, vanadium and zinc)
- Mercury
- Hexavalent chromium
- Cyanide
- Nitrogen (ammonia, nitrite, nitrate, total Kjeldahl and total)

- Phosphorus (total and bicarb. extract.)
- Total carbon, total organic carbon and organic matter
- Carbon: nitrogen ratio.

The chemical laboratory analytical results for the selected samples provided for determining whether there were likely to be any highly unsuitable materials to be avoided as specific layers within the growth material. Generally, it appears through this random selection of samples from a range of test pits that the majority of the soil materials with suitable texture classes will not have unsuitable chemical compositions for creating a Kandosol-equivalent soil. The laboratory analytical results are presented in **Appendix 3**.

Although the soil materials will not likely have unsuitable chemical compositions, this does not mean that they will not be deficient in certain nutrients and minerals to support vegetative growth. Ameliorants will be required, applied either during stockpiling and blending of suitable materials for the specific horizons of the Kandosol-equivalent growth medium or following placement of each horizon of the Kandosol-equivalent soil material.

1.4 Suggested Soil Sources to Create Kandosol-Equivalent (Anthroposol) Growth Material

It appears from this desktop review of geotechnical field logs and laboratory analytical results that there should be sufficient volumes of material of suitable quality to replicate the soil profile of a Kandosol to a depth of 2m over the WFSs.

Appendix 4 presents a table of available horizon volumes from the borrow areas against the required volumes for the growth medium capping based for various depths and slope areas (note, slope areas are still under investigation at the time of reporting as part of SLRs erosion assessment).

The results indicate that for the most part, replication can be achieved be by targeting layers that are considered to match the required physical parameters for each horizon of the growth medium; however, there may need to be some mixing of different materials for make up any deficit, particularly for the surface (A1 and A2) horizons. The calculations of potential available volumes of materials is on the basis of assuming the material available within each layer of each geotechnical bore hole is representative for a nominal area around each geotechnical bore hole. As such there is potential for an inherently large error in these calculations; however, given there appears to be substantially more material available than required overall, the potential error should be offset.

Based on the above characteristics of a Kandosol soil, it is suggested that the most appropriate soil materials listed in **Table 3** be used at the depths specified, or adjacent depth, to create the Kandosol-equivalent (Anthroposol) growth material for the WSFs capping. Note the potential sources are not listed in any priority order for each layer, rather they should be further field assessed on site at the time of excavation as to their actual suitability. Advice is provided on how to undertake this in **Section 1.6**.

The suggested sources are indicative for the Kandosol-equivalent growth material depth. These will need to be modified should a Dermosol-equivalent growth material be developed instead. Actual source and depth of placement should be dictated by increasing proportion of clay with depth based on soil texture classification and commensurate increase in plasticity to no more than medium plasticity, preferably low plasticity at 100-200 cm. This means potential sources could be moved one layer up or down where multiple sources in one layer demonstrate slightly higher or lower clay content and plasticity, where appropriate, such that they can provide the gradual increase in soil texture classification throughout the Kandosol-equivalent growth material. Where possible, gravel content is to be limited to the greatest extent practicable, in particular rocky material regarded as cobbles (60-200 mm) or greater and especially in the surface horizons (A1 and A2).

Table 3 Suggested Soil Sources to Create Kandosol Growth Material

Kandosol Growth Material Layers by Depth from Surface (cm)	Potential Soil Sources			Soil Texture Classification	
	Borrow Area	Site	Source Depth (cm)	Approximate USCS	NCST (2009) (Preferred, Excluding Gravel)
0-20 (A1 horizon) and 20-60 (A2 horizon)	A	NTP-05	0-10	Clayey Silty Sand to Silty Clayey Sand, Non-Plastic	Sandy Loam (SL), Sandy Clay Loam (SCL) to Clay Loam, Sandy (CL,S)
		NTP-07	0-20		
		DPIR-TP-01	0-20		
		DPIR-TP-03	0-20		
		DPIR-TP-04	0-20		
		DPIR-TP-06	0-10		
		DPIR-TP-06	350-480		
		GHD TP-01	0-15		
		GHD TP-01_B	0-10		
		GHD TP-02_B	0-10		
		GHD TP-04	0-10		
		GHD TP-05	0-5		
		GHD TP-05_B	0-5		
		GHD TP-06	0-10		
		GHD TP-07	0-10		
		GHD TP-08	0-10		
		GHD TP-09	0-20		
		GHD TP-16	0-15		
		GHD TP-17	0-10		
		GHD TP-18	0-10		
		GHD TP-19	0-10		
		GHD TP-20	0-20		
	B	SLR-TP-05	0-20		
		SLR-TP-06	0-20		
60-120 (B21 horizon)	A	NTP-01	0-20	Clayey Sandy Silt to Sandy Clayey Silt, Very Low to Low Plasticity	Clay Loam, Sandy (CL,S) to Sandy Light Clay (SLC)
		NTP-02	0-20		
		NTP-06	280-310		
		DPIR-TP-01	20-40		
		DPIR-TP-01	200-400		
		DPIR-TP-02	20-60		
		DPIR-TP-04	20-210		
		DPIR-TP-04	420-500		
		DPIR-TP-05	250-450		
		DPIR-TP-06	10-350		
		GHD TP-01	15-95		
		GHD TP-01	95-210		
		GHD TP-01_B	10-220		
		GHD TP-02	120-220		

Kandosol Growth Material Layers by Depth from Surface (cm)	Potential Soil Sources			Soil Texture Classification	
	Borrow Area	Site	Source Depth (cm)	Approximate USCS	NCST (2009) (Preferred, Excluding Gravel)
		GHD TP-02_B	10-200		
		GHD TP-02_B	340-440		
		GHD TP-04	10-230		
		GHD TP-05	5-60		
		GHD TP-05	60-190		
		GHD TP-06	10-210		
		GHD TP-07	10-250		
		GHD TP-08	10-280		
		GHD TP-09	20-260		
		GHD TP-16	15-210		
		GHD TP-17	10-155		
		GHD TP-18	10-170		
		GHD TP-19	10-220		
		GHD TP-20	20-40		
	B	SLR-TP-01	60-430		
		SLR-TP-02	60-200		
		SLR-TP-03	60-330		
		SLR-TP-05	20-160		
		SLR-TP-07	80-290		
120-200 (B22 horizon)	A	NTP-05	10-100	Silty Sandy Clay to Sandy Silty Clay, Low to Medium Plasticity	Sandy Light Clay (SLC) to Sandy Light Medium Clay (SLMC)
		NTP-06	310-400		
		NTP-07	80-100		
		DPIR-TP-01	40-200		
		DPIR-TP-02	60-500		
		DPIR-TP-03	20-310		
		GHD TP-01_B	220-480		
		GHD TP-02_B	200-340		
		GHD TP-06	210-250		
		GHD TP-06_B	140-170		
		GHD TP-15	200-220		
		GHD TP-16	210-250		
		GHD TP-17	155-190		
		GHD TP-18	170-250		
		GHD TP-19	220-280		
		GHD TP-20	40-280		

1.5 Stockpile Establishment

It is suggested that suitably sized stockpile areas be designated for each of the horizon categories. Each stockpile area is to be clearly designated and separated from the other stockpile areas. The preference is for the stockpiles to be established in the following way to prevent cross-contamination of stockpiles where excellent quality materials have been sourced for upper layers and lesser quality materials for lower layers:

- 0-20 cm (SL to SCL texture – A1 horizon) soil material placed at the highest location in the general landscape

- 20-60 cm (SCL to CL, S texture – A2 horizon) soil material placed either downslope of the A1 horizon (0-20 cm) stockpile or adjacent to the A1 horizon stockpile where the A2 horizon stockpile will not impact on the A1 horizon stockpile because both will drain immediately downslope away from each other
- 60-120 cm (CL, S to SLC texture – B21 horizon) soil material placed downslope of the A2 horizon (20-60 cm) stockpile or adjacent to the A2 horizon stockpile where the B21 horizon stockpile will not impact on the A1 or A2 horizon stockpiles because all three will drain immediately downslope away from each other
- 120-200 cm (SLC to SLMC texture – B22 horizon) soil material placed at the lowest location in the general landscape or adjacent to the B21 horizon stockpile where the B22 horizon stockpile will not impact on the A1, A2 or B21 horizon stockpiles because all four will drain immediately downslope away from each other.

1.6 Field Selection of Appropriate Horizon Materials

In the first instance, material with minimal gravel content is to be selected for all horizons, although this is most important for the A1 and A2 horizons and progressively less important for the B21 and then the B22 horizons. In all instances, where there is gravel, it is not to be associated with poorly developed soil material that is more consistent with weathered parent material (i.e. B/C or C horizons) rather than recognisably developed B horizon material.

Prior to each layer of the natural soil profiles being excavated, their pH and electrical conductivity (EC) be tested using a field pH/electrical conductivity kit/meter and soil field texture be confirmed, without the coarse fragments (gravel (>2 mm)), to more effectively grade them in accordance with the *Australian Soil and Land Survey Field Handbook* (NCST, 2009). Reference is to be made to the pH and EC ranges provided in **Table 2** and Recommended Scale (top scale on page 162), figure 16 on page 163 and the field texture grades on page 164-166 of the *Australian Soil and Land Survey Field Handbook* (NCST, 2009), to confirm each layer's suitability in accordance with the soil texture classifications in column 5 of **Table 3**.

For the 0-20 (sandy loam to sandy clay loam texture – A1 horizon) and 20-60 (sandy clay loam to clay loam, sandy texture – A2 horizon) soil materials, preference is to be given to sources at or close to the soil surface. This is to include existing humus, leaf, twig and bark, microbial and seed material to the greatest extent practicable thereby retaining some biologically active organic content in the surface materials. This will likely improve the potential for rapid successful regeneration of vegetation/ pasture and lowering the risk of failure.

Additionally, for the 60-120 (clay loam, sandy to sandy light clay – B21 horizon) and 120-200 (sandy light clay to light medium clay – B22 horizon) soil materials, preference is to be given to sources between the surface and 2 m, where practicable, to minimise the likelihood of unfavourable physical and chemical properties, including gleyed colouring.

The suitably classified and appropriately selected materials can then be excavated and transported to the applicable horizon category stockpile area.

All excavations of materials should be supervised by an appropriately qualified and experienced soil scientist alongside the site geotechnical engineer to ensure greatest possible success with identifying and confirming suitable soil layer materials and ensuring grading and stockpiling are performed as required. All growth material works should be governed by a detailed Planning Construction Soil (Growth Material) Management Plan for the construction and revegetation establishment phases. An overview of growth material management practices is provided in **Section 1.7**.

1.7 Overview of Growth Material Management Practices

1.7.1 Stockpile Management

1.7.1.1 Hydroseeding of Growth Material Stockpiles

Where soil material for any growth material horizon is to be stockpiled for >3 months and/or there is a high likelihood of rain, the stockpile should be hydroseeded with a suitable seed mix (e.g. Japanese millet, annual couch and/or annual and/or perennial native grasses) and watered as needed to ensure vigorous and lush growth. This will form a protective layer of vegetation as soon as possible to prevent any immediate possibility of erosion and loss of this material. Depending on the storage period for the stockpile, the perennial native species will progressively replace the annual species thereby ensuring continued protection of the stockpile surface from erosion. All grasses will also enhance any inherent chemical and biological properties by mulching down and being incorporated into the growth medium by microbes in preparation for final placement. Should the grasses also reach maturity and successfully set seed, they will start to establish a seed bank in preparation for continued protection of the stockpile or establishing a vegetative cover on the WSFs.

1.7.1.2 Weed Control on Growth Material Stockpiles

Weeds have the potential to interfere with successful revegetation of the growth material once placed on the WSF capping material. Where weeds are identified on the stockpiles, they are to be prevented from flowering by appropriate control methods for the weed species identified and to minimise any effects on the hydroseeded grass species. This may mean sufficiently regular inspections and treatment at a rate commensurate with the shortest growth cycle weed species present, ego potentially weekly. Where weeds are not adequately controlled and establish seed banks from successfully flowering and seeding, the stockpiled soil material may have to be scalped to remove the weed seed bank and this material disposed of, potentially wasting a limited resource required for the success of growth material and revegetation establishment on the WSF capping.

1.7.1.3 Inspections and Monitoring of Growth Material Stockpiles

Regular inspections should be made of all the growth material stockpiles to monitor the stockpiles for erosion effects from wind or water, vegetative coverage to ensure it is more than adequate, and weed infestations, and to ensure they are being controlled and prevented from flowering.

Inspections should be immediately following rainfall events, where possible, and at regular intervals sufficient to ensure any erosion is addressed as soon as possible, hydroseeded grass species are establishing and maintaining a high foliage cover, and the fastest growing and maturing weed species are unable to flower and seed between inspections and/or treatments.

1.7.1.4 SL to SCL Texture (0-20 cm) A1 Horizon Soil Material

The A1 horizon (0-20 cm (SL to SCL texture)) soil material is to be stockpiled no greater than 2 m high with batters no steeper than the material's natural dry angle of repose without vegetation. This is to preserve any inherent organic content and, where stored for >3 month, ensure maximum surface area for hydroseeding to generate as much additional organic material for incorporation ahead of final placement whilst providing for the most stable form to minimise erosion potential. Final placement of this material will be on top of the A2 horizon (20-60 cm) Kandosol-equivalent growth material as a topsoil (A1 horizon).

1.7.1.5 SCL to CL, S (20-60 cm) A2 Horizon Soil Material

The 20-60 cm (SCL to CL, S texture) soil material is to be stockpiled no greater than 2 m high with batters no steeper than the material's natural dry angle of repose without vegetation. This is to preserve any inherent organic content and, where stored for >3 month, ensure maximum surface area for hydroseeding to generate as much additional organic material for incorporation ahead of final placement whilst providing for the most stable form to minimise erosion potential. Final placement of this material will be on top of the B21 horizon (60 -120 cm) Kandosol-equivalent growth material as a sub-topsoil (A2 horizon).

