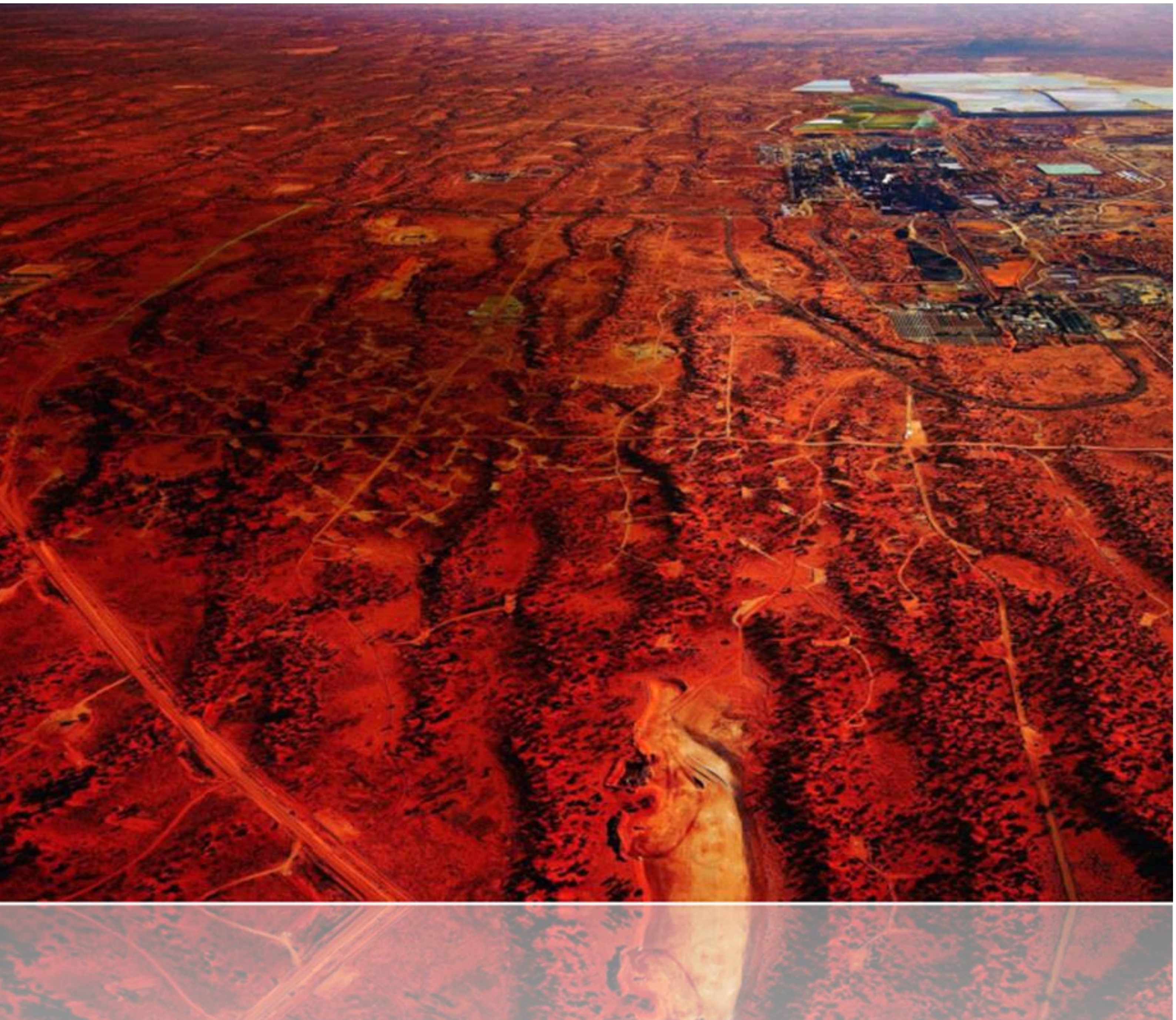
CLOSURE MANAGEMENT AND REHABILITATION PLAN

OLYMPIC DAM

May 2019



This Closure and Rehabilitation Plan has been prepared as information only and is not to be relied on as final or definitive. It would continue to be developed and would be subject to change.

Closure Management Plan Summary

Olympic Dam Mine	
Project	Olympic Dam
Document Title	Olympic Dam Mine Closure Management and Rehabilitation Plan
Document Reference	99232
Mining Tenements	Special Mining Lease 1
Company Name	BHP Billiton Olympic Dam Corporation Pty Ltd

Electronic Approval Record

Business Role	Name
Authors Role	**Name**
Principal Strategic Planning	Don Grant
Principal Environment A&I	Murray Tyler
Principal Closure Planning	Craig Lockhart
Reviewer Role	**Name**
Manager Closure Planning	Rebecca Wright
Superintendent Environment, Radiation and Occupational Hygiene	James Owen
Principal Legal	Zoe Jones
Approver Role	**Name**
Head of Environment Analysis and Improvement	Gavin Price
Head of Geoscience and Resource Engineering	Amanda Weir
Asset President Olympic Dam	Laura Tyler

Document Amendment Record

Version. No	Page Number	Change Effected	Date of Change
4		Update to 2013 document to reflect current LoA	May 2019

Key Stakeholders

Department	Position
Water Planning	Superintendent Water Planning
Mine Planning	Manager Mine Planning
Corporate Affairs	Head of Corporate Affairs
Land and Tenements	Superintendent Tenure
Environment A&I	Manager Environment

Table of Contents

Figures

Tables

Abbreviations

Abbreviation	Meaning
BOM	Australian Bureau of Meteorology
CAF	Cement Aggregated Fill
CMRP	Closure Management and Rehabilitation Plan
EL	Exploration Lease
FIFO	Fly-In-Fly-Out
GAB	Great Artesian Basin
GLD	Guideline
ICMM	International Council for Mining and Metals
IPCC	Intergovernmental Panel on Climate Change
LGA	Local Government Area
LoA	Life of Asset
MCA	Minerals Council of Australia
Mtpa	Million tonnes per annum
OBP	Optimised Base Plan
OD	Olympic Dam
PEL	Petroleum Exploration Licence
PELA	Petroleum Exploration Licence Application
RSF	Rock Storage Facility
SA	South Australia
SML	Special Mining Lease
TEO	Targeted Environmental Outcome
TRS	Tailings Retention System

1 Executive Summary

Olympic Dam is situated 570 kilometres (km) north of Adelaide in South Australia, and is a producer of copper, uranium, gold and silver. The current (FY19) ore reserve