1.7.1.6 CL, S to SLC (60-120 cm) B21 Horizon Soil Material

The B21 horizon (60-120 cm (CL, S to SLC texture)) soil material can be stockpiled up to 3 m high with batters no steeper than the material's natural dry angle of repose without vegetation. Final placement of this material will be on top of the B22 horizon (120-200 cm) Kandosol-equivalent growth material as the upper subsoil (B21 horizon).

1.7.1.7 SLC to SLMC (120-200 cm) B22 Horizon Soil Material

The B22 horizon (120-200 cm (SLC to SLMC texture)) soil material can be stockpiled up to 3 m high with batters no steeper than the material's natural dry angle of repose without vegetation. Final placement of this material will be on top of the clay capping as the lower subsoil (B22 horizon).

1.7.2 Growth Material Mixing and Sampling Prior to Placement and Revegetation

Excavation and placement of the respective materials at each stockpile location should ensure maximum mixing without excessive overworking of the soil materials, which would degrade the soil structure, where there is reasonable structure. This is to ensure adequate mixing of the materials for each horizon of the Kandosol-equivalent soil ahead of spreading over the clay capping on the WSFs.

As sufficient volume for each stockpile is being approached or use of the material is impending as capping progresses, a representative number of samples are to be collected, bulked and submitted to a laboratory that is NATA-accredited for undertaking most of the analyses required to understand the physical and chemical properties of the respective horizon material.

For sampling of the topsoil stockpiles, samples are not to be taken directly from the surface as this will give a skewed interpretation of the quality of the topsoil, given it may have a cover crop incorporating organic material into it. The surface material represents a small fraction of the overall stockpile so will largely disappear once mixed, so a sample should be taken >200 mm beneath the surface, preferably quite deep as this will be most representative. Also, should the protective cover crop have been poorly managed and is full of weeds, the surface layer of the topsoil stockpile may have to be scalped and discarded to get rid of the weed seed bank, so samples should not to be collected from the surface.

A sufficient number of samples are to be collected from around each stockpile and then bulked together. Each stockpile should have its own bulked sample to be analysed. The number should be representative of the size of the stockpile, i.e. for small stockpiles only 3-4 samples may be required, however, for large to really large stockpiles, anywhere from 6-10 or more samples will be required and bulked together.

1.7.3 Growth Material Testing and Treatment Prior to Placement and Revegetation

Following sampling, bulking and submission of samples for each growth material horizon stockpile, the bulked samples are to be analysed for the parameters outlined in **Table 4**Error! Reference source not found..

Table 4 Laboratory Testing of Growth Material Layers Following Placement

Parameter	Layers			
	0-20 cm (SL-SCL) (A1 horizon)	20-60 cm (SCL-CL, S) (A2 horizon)	60-120 cm (CL, S-SLC) (B21 horizon)	120-200 cm (SLC-SLMC) (B22 horizon)
pH (1:5 water) and pH (CaCl2)	✓	✓	✓	✓
Electrical conductivity	✓	✓	✓	✓
Chloride	✓	✓	✓	✓
Acid neutralizing capacity	✓	✓	✓	✓
Cation exchange capacity, exchangeable cations and acidity, calcium: magnesium ratio and exchangeable sodium percentage (ESP)	✓	✓	✓	✓
Particle size distribution (by sieve and hydrometer) for the following fractions: clay (<2 µm), silt (0.002 (2 µm)-0.02 mm), fine sand (0.02-0.2 mm), coarse sand (0.2-2 mm) and gravel (>2 mm)	✓	✓	✓	✓
Emerson aggregate test	✓	✓	✓	✓
Bicarbonate extractable potassium	✓	✓		
Sulfur	✓	✓		
Boron	✓	✓		
Extractable metals (Cu, Fe, Mn, Zn)	✓	✓		
Nitrogen (ammonia, nitrite, nitrate, total Kjeldahl and total)	✓	✓		
Phosphorus (total and bicarb. extract.)	✓	✓		
Total carbon, total organic carbon and organic matter	✓	✓		
Carbon: nitrogen ratio	✓	✓		

Following analysis for each layer, the results are to be used to determine whether any specific physical, chemical and/or biological treatments are required to ensure the growth material meets the indicative growth material success criteria (refer to **Section 1.7.4**).

The results of the particle size distribution analysis on the bulked samples are to be categorised according to the recommended scale in NCST (2009), page 162. The scale is to be grouped as follows, disregarding the gravel fraction post analysis (except that the gravel content should not dominate the other fractions), to confirm the texture, in accordance with NCST (2009), figure 16, page 163 and the field texture grades on pages 164-166:

- Clay: <2 µm
- Silt: 0.002 (2 µm)-0.02 mm
- Fine sand: 0.02-0.2 mm
- Coarse sand: 0.2-2 mm.

This will confirm the stockpiled soil material has a suitable texture for the Kandosol-equivalent growth material horizon that the respective stockpile is designated for.

Where the above particle size distribution does not meet the texture specifications for the particular Kandosol-equivalent horizon, additional soil material of the appropriate particle size(s) is to be sourced in sufficient volume to make up the desired texture. On completion of adding and mixing the additional material, the stockpile is to be re-tested for particle size distribution to confirm it meets the texture specification. This process is to be repeated until the texture specification is met for all stockpiles.

Where particular stockpiles of materials do not quite meet the physical, chemical and/or biological specifications (refer to **Section 1.7.4**)Error! Reference source not found., a range of ameliorants may be considered, including, but not limited to:

- Gypsum – to maintain existing pH, increase cation exchange capacity, increase calcium to magnesium ratio, reduce sodicity, improve soil structure
- Lime – to raise pH, increase cation exchange capacity, increase calcium to magnesium ratio, reduce sodicity, improve soil structure
- Humus – to increase organic matter content, improve structure, increase nutrient content, improve water holding capacity
- Fertiliser – to increase nutrient content
- Liquid sulfur – to lower soil pH, increase sulfur availability, increase nitrogen utilisation.

These ameliorants are to be applied to the respective stockpile prior to placement of the growth material onto the growth material area and spread to further mix the combined source materials for that horizon and incorporate the ameliorants.

1.7.4 Establishment Phase Growth Material Monitoring

The growth material should be monitored bi-annually for the revegetation establishment phase. Monitoring should be towards the end of the dry season and at the end of the wet season to compare soil physical and chemical changes that result from annual and seasonal climate variations and on-going revegetation management practices.

Monitoring should include full soil profile (down to the clay capping but not into the clay capping) description and sampling using a hand auger or push tube at all revegetation monitoring sites with laboratory analysis for comparison against growth material design and success criteria, previous growth medium soil profile monitoring results, and revegetation monitoring data.

Indicative growth material design and success criteria are provided in **Table 5**. Where adjustments are made to the growth material design due to availability of materials, e.g. depths of horizons or growth material more in line with a Dermosol texture profile, etc, these design and success criteria will need to be adjusted accordingly.

Table 5 Growth Material Design and Success Criteria

Attribute	Description
Slope:	Consistent with final design gradients
Runoff:	Very slow to moderately rapid (refer to NCST, 2009, pp144-145)
Permeability:	Slowly to moderately permeable (refer to NCST, 2009, pp200-202)
Drainage:	Moderately to well-drained (refer to NCST, 2009, pp202-204)
Surface rock:	<1%
Horizon:	A1
Depth:	From 0 to 0.2 m
Texture:	Sandy loam to sandy clay loam (refer to NCST, 2009, pp164-166)
Colour:	Dark brown (may tend reddish or yellowish) (refer to Munsell colour charts)
Fabric:	Earthy (refer to NCST, 2009, pp181-182)
Pedality:	Massive (refer to NCST, 2009, pp171-180)
pH $_{(1:5\ soil:water)}$:	Range from 4.5 to 5.5
EC:	At least 10 µS/cm
Salinity:	Very low to low
Chloride:	<10 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1
Total P:	At least 50 mg/kg
Bicarb Extr. P:	At least moderate (>20-40 mg/kg)
Total Kjeldahl N:	At least moderate (>150-250 mg/kg)
Total Organic Carbon:	At least moderate (>1.5-2.5%)
Sulfur:	<10 mg/kg
Horizon:	A2
Depth:	From 0.2 to 0.6 m
Texture:	Sandy clay loam to clay loam, sandy (refer to NCST, 2009, pp164-166)
Colour:	Brown (may tend reddish or yellowish) (refer to Munsell colour charts)
Fabric:	Earthy (refer to NCST, 2009, pp181-182)
Pedality:	Massive (refer to NCST, 2009, pp171-180)
pH:	Range from 5.0 to 6.0
EC:	At least 10 µS/cm
Salinity:	Low to medium
Chloride:	<10 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1
Total P:	At least 50 mg/kg
Bicarb Extr. P:	At least moderate (>20-40 mg/kg)
Total Kjeldahl N:	At least moderate (>150-250 mg/kg)
Total Organic Carbon:	At least moderate (>1.5-2.5%)

Attribute	Description
Sulfur:	<10 mg/kg
Horizon:	B21
Depth:	From 0.6 to 1.2 m
Texture:	Clay loam, sandy, to light clay (refer to NCST, 2009, pp164-166)
Colour:	Strong brown (may tend red or yellow) (refer to Munsell colour charts)
Fabric:	Earthy (refer to NCST, 2009, pp181-182)
Pedality:	Massive to weak (refer to NCST, 2009, pp171-180)
pH:	Range from 5.0 to 6.0
EC:	At least 2 µS/cm
Salinity:	Low to high
Chloride:	<20 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1
Horizon:	B22
Depth:	From 1.2 to 2.0 m
Texture:	Sandy light clay to sandy light medium clay (refer to NCST, 2009, pp164-166)
Colour:	Strong brown (may tend dark red or yellow) (refer to Munsell colour charts)
Fabric:	Earthy (refer to NCST, 2009, pp181-182)
Pedality:	Massive to moderate (refer to NCST, 2009, pp171-180)
pH:	Range from 5.0 to 6.0
EC:	At least 5 µS/cm
Salinity:	Low to high
Chloride:	<50 mg/kg
CEC:	At least 5.0 cmol+/kg
Exch. Sodium % (ESP):	Non-sodic
Ca:Mg ratio:	>1

1.7.5 Post-Establishment Phase Growth Material Monitoring

The growth material should continue to be monitored bi-annually biennially for the next 10 years, post-establishment phase, and thereafter biannually every 5 years. Monitoring should be towards the end of the dry season and at the end of the wet season to compare soil physical and chemical changes that result from annual and seasonal climate variations and on-going vegetation management practices.

Monitoring should include full soil profile (down to the clay capping but not into the clay capping) description and sampling using a hand auger or push tube at all revegetation monitoring sites with laboratory analysis for comparison against growth material design and success criteria, previous growth medium soil profile monitoring results, and revegetation monitoring data.

Indicative growth material design and success criteria are provided in **Table 5**. Where adjustments are made to the growth material design due to availability of materials, e.g. depths of horizons or growth material more in line with a Dermosol texture profile, etc, these design and success criteria will need to be adjusted accordingly.

2 Conclusion/Summary

The ideal growth material for the WSF would be a soil profile similar to the Kandosols that naturally occur and are dominant throughout the surrounding landscape. The preferred Kandosol growth medium would consist of the following soil horizons (layers) at these preferred depths, although these may be varied to accommodate the volumes of available materials:

- 0-20 cm (SL to SCL texture – A1 horizon)
- 20-60 cm (SCL to CL,S texture – A2 horizon)
- 60-120 cm (CL,S to SLC texture – B21 horizon)
- 120-200 cm (SLC to SLMC texture – B22 horizon).

The quantity of available soil materials from the available borrow areas appears to not provide sufficient material of the exact textures required for the A1 and A2 horizons of the Kandosol. There appears, however, to be sufficient separate materials to be able to manufacture sufficient volumes of soil materials to create the desired A1 and A2 textures.

The quantity of available soil materials from the available borrow areas appears to provide well and truly sufficient material for the B21 and B22 horizons.

The quality of the soil materials available from the borrow areas appears, in the main, to be suitable for the Kandosol soil profile. There were limited instances of unsuitable materials displaying very strongly acidic, marginally sodic, etc chemical properties; however, should these materials be harvested the dilution factor with the significantly larger volumes of good material would likely nullify their effects and/or they could be treated with small volumes of readily available ameliorants, such as lime and gypsum.

Should it not be practicable to construct the Kandosol growth medium from the available materials, the alternative would be a Dermosol soil. A Dermosol soil has slightly more clay than a Kandosol, particularly in the surface horizons making it more uniformly clay rather than distinctly graduated. The preferred Dermosol growth medium would consist of the following soil horizons (layers) at these preferred depths, although these may be varied to accommodate the volumes of available materials:

- 0-20 cm (SCL to CL, S texture – A1 horizon)
- 20-60 cm (CL,S to SLC texture – A2 to B21 horizon)
- 60-120 cm (SLC to SLMC texture – B21 to B22 horizon)
- 120-200 cm (SLMC to SMC texture – B22 to B23 horizon).

The quantity of available soil materials from the available borrow areas appears likely to provide sufficient material for all horizons of the Dermosol, although some mixing may be required to create additional material sufficient for the upper horizons.

Similar to the Kandosol, the quality of the soil materials available from the borrow areas appears, in the main, to be suitable given the likely dilution factor with the significantly larger volumes of good material nullifying the effects of the poor materials and/or they could be treated with small volumes of readily available ameliorants, such as lime and gypsum.

For either the Kandosol or Dermosol growth material profile, field and laboratory testing at the time of harvesting (during construction) by suitably qualified field and laboratory soil scientists would be sufficient to identify appropriate materials for stockpiling and amelioration ahead of placement on the WSF. A detailed Planning Construction Soil (Growth Material) Management Plan would be advisable to provide detailed instruction to the construction contractor at the time of tendering.

3 References

Lynch, B 2010, "*Land Systems of the Northern Part of the Northern Territory, 1:250,000*", Natural Resources Division, Department of Natural Resources, Environment, the Arts and Sport, Northern Territory.

NCST 2009, "*Australian Soil and Land Survey Field Handbook*", 3rd Ed, CSIRO Publishing, Collingwood, VIC.

Wood, BG 1976, "*A Report on the Land Units on and Surrounding Mr. E. Kerle's Property Near Batchelor*", Department of the Northern Territory, Forestry, Fisheries & Land Conservation Branch, Land Conservation Section, Darwin, NT.

Wood, BG and Day, KJ 1976, "*Report of the Land Units of the Batchelor Township Area*", Department of the Northern Territory, Forestry, Fisheries & Land Conservation Branch, Land Conservation Section, Darwin, NT.

APPENDIX 1

SALI Database Soil Profile Descriptions

Attribute	Description	Description	Description	Description	Description
Location:	E: -1256142.596, N: 8502275.983	E: -1256627.943, N: 8502454.046	E: -1252685.820, N: 8503684.654	E: -1258391.038, N: 8509097.332	E: -1258542.266, N: 8502176.567
Survey:	Gamba Grass Carbon Project, Batchelor, Charles Darwin University	Gamba Grass Carbon Project, Batchelor, Charles Darwin University	Report on the Land Units of the Batchelor Township Area	A Report on the Land Units on and surrounding Mr. E. Kerle's Property near Batchelor	A Report on the Land Units on and surrounding Mr. E. Kerle's Property near Batchelor
Survey Code:	BATCH14	BATCH14	BATCH25	EKERL10	EKERL10
Site No.:	2	1	4	20	26
Date Described:	25-Nov-2014	25-Nov-2014	14-Sep-1976	19-Sep-1976	20-Sep-1976
Date Entered into Database:	04-Dec-2014	04-Dec-2014	07-Jul-2005	06-Jul-2005	08-Jul-2005
Accuracy:	Accuracy estimated to be within a radius of 0-30 metres	Accuracy estimated to be within a radius of 0-30 metres	Accuracy estimated to be within a radius of 30-100 metres	Accuracy estimated to be within a radius of 30-100 metres	Accuracy estimated to be within a radius of 30-100 metres
Landform Element:	Plain	Plain	Plain	Not Described	Not Described
Landform Pattern:	Plain	Plain	Not Described	Not Described	Not Described
Land System:	Woodcutter (Wdc)	Woodcutter (Wdc)	Woodcutter (Wdc)	Woodcutter (Wdc)	Woodcutter (Wdc)
Slope:	0.5%	0.5%	-	-	-
Drainage:	Well drained	Imperfectly drained	Well drained	Well drained	Imperfectly drained
Permeability:	Highly permeable	Moderately permeable	Highly permeable	Moderately permeable	Slowly permeable
Runoff:	Slow	Slow	Very slow	Not Described	Rapid
Surface rock:	0%	0%	0%	0%	
ASC:	Kandosol	Kandosol	Kandosol	Kandosol	Kandosol
Substrate:	Not Described	Not Described	Not Described	Not Described	Quartz
Horizon:	A1	A1	A1	A1	A11
Depth:	0 - 0.12 m	0 - 0.07 m	0 - 0.1 m	0 - 0.1m	0 - 0.1 m
Texture:	Sandy loam	Sandy clay loam	Sandy loam	Sandy loam	Loam
Colour:	Dark reddish brown	Dark brown	Dark brown	Dark reddish brown	Very dark greyish brown
Fabric:	Sandy (grains prominent)	Earthy	Earthy	Earthy	Earthy
Pedality:	Massive	Massive	Massive	Massive	Massive
pH:	4.9	4.5	5.5	6	6
Horizon:	A3	A2	A2	B1	A12
Depth:	0.12 - 0.3 m	0.07 - 0.2 m	0.1 - 0.4 m	0.1 - 0.6 m	0.1 - 0.2 m
Texture:	Sandy loam	Clay loam, sandy	Sandy clay loam	Sandy clay loam	Loam
Colour:	Reddish brown	Brown	Dark yellowish brown	Dark red	Very dark greyish brown
Fabric:	Sandy (grains prominent)	Earthy	Earthy	Earthy	Earthy
Pedality:	Massive	Massive	Massive	Massive	Massive
pH:	5.1	4.9	5.8	6	6
Horizon:	B21	B1	B21	B21	A2
Depth:	0.3 - 0.4 m	0.2 - 0.8 m	0.4 - 0.8 m	0.6 – 1 m	0.2 - 0.4 m
Texture:	Sandy clay loam	Clay loam, sandy	Sandy clay loam	Clay loam	Sandy loam
Colour:	Red	Yellowish red	Strong brown	Dark red	Dark yellowish brown
Fabric:	Sandy (grains prominent)	Earthy	Earthy	Earthy	Earthy
Pedality:	Massive	Massive	Massive	Massive	Massive
pH:	5	5.2	6	5.5	5.8
Horizon:	B22	B21	B22c	B22	B1
Depth:	0.4 - 0.7 m	0.8 - 1.25 m	0.8 - 1.5 m	1 - 1.6 m	0.4 - 0.6 m
Texture:	Sandy clay loam	Light medium clay	Light clay	Clay loam	Sandy clay loam
Colour:	Dark red	Red	Yellowish red	Dark red	Strong brown
Fabric:	Sandy (grains prominent)	Earthy	Earthy	Earthy	Earthy
Pedality:	Massive	Moderate	Massive	Massive	Massive
pH:	5.4	5.1	5.8	5.5	6
Horizon:	B23	B22	-	-	B2
Depth:	0.7 - 0.9 m	1.25 - 1.4 m	-	-	0.6 - 0.9 m
Texture:	Sandy clay loam	Light clay	-	-	Clay loam

Attribute	Description	Description	Description	Description	Description
Colour:	Dark red	Red	-	-	Yellowish red
Fabric:	Sandy (grains prominent)	Earthy	-	-	Earthy
Pedality:	Massive	Moderate	-	-	Massive
pH:	5	5.4	-	-	5.5

APPENDIX 2

Historical Laboratory Data for SALI Database Kandosols Described in Appendix 1

Source: Wood and Day (1976)

Depth (cm)	pH (1:5)	C.E.C. m.eq. %	E.C. µmhos cm⁻¹	T.S.S. %	Total % P	Total % K	Total % S	Phos. Ext. S(ppm)	Org. N %	Org. C %	Bicarb. P	Bicarb. K	Exch. Cations m.eq. % Ca	Mg	Na	K	D.T.P.A. Cu	D.T.P.A. Zn	Total Cu	Total Zn
SANDY RED EARTH																				
0- 10	5.8	6.2	15.8	.006	.015	.10	.0072	.2	.058	2.01	-	35	0.9	1.2	.2	.1	6.2	0.5	23	12
10- 35	5.9	5.0	9.6	.004	.015	.10	.0165	.1	.034	0.75	-	10	0.2	1.3	.1	.1	5.0	0.4	33	13
35-150	5.8	5.0	5.1	.002	.018	.10	.0043	.1	-	-	-	-	0.1	2.0	.1	.1	5.0	0.1	27	21
LOAMY RED EARTH																				
0- 15	6.2	8.0	27.8	.015	.02	.27	.023	.22	.07	1.27	1.2	85	1.9	1.8	.15	.22	1.8	.7	41	27
15- 50	5.8	6.2	9.4	.004	.018	.30	.014	.8	-	-	-	47	0.2	2.1	.15	.15	.35	.5	60	30
50-150	5.6	5.1	5.9	.002	.017	.37	.01	.6	-	-	4.5	30	0.1	2.5	.2	.1	.15	.6	87	30

APPENDIX 3

Laboratory Results on Representative Test Pit Samples

				pH (1:5 water)		pH (CaCl2)		Acid Neutralising Capacity			ExchangeAcidity		Exchangeable Cations (cmol/kg)				Cation Exchange Capacity (cmol/kg)		ESP		Ca/Mg Ratio		Mg/K Ratio	
Area	**Site**	**Depth**	**Texture**	Value	Rating	Value	Rating	H2SO4	CaCO3	Fizz Rating	Exg. Acidity	Exg. Aluminium	Ca	Mg	K	Na	Value	Rating	Value	Rating	Value	Rating	Value	Rating
STP	**5**	0-50	Silty Gravelly Sand	5.0	Very Strongly Acidic	4.4	Very Strongly Acidic	<0.5	<0.1	0	1	0.8	<0.1	0.5	0.1	<0.1	1.8	Very Low	1.9	Non sodic	<0.1	Mg deficient	14.6	-
STP	**7**	0-50	Sand	5.5	Strongly Acidic	4.5	Very Strongly Acidic	2.4	0.2	0	0.6	0.5	<0.1	0.2	<0.1	<0.1	1.0	Very Low	6.7	Marginally Sodic	<0.1	Mg deficient	-	-
WRTP	**2**	0-50	Gravelly Clay	4.8	Very Strongly Acidic	4.3	Very Strongly Acidic	4.8	0.5	0	1.2	1	1.3	2.7	<0.1	<0.1	5.4	Very Low	0.4	Non sodic	0.5	Ca deficient	-	-
WRTP	**15**	10-20	Sandy Gravel	6.2	Slightly Acidic	5.2	Strongly Acidic	3.6	0.4	0	-	-	0.5	2.6	<0.1	<0.1	3.2	Very Low	0.7	Non sodic	0.2	Ca deficient	-	-
WRTP	**12**	40-50	Clayey Gravel	6.0	Moderately Acidic	5.2	Strongly Acidic	1.9	0.2	0	0.5	<0.1	0.8	0.3	<0.1	<0.1	1.7	Very Low	1.2	Non sodic	2.7	Ca low	-	-
WRTP	**14**	40-60	Clayey Sand	6.0	Moderately Acidic	5.4	Strongly Acidic	3.5	0.4	0	<0.1	<0.1	3.0	0.8	<0.1	<0.1	3.8	Very Low	0.6	Non sodic	3.8	Ca low	-	-
STP	**3**	40-60	Gravelly Sand	5.3	Strongly Acidic	4.3	Very Strongly Acidic	2.1	0.2	0	0.7	0.6	<0.1	0.2	<0.1	<0.1	1.1	Very Low	4.8	Non sodic	<0.1	Mg deficient	-	-
STP	**5**	50-60	Clayey Sand	5.5	Strongly Acidic	4.5	Very Strongly Acidic	3.1	0.3	0	0.6	0.5	<0.1	2.2	0.1	<0.1	3.1	Very Low	1.3	Non sodic	<0.1	Mg deficient	5	-
NTP	**1**	60-80	Sandy Clay	6.7	Neutral	6.0	Moderately Acidic	2.6	0.3	0	<0.1	<0.1	2.3	1.0	0.2	<0.1	3.6	Very Low	0.3	Non sodic	2.3	Ca low	4.8	-
STP	**6**	70-90	Gravelly Sand	5.8	Moderately Acidic	5.3	Strongly Acidic	2.2	0.2	0	<0.1	0.1	<0.1	0.8	<0.1	<0.1	1.0	Very Low	3.3	Non sodic	<0.1	Mg deficient	-	-
WRTP	**4**	80-100	Clayey Gravel	6.3	Slightly Acidic	6.0	Moderately Acidic	0.9	<0.1	0	<0.1	0.1	0.6	0.1	<0.1	<0.1	0.8	Very Low	0.1	Non sodic	6.0	Balanced	-	-
STP	**7**	90-100	Clayey Sand	5.4	Strongly Acidic	4.4	Very Strongly Acidic	0.6	<0.1	0	0.9	0.8	<0.1	0.8	<0.1	<0.1	2.0	Very Low	4.3	Non sodic	<0.1	Mg deficient	-	-
NTP	**5**	150-170	Clayey Gravel	6.2	Slightly Acidic	5.9	Moderately Acidic	4.4	0.4	0	-	-	1.2	2.6	<0.1	<0.1	3.8	Very Low	0.5	Non sodic	0.5	Ca deficient	-	-
NTP	**7**	380-400	Silty Sandy Clay	7.4	Mildly Alkaline	6.7	Neutral	7.6	0.8	0	-	-	7.3	30.2	0.2	0.2	37.9	High	0.5	Non sodic	0.2	Ca deficient	171	-
NTP	**1**	530-540	Silty Clay	6.3	Slightly Acidic	5.4	Strongly Acidic	7.6	0.8	0	-	-	7.8	8.6	0.2	<0.1	16.6	Moderate	0.2	Non sodic	0.9	Ca deficient	41.7	-

				EC (1:5, µS/cm)		Chloride (mg/kg)	Sulfur (mg/kg)	Bicarbonate Exactable K (mg/kg)	Silicon (mg/kg)	Boron (mg/kg)	Extractable Metals				Total Metals (mg/kg)														Mercury (mg/kg)	Hexavalent Chromium (mg/kg)	Total Cyanide (mg/kg)
Area	**Site**	**Depth**	**Texture**	Value	Rating	Value	Value	Value	Value	Value	Cu	Fe	Mn	Zn	As	Ba	Be	B	Cd	Cr	Co	Cu	Pb	Mn	Ni	Se	V	Zn	Value	Value	Value
STP	**5**	0-50	Silty Gravelly Sand	5.0	-	<10	<10	137	5	<0.2	<1.00	2.25	<1.00	<1.00	<5	10	<1	<50	<1	<2	<2	<5	5	7	<2	<5	9	<5	<0.1	<0.5	<1
STP	**7**	0-50	Sand	1.0	-	<10	10	<100	10	<0.2	<1.00	5.55	<1.00	<1.00	<5	<10	<1	<50	<1	<2	<2	<5	<5	<5	<2	<5	<5	<5	<0.1	<0.5	<1
WRTP	**2**	0-50	Gravelly Clay	38.0	-	<10	923	102	7	<0.2	22.2	53.3	3.46	<1.00	12	20	<1	<50	<1	32	7	307	62	41	12	<5	64	14	0.1	<0.5	<1
WRTP	**15**	10-20	Sandy Gravel	3.0	-	<10	33	<100	7	<0.2	<1.00	18.9	5.54	<1.00	5	30	1	<50	<1	102	6	<5	9	94	9	<5	121	<5	<0.1	<0.5	<1
WRTP	**12**	40-50	Clayey Gravel	2.0	-	<10	11	<100	8	<0.2	<1.00	7.58	<1.00	<1.00	8	<10	<1	<50	<1	14	<2	<5	<5	52	<2	<5	40	<5	<0.1	<0.5	<1
WRTP	**14**	40-60	Clayey Sand	5.0	-	<10	39	<100	22	<0.2	<1.00	15	18.4	<1.00	<5	40	<1	<50	<1	33	4	8	6	341	5	<5	65	<5	<0.1	<0.5	<1
STP	**3**	40-60	Gravelly Sand	2.0	-	<10	<10	102	10	<0.2	<1.00	4.41	<1.00	<1.00	<5	<10	<1	<50	<1	<2	<2	<5	<5	<5	<2	<5	<5	<5	<0.1	<0.5	<1
STP	**5**	50-60	Clayey Sand	2.0	-	<10	20	<100	6	<0.2	<1.00	9.23	<1.00	<1.00	<5	10	<1	<50	<1	5	<2	<5	<5	<5	<2	<5	8	<5	<0.1	<0.5	<1
NTP	**1**	60-80	Sandy Clay	4.0	-	<10	<10	188	4	<0.2	<1.00	5.14	<1.00	<1.00	9	20	<1	<50	<1	72	8	10	19	290	6	<5	110	<5	<0.1	1.3	<1
STP	**6**	70-90	Gravelly Sand	2.0	-	<10	<10	<100	6	<0.2	<1.00	2.74	<1.00	<1.00	<5	<10	<1	<50	<1	57	<2	<5	<5	11	<2	<5	22	<5	<0.1	<0.5	<1
WRTP	**4**	80-100	Clayey Gravel	5.0	-	<10	19	<100	6	<0.2	30.5	7.63	<1.00	<1.00	<5	<10	<1	<50	<1	11	4	72	<5	16	5	<5	9	<5	<0.1	<0.5	<1
STP	**7**	90-100	Clayey Sand	4.0	-	<10	<10	105	9	<0.2	<1.00	3.84	<1.00	<1.00	<5	10	<1	<50	<1	8	<2	<5	14	<5	<2	<5	31	<5	<0.1	<0.5	<1
NTP	**5**	150-170	Clayey Gravel	3.0	-	<10	<10	<100	6	<0.2	<1.00	8.42	5.92	<1.00	<5	80	1	<50	<1	21	17	<5	8	1440	15	<5	36	<5	<0.1	<0.5	<1
NTP	**7**	380-400	Silty Sandy Clay	36.0	-	20	11	109	25	<0.2	<1.00	5.2	<1.00	<1.00	<5	370	2	<50	<1	24	68	93	9	1900	50	<5	151	<5	<0.1	<0.5	<1
NTP	**1**	530-540	Silty Clay	3.0	-	<10	<10	161	17	<0.2	<1.00	13.6	22.6	<1.00	16	220	4	<50	<1	40	19	59	<5	2230	71	<5	55	17	<0.1	<0.5	<1

				Phosphorus (mg/kg)			Nitrogen (mg/kg)						Total Carbon (%)		TOC (%)		OM (%)		C:N Ratio		Moisture Content (%)
Area	**Site**	**Depth**	**Texture**	Total Phosphorus	Bicarb. Extrac	Rating	Ammonia	Nitrite	Nitrate	Nitrite & Nitrate (Sol.)	Total Kjeldahl Nitrogen	Total Nitrogen	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value
STP	**5**	0-50	Silty Gravelly Sand	60	<5	Very Low	<20	<0.1	<0.1	<0.1	430	430	0.13	-	<0.5	Very Low	0.8	-	10.8	-	3.3
STP	**7**	0-50	Sand	36	<5	Very Low	<20	<0.1	<0.1	<0.1	170	170	0.09	-	<0.5	Very Low	<0.5	-	<0.02	-	1.8
WRTP	**2**	0-50	Gravelly Clay	58	40	Moderate	<20	<0.1	0.5	0.5	90	90	0.36	-	<0.5	Very Low	0.7	-	44.9	-	10.8
WRTP	**15**	10-20	Sandy Gravel	221	<5	Very Low	<20	<0.1	<0.1	<0.1	300	300	0.83	-	0.6	Very Low	1	-	19.3	-	5.6
WRTP	**12**	40-50	Clayey Gravel	135	<5	Very Low	<20	<0.1	<0.1	<0.1	180	180	0.13	-	<0.5	Very Low	0.7	-	22.6	-	6.6
WRTP	**14**	40-60	Clayey Sand	74	<5	Very Low	<20	<0.1	0.1	0.1	390	390	0.35	-	<0.5	Very Low	0.8	-	11.9	-	9.7
STP	**3**	40-60	Gravelly Sand	55	<5	Very Low	<20	<0.1	<0.1	<0.1	140	140	0.07	-	<0.5	Very Low	<0.5	-	<0.02	-	3.4
STP	**5**	50-60	Clayey Sand	60	<5	Very Low	<20	<0.1	<0.1	<0.1	130	130	0.03	-	<0.5	Very Low	<0.5	-	<0.02	-	7.4
NTP	**1**	60-80	Sandy Clay	85	<5	Very Low	<20	<0.1	<0.1	<0.1	190	190	0.07	-	<0.5	Very Low	<0.5	-	<0.02	-	13.1
STP	**6**	70-90	Gravelly Sand	67	<5	Very Low	<20	<0.1	<0.1	<0.1	90	90	0.06	-	<0.5	Very Low	<0.5	-	<0.02	-	5
WRTP	**4**	80-100	Clayey Gravel	73	<5	Very Low	<20	<0.1	<0.1	<0.1	50	50	0.07	-	<0.5	Very Low	<0.5	-	<0.02	-	4.2
STP	**7**	90-100	Clayey Sand	80	<5	Very Low	<20	<0.1	0.2	0.2	130	130	0.03	-	<0.5	Very Low	<0.5	-	<0.02	-	15.9
NTP	**5**	150-170	Clayey Gravel	180	<5	Very Low	<20	<0.1	<0.1	<0.1	130	130	0.07	-	<0.5	Very Low	<0.5	-	<0.02	-	9.9
NTP	**7**	380-400	Silty Sandy Clay	25	<5	Very Low	<20	<0.1	<0.1	<0.1	<20	<20	0.19	-	<0.5	Very Low	<0.5	-	-	-	27.8
NTP	**1**	530-540	Silty Clay	21	<5	Very Low	<20	<0.1	<0.1	<0.1	40	40	0.05	-	<0.5	Very Low	<0.5	-	<0.02	-	24.5

APPENDIX 4

Volumes of Soil Materials Available and Required for the Growth Medium on the WSF

Kandosol Growth Material Layers by Depth from Surface (cm)	Soil Texture Classification: Approximate USGS	Soil Texture Classification: NCST (2009) (Preferred, Excl Gravel)	Approximate Preferred Particle Size Distribution Ranges (%)	Soil Structure	Potential Source: Area	Potential Source: Zone	Total Volume (m^3): Zone	Total Volume (m^3): Area	Total Volume (m^3): Horizon	Range of Depths By Horizon (m)	1V:2.5H & 1V:3.5H Surface Area (m^2): WSF (East)	1V:2.5H & 1V:3.5H Surface Area (m^2): WSF (West)	1V:2.5H & 1V:3.5H Surface Area (m^2): Total of WSFs	1V:2.5H & 1V:3.5H Total Volume of Material Required (m^3)	1V:2.5H & 1V:3.5H Surplus/ Deficit (m^3)	1V:2.0H & 1V:3.0H Surface Area (m^2): WSF (East)	1V:2.0H & 1V:3.0H Surface Area (m^2): WSF (West)	1V:2.0H & 1V:3.0H Surface Area (m^2): Total of WSFs	1V:2.0H & 1V:3.0H Total Volume of Material Required (m^3)	1V:2.0H & 1V:3.0H Surplus/ Deficit (m^3)	1V:4H & 1V:6.25H Surface Area (m^2): WSF (East)	1V:4H & 1V:6.25H Surface Area (m^2): WSF (West)	1V:4H & 1V:6.25H Surface Area (m^2): Total of WSFs	1V:4H & 1V:6.25H Total Volume of Material Required (m^3)	1V:4H & 1V:6.25H Surplus/ Deficit (m^3)
0-20 (A1 horizon) and 20-60 (A2 horizon)	Clayey Silty Sand to Silty Clayey Sand, Non-Plastic	Sandy Loam (SL)	Clay: 8-20 Silt: 2-10 Sand: 71-91	Massive	Borrow Area A	1	100,964	152,001	**193,443**	0.4	273,485	245,885	519,370	**207,748**	-14,305	282,958	252,937	535,895	**214,358**	-20,915	277,922	249,230	527,152	**210,861**	-17,418
						2	11,760																		
						3	14,670																		
						4	9,300																		
						5	14,690																		
		Sandy Clay Loam (SCL)	Clay: 18-33 Silt: 2-8 Sand: 65-82			Stripped	618			0.5				**259,685**	-66,242				**267,948**	-74,505				**263,576**	-70,133
					Borrow Area B	2	34,702	41,441																	
						3	6,739																		
					WSF (East)	B	2,437	No Longer Available																	
						F (Nth)	3,924																		
		Clay Loam, Sandy (CL,S)	Clay: 21-35 Silt: 6-15 Sand: 50-70			H,I,K	2,345			0.6				**311,622**	-118,179				**321,537**	-128,094				**316,291**	-122,848
						K	8,076																		
						I,F (Sth)	1,241																		
						I	6,204																		
						J	4,094																		
60-120 (B21 horizon)	Clayey Sandy Silt to Sandy Clayey Silt, Very Low to Low Plasticity	Clay Loam, Sandy (CL,S)	Clay: 21-35 Silt: 6-15 Sand: 50-70	Massive to Weak	Borrow Area A	1	310,533	1,111,886	**3,154,690**	0.6	273,485	245,885	519,370	**311,622**	2,843,068	282,958	252,937	535,895	**321,537**	2,833,153	277,922	249,230	527,152	**316,291**	2,838,398
						2	346,377																		
						3	32,754																		
						4	125,897																		
						5	283,328			0.7				**363,559**	2,791,131				**375,127**	2,779,563				**369,006**	2,785,683
						Stripped	12,997																		
		Sandy Light Clay (SLC)	Clay: 27-40 Silt: 2-20 Sand: 40-71		Borrow Area B	1	1,553,003	2,042,804																	
						2	486,640																		
						3	3,160																		
					WSF (East)	B	3,389	No Longer Available		0.8				**415,496**	2,739,194				**428,716**	2,725,974				**421,722**	2,732,968
						F (Nth)	7,872																		
						F (Sth)	49,639																		
						I,F (Sth)	26,055																		
120-200 (B22 horizon)	Silty Sandy Clay to Sandy Silty Clay, Low to Medium Plasticity	Sandy Light Clay (SLC)	Clay: 27-40 Silt: 2-20 Sand: 40-71	Weak to Moderate	Borrow Area A	1	331,646	802,532	**802,532**	0.8	273,485	245,885	519,370	415,496	387,036	282,958	252,937	535,895	428,716	373,816	277,922	249,230	527,152	421,722	380,810
						2	319,475																		
						3	79,409																		
						4	68,536			0.9				467,433	335,099				482,306	320,226				474,437	328,095
						Stripped	3,465																		
		Sandy Light Medium Clay (SLMC)	Clay: 40-45 Silt: 2-20 Sand: 35-58		WSF (East)	B	13,301	No Longer Available																	
						F (Nth)	47,665																		
						K	12,114			1.0				519,370	283,162				535,895	266,637				527,152	275,380
						F (Sth)	16,209																		
						I,F (Sth)	26,055																		

APPENDIX E

Deswik Block Modelling

MEC MINING

TRUSTED EXPERTISE. PROVEN OUTCOMES.




Haulage Model

SLR Rum Jungle

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

MEC Mining was engaged by SLR to complete the haulage modelling for the Rum Jungle rehabilitation project. The project requires the hauling of potentially acid-forming (PAF) material to new waste storage facilities (WSF), to be encapsulated inside non-acid forming (NAF) material, to protect the environment from further harm.

Included in this work is the removal of radioactive soils, copper heap leach pad and other miscellaneous salt and metal contaminated soils to the new waste storage facilities. Further to this, the excavation areas together with the new waste storage facilities require capping with clay and growth medium (GM), to allow the regrowth of local flora.

All material movements have been simulated using a haulage model in Deswik LHS software to estimate the number of trucks required to complete the project in the desired timeframe.

This report is to be read in parallel with the attached presentation *Rum Jungle - Haulage Model 200513*.

2 SOURCE MATERIAL MOVEMENT

The material movement is broken down by source location and year in Figure 1. Due to the location of the project, it is assumed that haulage will begin in the first month of the dry season and material movement will be reduced during each wet season. Due to the hazard that the radioactive soils pose these need to be removed as a priority and covered in the WSF, so all three locations are removed in Year 1.

Sand begins hauling from the borrow pit in mid-Year 2, after the barging facility has been completed. This sand is required to line the base of Main Pit before the pit is backfilled with PAF material.

Clay and GM are hauled progressively as sections of the WSF are completed and ready for capping.

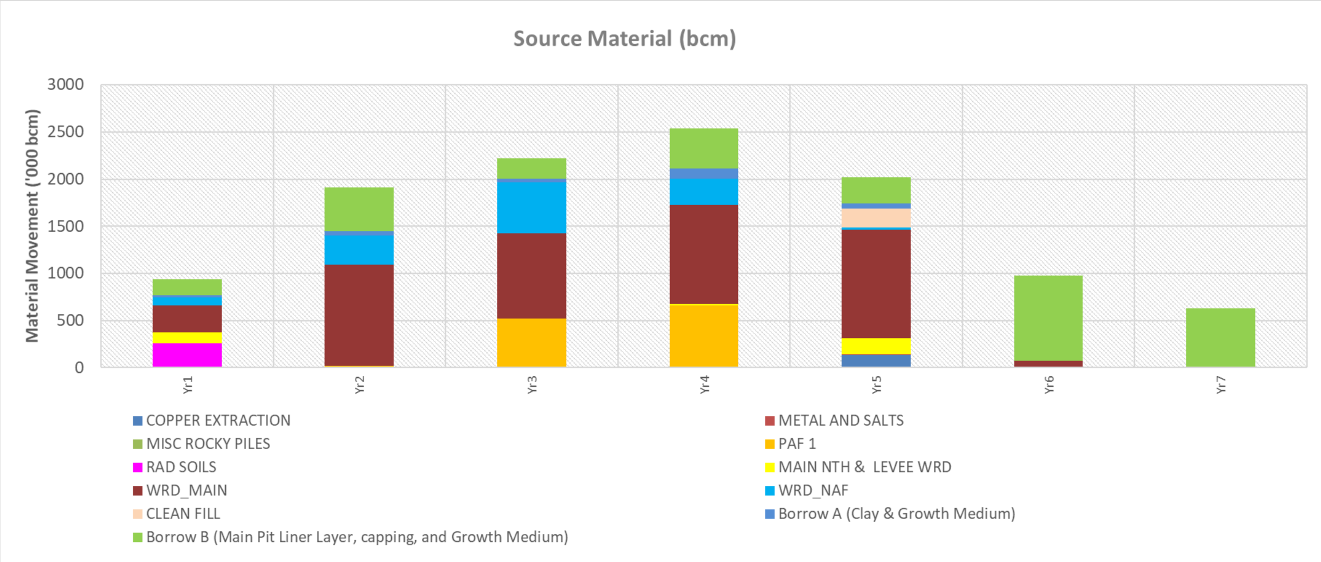

Figure 1: Source Material by Year

3 DESTINATION MATERIAL MOVEMENT

The destination of the hauled material is dependent on the type of material. The WSF are created in layers to effectively encapsulate the PAF material. NAF and treated low PAF material are hauled to the WSF to create the Starter Bunds as shown in Figure 2 to encapsulate the PAF material. The WSF is created in half metre lifts with the NAF Starter Bunds created first, followed by the PAF, clay capping and GM. The yearly breakdown of material movement hauled by destination can be seen in Figure 3.

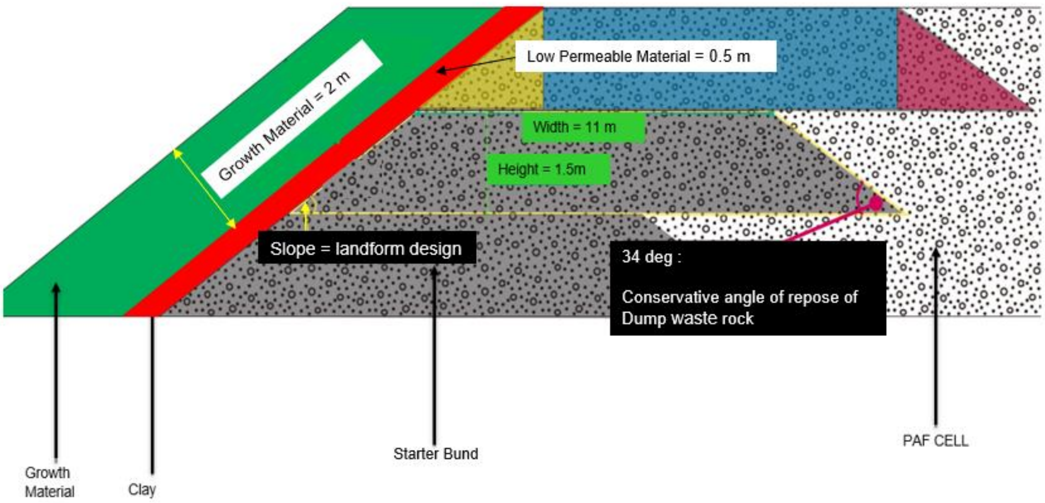

Figure 2: WSF cell creation

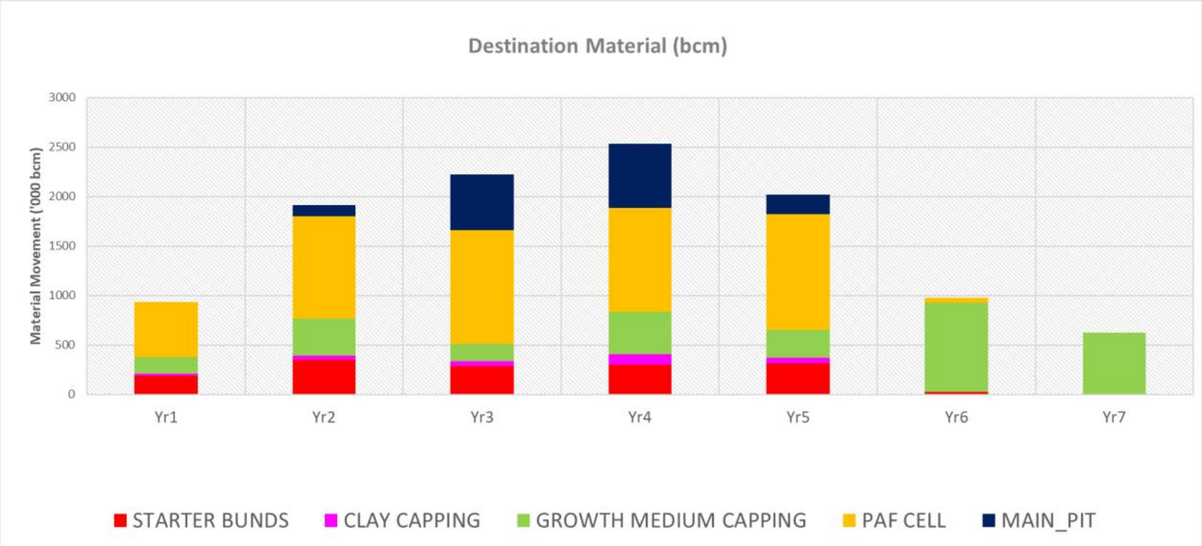

Figure 3: Destination material by year

4 HAULAGE MODEL

4.1 Truck hours

The haulage model uses the material movement source and destination together with the designed haulage network to calculate the required monthly truck hours. The haulage network used was created by MEC Mining using Deswik Landform Haulage Simulation (LHS). Further detail on the haulage simulation can be found in the SLR Haul Road Design Report.

In the haulage model two different truck types were used to move the material:

- CAT740B (~40t capacity) for hauling waste to WSF and Main Pit and for hauling from sand borrow pits
- Mack Bigfoot (~98t capacity) for hauling longer distances from the clay borrow pits to the WSF

These trucks are assumed to operate on a 12-hour day shift only arrangement with a 70% effective utilisation (combined availability and utilisation). This equates to 8.4-hour operating hours per shift.

To control the direction of material flow each of the dumps have dependencies which have been dictated by the stage priorities. The WSF was separated into two domains, the Eastern WSF (EWSF); and the Western WSF (WWSF). The EWSF is the highest priority, while the WWSF is second priority. Both WSF domains will be built from north to south. Inside the WSF in each half metre lift the starter bund material is the highest priority, followed by PAF, before capping the outer surface of the starter bund with Clay and GM.

The haul road design has allocated speed limits for each portion of the haulage network and these have been applied in the haulage model. The maximum speed limit is 50km/hr with reductions to 45km/hr around intersections.

Using calibration factors from similar haulage models, the rolling resistance was set to 4% for loaded trucks and 3% for unloaded trucks and a 5% cycle time increase was added to better suit practical situations.

Figure 4 and Figure 5 below show the monthly truck hours and truck numbers from the haulage model. As can be seen the CAT740B truck numbers in the dry season ramp up from 10 to 19 over the first 3 years and then increase to 22 for years 4 and 5. The CAT740B truck numbers during the wet season is 9 to 10. Due to the large haulage capacity of the Mack Bigfoot (180t) there is a requirement of only one truck for the duration of the project to haul the clay required for impervious layers.

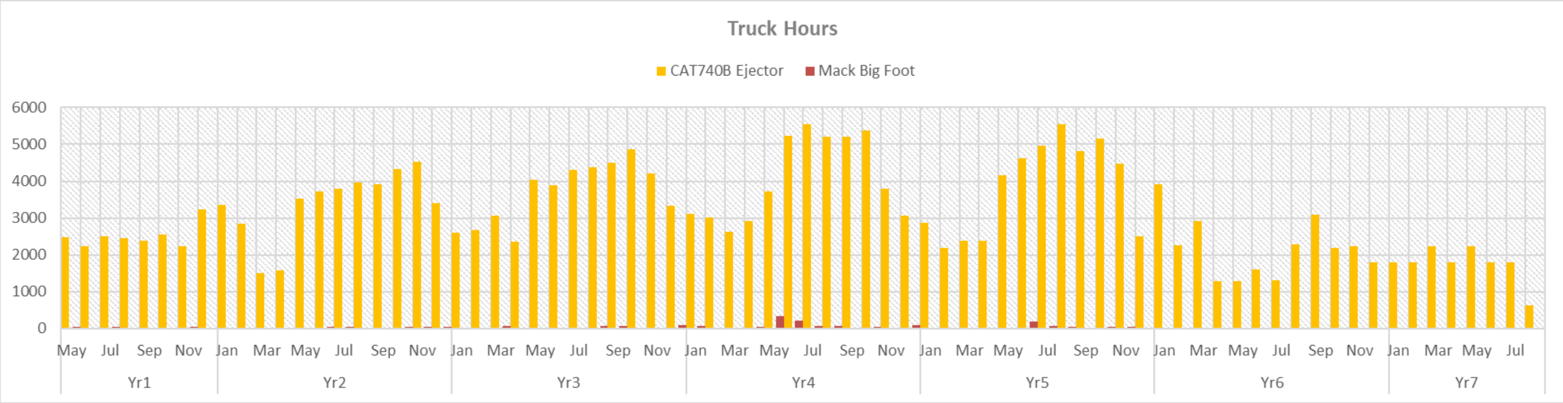

Figure 4: Haulage model monthly truck hours

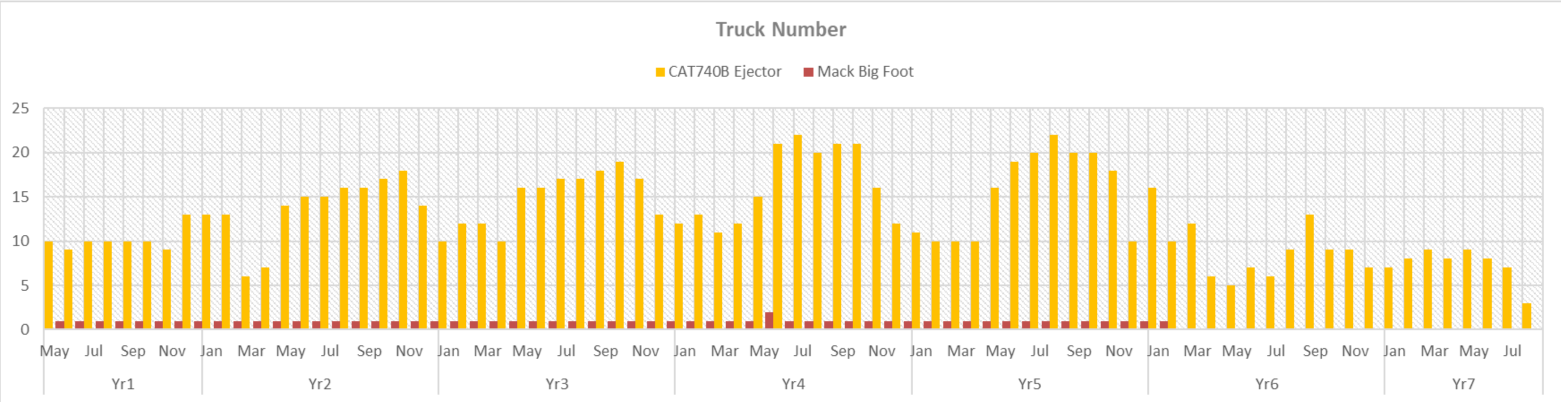

Figure 5: Haulage model monthly truck number

4.2 Excavation Schedule

Excavation areas were scheduled based on the following considerations:

- Radioactive soils are prioritised to be removed and covered
- Main North WRD to be removed by the end of year 1 to setup the barging facility
- Haulage to Main Pit begins as soon as the Barging Facility is ready
- Dysons WRD (and if required, Main WRD) are hauled simultaneously to supply NAF and Low PAF for WSF construction

Figure 6 shows the excavation locations and the scheduled removal dates.

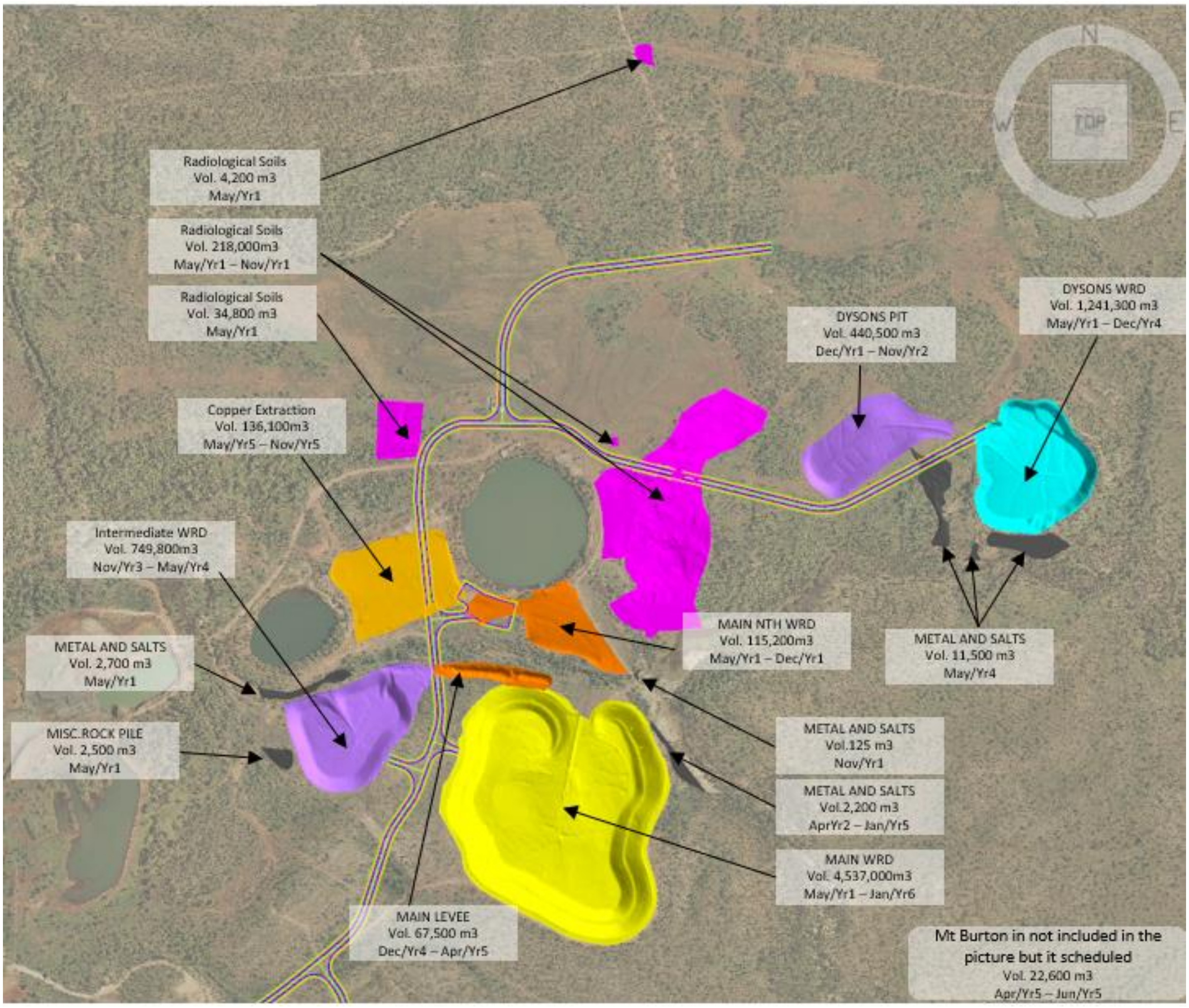

Figure 6: Excavation schedule and period

4.3 WSF Construction Sequence

To reduce the size of PAF material exposed during the start of the wet season the construction of the WSF needs to be staged. The size of each stage is dependent on the material movement planned during the dry season. Additionally, restrictions have also been placed on the hauling of clay during wet seasons.

Figure 7 shows the staged construction of the two WSF. Main Pit is to be backfilled with the high PAF material. This is initially started by hauling sand to line the pit and then the PAF material from Dysons Pit and followed by Intermediate WRD.

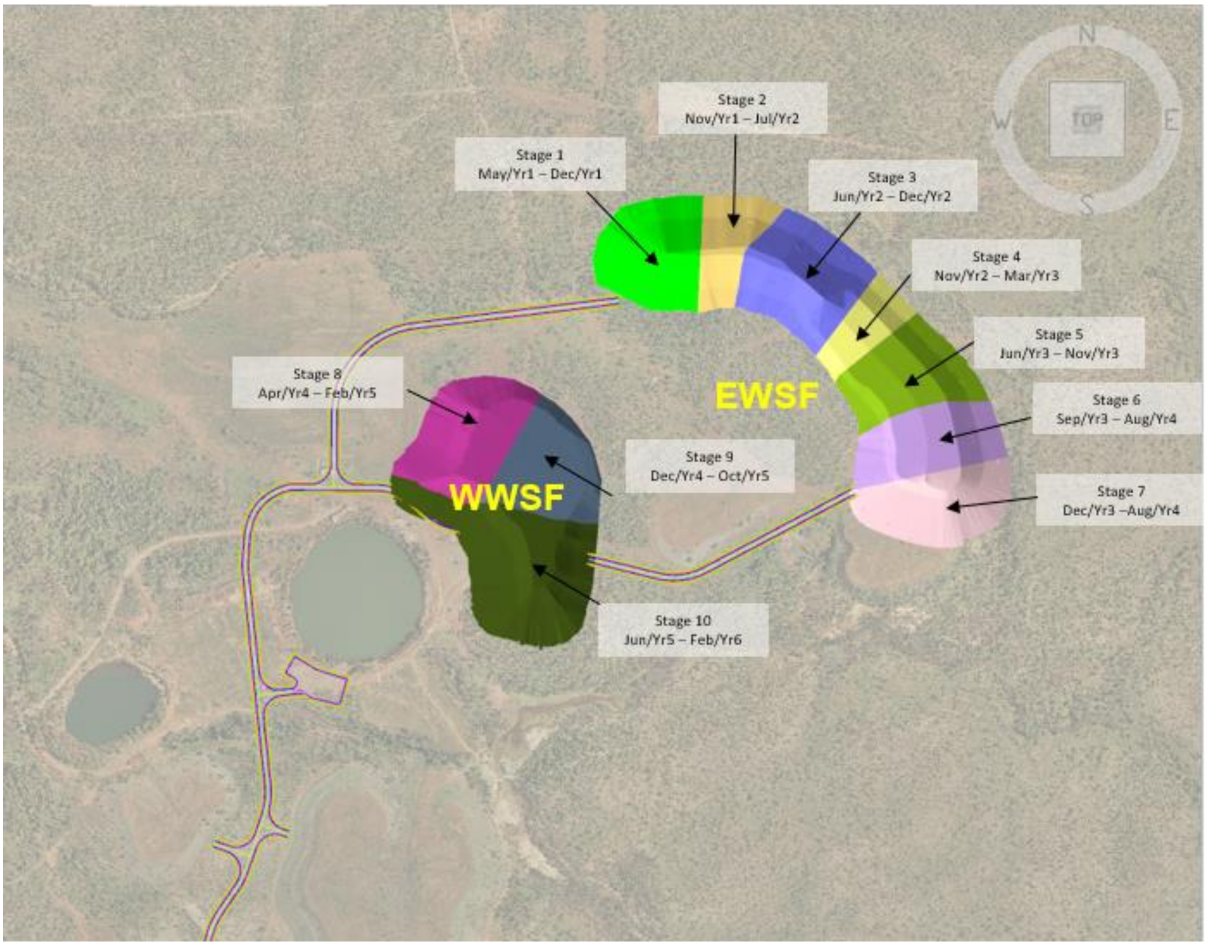

Figure 7: WSF construction sequence and period

4.4 Excavation Backfill Sequence

All excavation areas need to be backfilled after completion with GM and in the case of Dysons Pit, initially clay-lined. This needs to be completed as a priority in the case of the radiation soils and Dysons Pit. Figure 8 shows the backfill locations and periods.

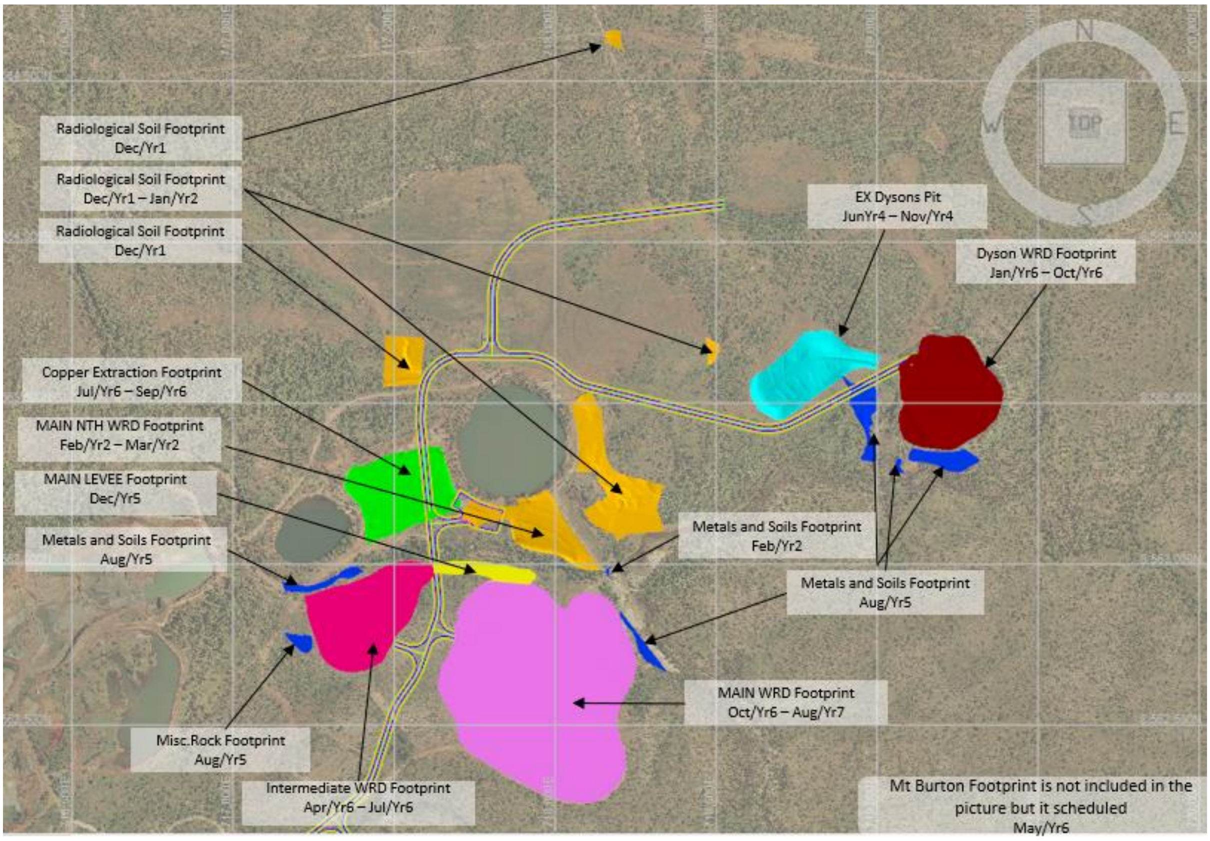

Figure 8: Excavation footprint backfill sequence and period

4.5 Yearly Progress

Figure 9 and Figure 10 show the yearly progress plots of the excavation locations, WSF and backfill. For greater detail please refer to the attached presentation.

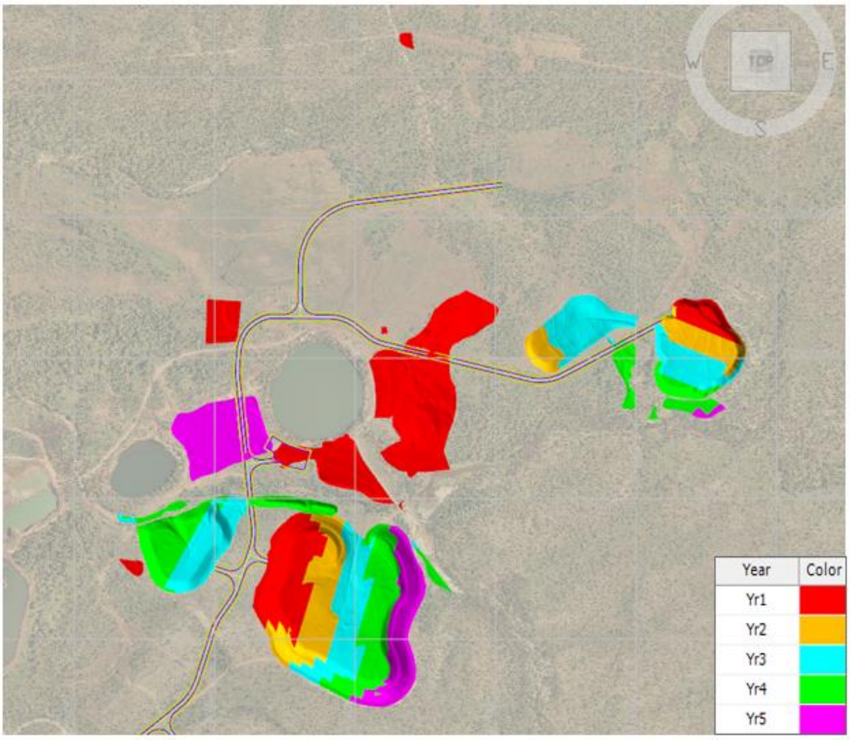

Figure 9: Excavation location yearly progress

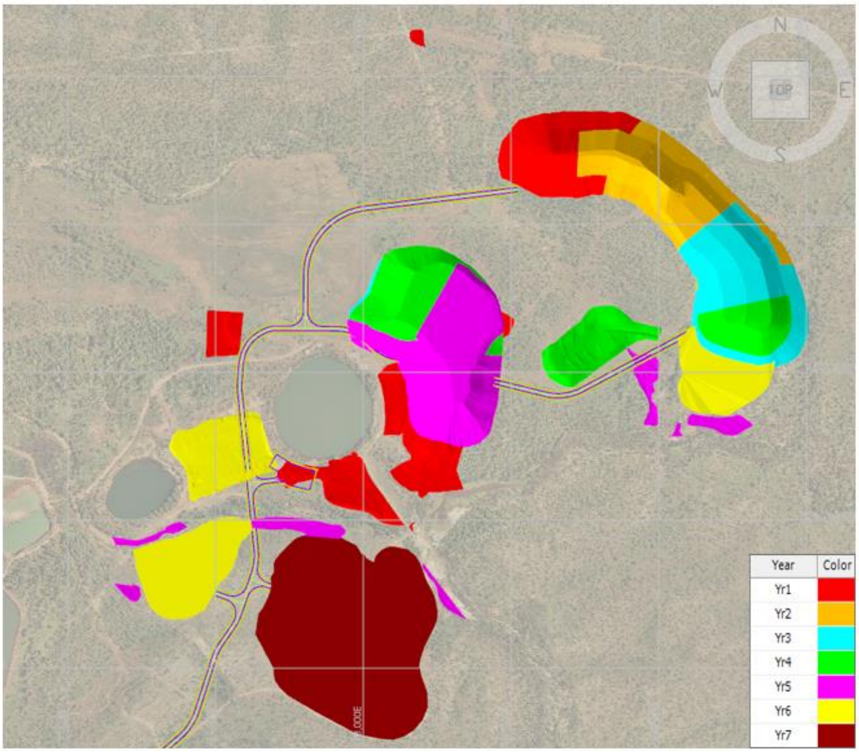

Figure 10: WSF and backfill yearly progress

5 BARGING FACILITY

The backfilling of Main Pit is to utilise a barge to distribute the PAF material evenly throughout the pit. To complete this requires the construction and operation of a barging facility on the shore of Main Pit. The southwestern edge of Main Pit was chosen due to its flat location, easy access to the haulage network and is far enough from the crest of the pit ramp to not hinder the barge filling.

The barging facility layout can be seen in Figure 11 and includes:

- Loader fed Crushing and Screening Plant (CSP)
- Loader fed Barge hopper and conveyor system
- Raw stockpile
- Product stockpile
- Area for the CAT740B dump truck and the loader activities
- Boat ramp and maintenance area for the barge has been assumed to be situated at the top of the pit ramp

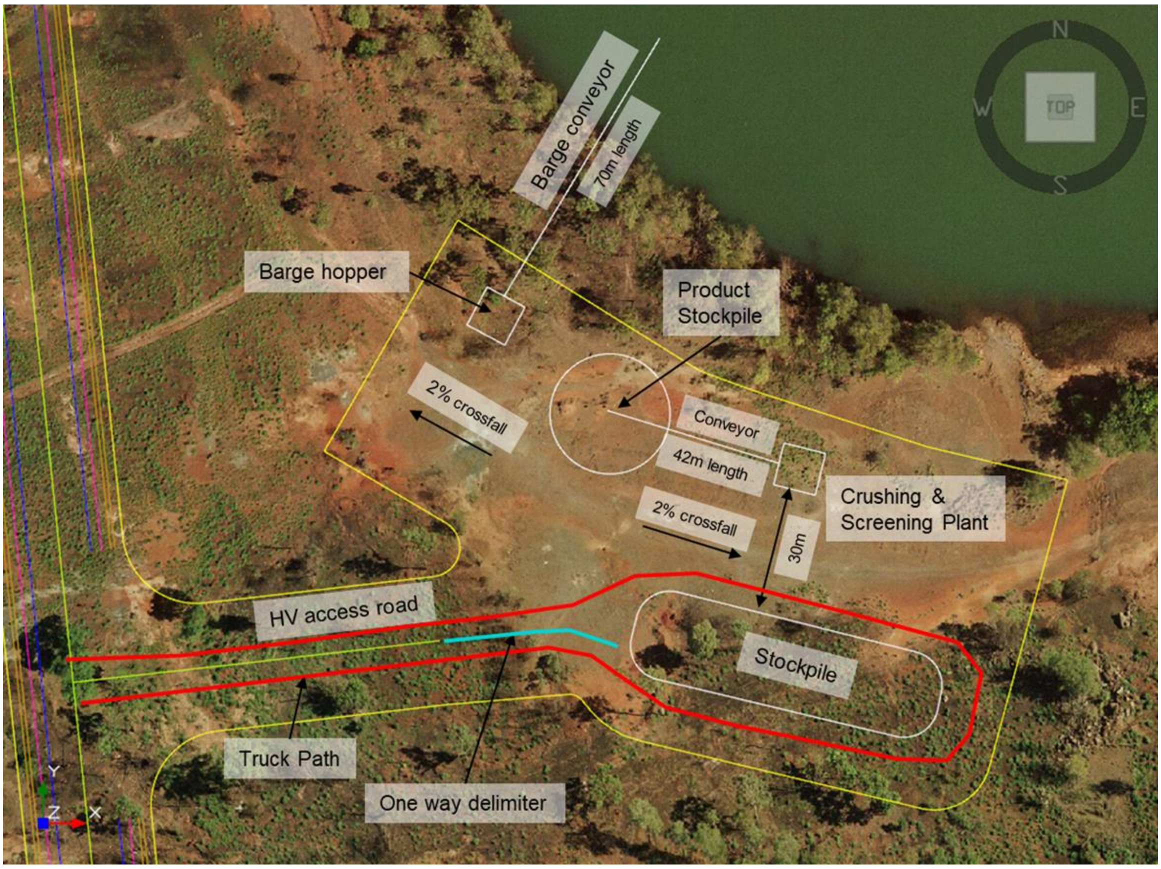

Figure 11: Barging facility layout

The barging facility needs to support the PAF material movement. Table 1 shows the production rate required for the barging facility to comply with the PAF material movement. The maximum restraint for the backfill into Main Pit is the ability to treat the displaced water which is capped at 4kbcm a day which equates to 811t/hr of barging capacity. The barging facility CSP needs to be set up at a larger production rate than is shown in the production rate in Table 1. Based on the production rate in Year 4 of 568t/hr, it is recommended that the CSP production rate is nominated at 600t/hr.

Table 1: Barging facility production

	Year 2	Year 3	Year 4	Year 5*
Volume (bcm)	116,500	560,271	705,918	75,243
Tonnes (t)	256,300	1,232,594	1,553,020	165,534
Calendar Hours (hr)	3,036	3,036	3,036	708
Available Hours (hr)	2,732	2,732	2,732	637
Production Rate (t/hr)	94	451	568	260

* 2 months in Year 5

To support the barging facility plant production rate there is a requirement for two wheel loaders to be operating, allowing for redundancy in the system. Table 2 provides assumptions used to determine the required size of the loaders. The two loaders allow for redundancy in the system; however, other options can be explored regarding moving to 1 loader and doubling the plant production or removing the product stockpile and the screening plant feeding straight into the barge hopper.

Table 2: Loader capacity

	Quantity	Unit
Crushing plant capacity	600	t/hr
Density	2.53	t/bcm
Instantaneous Loader Productivity	237	bcm/hr
Dump to hopper	20	sec
Average cycle time	60	sec
Effective bucket capacity	5.3	bcm
Effective mass in bucket	13.5	t
Swell in bucket	20	%
Bucket fill factor	95	%
Bucket factor	0.8	
Bucket capacity	6.7	bcm
Example Loaders:	Caterpillar 988; Komatsu WA600	

DOCUMENT INFORMATION

DOCUMENT CHANGE CONTROL

Version	Description of Changes/amendments	Author (s)	Date
1.	Creation of document	Lukman Hakim	24/04/20
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APPENDIX F

Haul Road Design

TRUSTED EXPERTISE. PROVEN OUTCOMES.

Haul road design

SLR Rum Jungle

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

MEC Mining was engaged by SLR to complete the haul road design for the Rum Jungle rehabilitation project. The haul road design is to include:

- Road geometry
- Pavement thickness design
- Superelevation design
- Intersection design and signage
- Speed limit designation
- Cut and fill volumes
- Construction plans

The purpose of this work is to design a haulage network that will be constructed and used during the rehabilitation project at Run Jungle. The haul road design and associated speed limits will also be used as the basis of the haulage model.

This report is to be read in parallel with the attached presentation *Rum Jungle - Haul Road Design 200513.*

2 ROAD GEOMETRY

The haul road geometry is composed of three main parts:

- Running width (or lane width)
- Drain width
- Safety berm width (or windrow width)

The main parameters used for the design include:

- Crossfall: 2 - 3%
- Running width: 14.6m
- Drain width: 2.5m
- Drain slope: 1:4
- Windrow width: 5.2m
- Windrow flat top width: 1.0m
- Windrow height above road: 1.0m
- Windrow slope: 37°

The largest haul truck assumed for the haul road design is the articulated CAT745C. This haul truck has a maximum width of 4.17m and wheel height of 1.9m. The running width of the haul road is required to be 3.5 times the maximum width of the largest truck, 14.6m. The windrow height is required to be half the wheel height of the largest haul truck, 1.0m. Figure 1 below shows the design specifications of the haul road geometry.

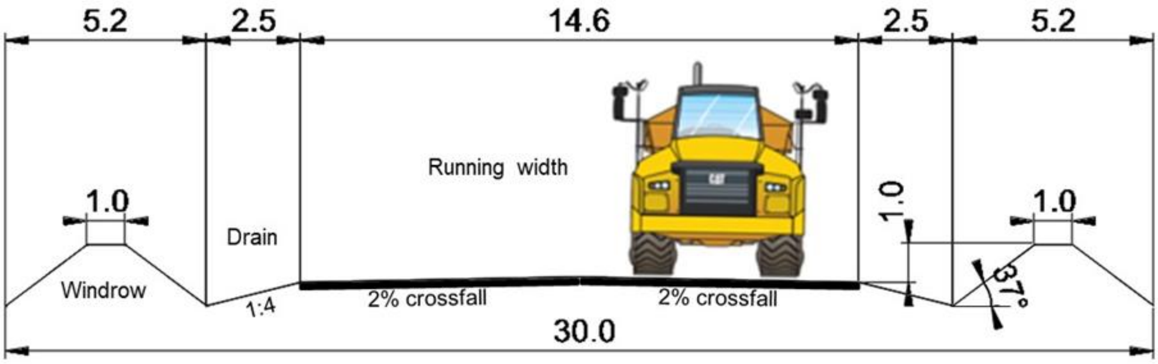

Figure 1: Haul road geometry

3 PAVEMENT THICKNESS DESIGN

According to the supplied CBR ratings, the haul road network was broken into nine separate zones as shown in Figure 2. The pavement thickness was determined by calculating the base and wearing surface thicknesses based on the CBR and then combining into the pavement thickness. The zone CBR and thicknesses are outlined in Table 1 below.

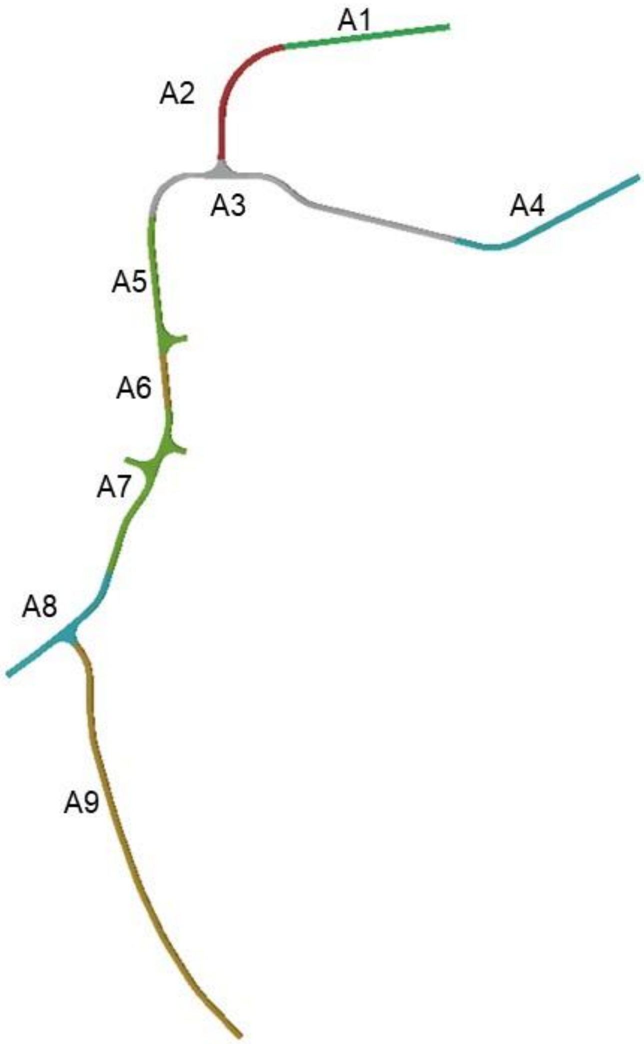

Figure 2: Haul road network CBR zones

Table 1: Pavement Thickness

Zone	CBR (%)	Base (m)	Wearing Surface (m)	Pavement (m)
A1	25	0.15	0.12	0.27
A2	10	0.25	0.15	0.40
A3	40	0.10	0.10	0.20
A4	30	0.15	0.10	0.25
A5	20	0.15	0.15	0.30
A6	15	0.20	0.15	0.35
A7	20	0.15	0.15	0.30
A8	30	0.15	0.10	0.25
A9	15	0.20	0.15	0.35

4 SUPERELEVATION DESIGN

Figure 3 below shows there are nine superelevations designed in the haul road network. Table 2 details the design specifics for these nine superelevations.

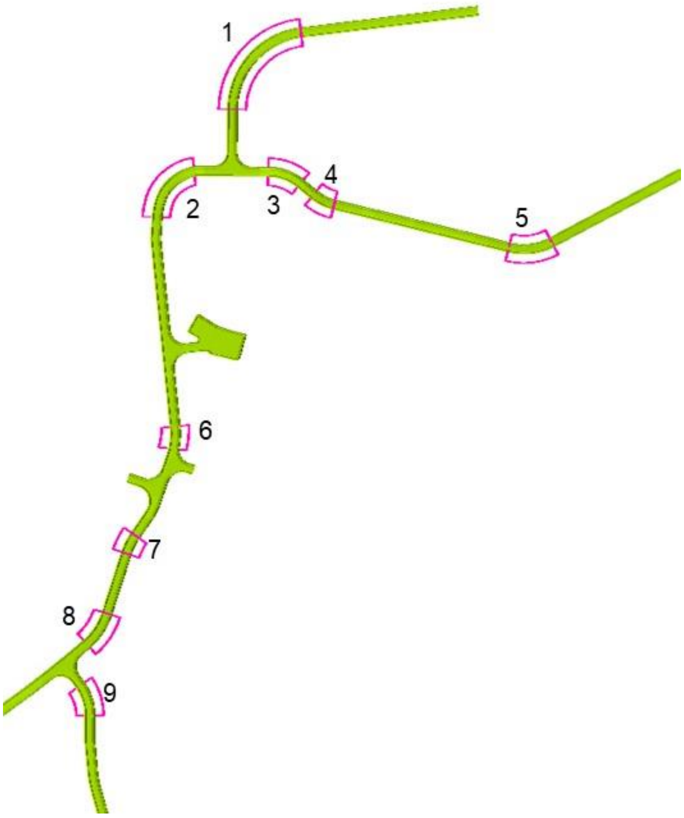

Figure 3: Superelevation designs in haul road network

Table 2: Superelevation design table

Position	Superelevation rate (%)	Radius (m)	Speed limit (km/h)
1	2	228	50
2	3	125	45
3	3	150	50
4	3	142	50
5	3	175	50
6	2	200	45
7	2	200	45
8	2	200	45
9	3	148	50

5 INTERSECTION DESIGN AND SIGNAGE

There are five "T" intersections in the haul road network as shown below in Figure 4.

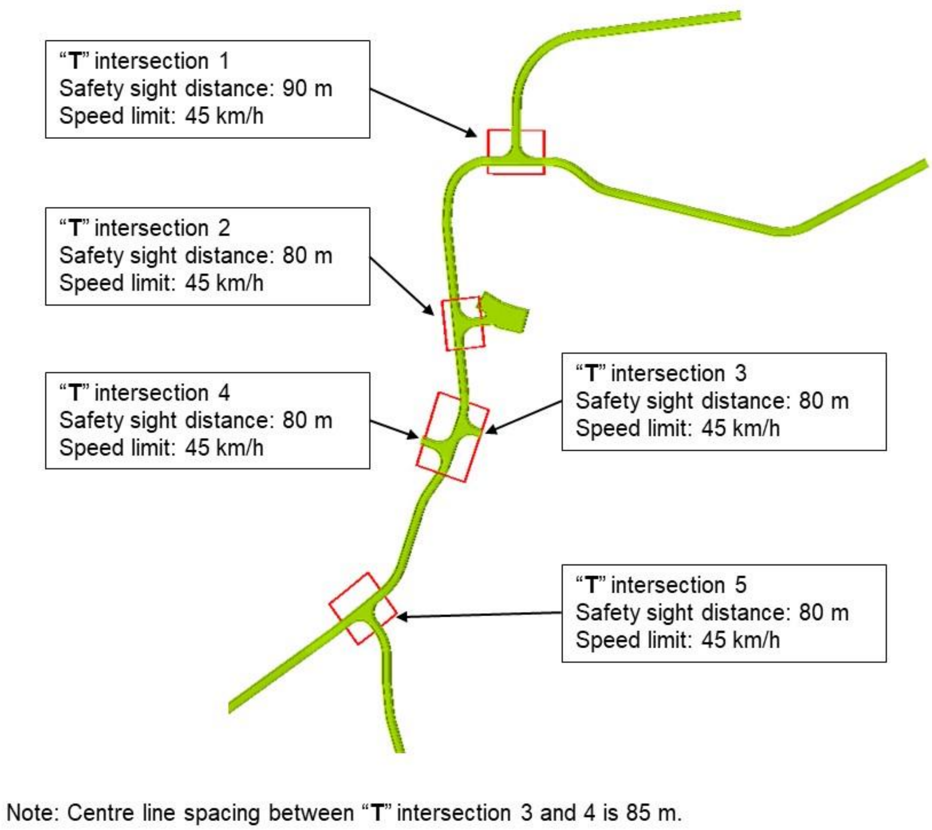

Figure 4: Haul network intersections

Each of the intersections will require adequate signage to be installed to provide awareness on the approach to the intersection and clear direction within the intersection. Figure 5 shows an example of the signage to be installed at "T" intersection 1. The remaining intersections are included in the attached presentation.

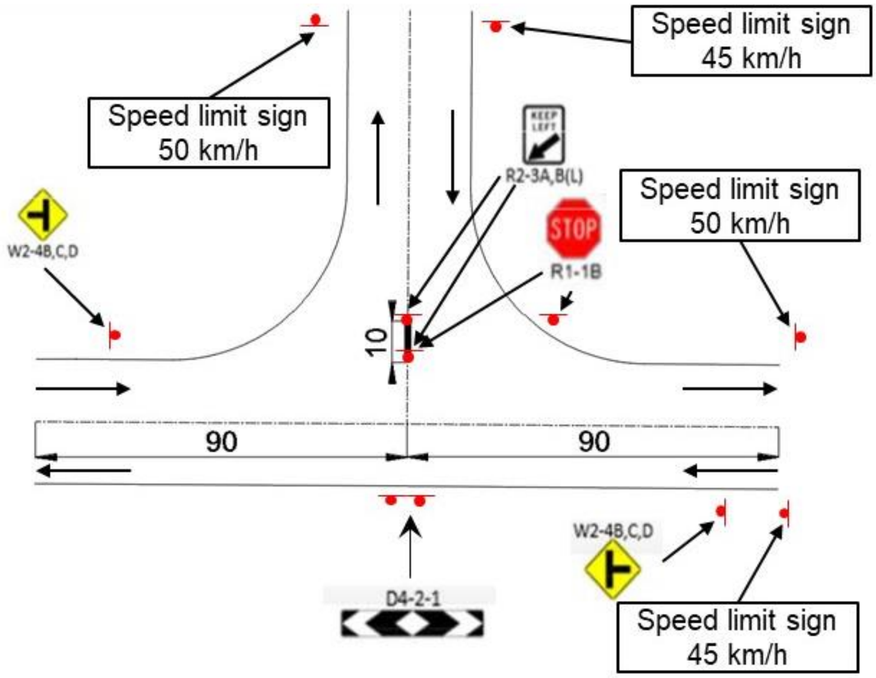

Figure 5: Intersection signage example from "T" intersection 1

6 SPEED LIMIT DESIGNATION

The speed limits applied to the haulage network were determined using sightlines to intersections and superelevation speeds. Figure 6 shows the breakdown of the speed limits. As can be seen, the speed limit has been reduced in the high traffic areas at intersections.

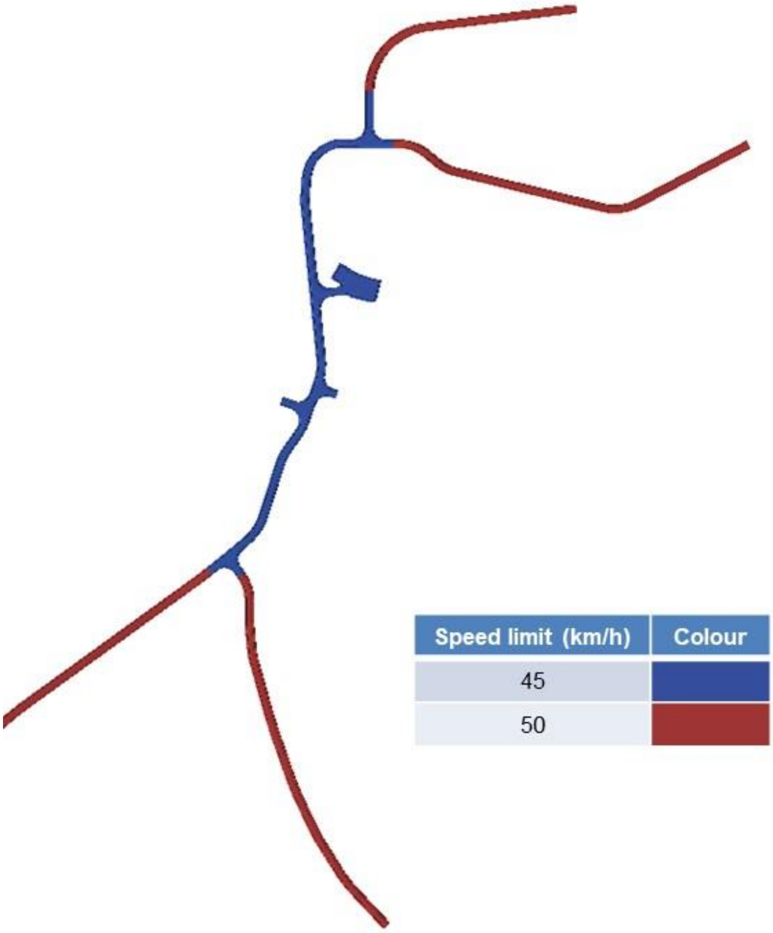

Figure 6: Speed limit designations

7 CUT AND FILL VOLUMES

7.1 Haul Road Design

Cut and fill volumes have been calculated for each zone of the haul road network. Within each of these zones, the cut and fill volumes have been calculated in 50m sections to increase the granularity of the result. The cut and fill volumes are outlined in Table 3 below. The fill volume includes the pavement and bund volumes, but have been broken out in the table for improved understanding.

Table 3: Cut and Fill volume by zone

Zone	Cut volume (bcm)	Fill volume (bcm)	Pavement (bcm)	Bunds (bcm)
A1	5,445	12,795	2,778	3,935
A2	2,615	18,301	3,548	7,010
A3	17,778	45,090	4,535	14,388
A4	20,941	17,697	3,113	5,809
A5	8,322	15,870	3,238	4,590
A6	4,766	8,042	1,179	2,601
A7	13,249	23,778	4,713	6,774
A8	5,228	12,420	2,513	3,928
A9	10,760	46,479	9,433	16,692
Total	**89,104**	**200,472**	**35,050**	**65,727**

7.2 Drainage Design

Due to the location of the project, the water management for the haul road is a major concern. Each of the low points in the haul road requires either a sediment trap or a holding dam depending on access to an outlet. For the haul road, there is a requirement to build eight dams and 6 sediment traps and they can be seen in Figure 7. The assumption was made that the dams would need to hold two days worth of water and the sediment traps as they are designed as two adjoining dams would need to hold a days worth of water in each dam. The volume required for each dam or sediment trap was calculated using the surface area of haul road feeding that low point multiplied by the highest recorded rainfall in 24 hours. The cut and fill volumes required to create the water storages are outlined in Table 4.

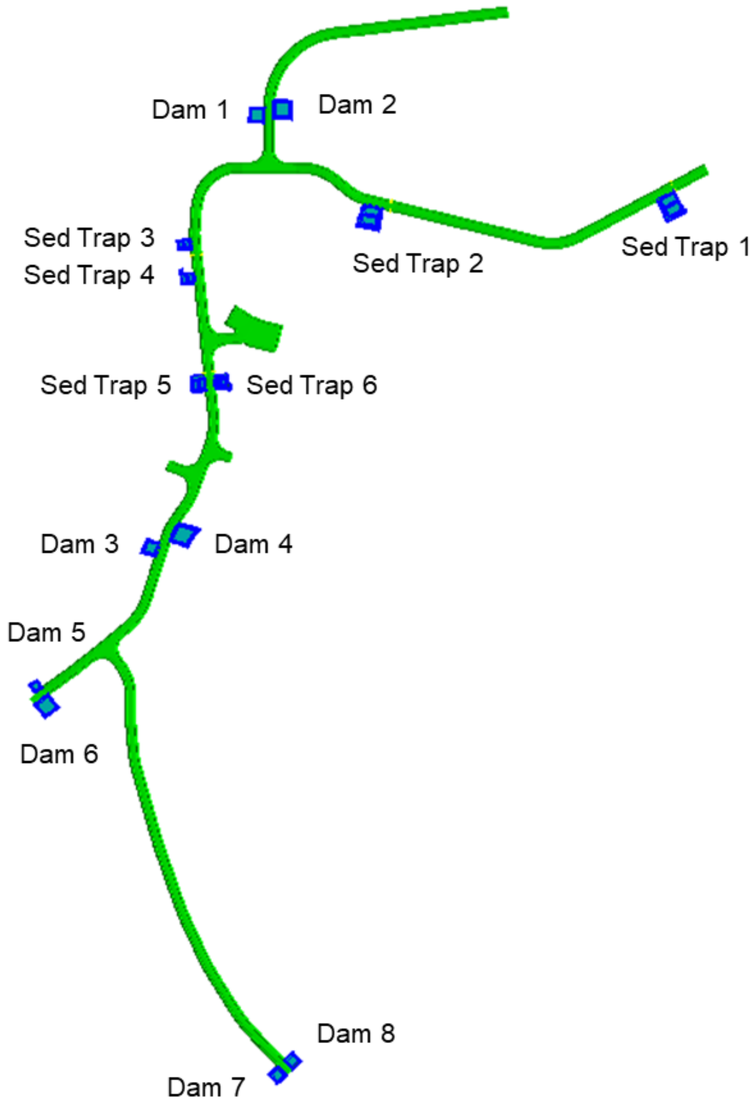

Figure 7: Haul road drainage design

Table 4: Haul road drainage cut and fill volumes

Water Storage	Cut Volume (m^3)	Fill Volume (m^3)
Dam 1	4,072	238
Dam 2	9,600	302
Dam 3	5,144	230
Dam 4	14,726	399
Dam 5	1,490	197
Dam 6	6,898	377
Dam 7	4,369	283
Dam 8	3,266	243
Sed Trap 1	3,804	3,922
Sed Trap 2	4,684	3,465
Sed Trap 3	1,837	456
Sed Trap 4	2,241	247
Sed Trap 5	5,283	622
Sed Trap 6	6,018	906
Total	**73,432**	**11,888**

8 CONSTRUCTION PLANS

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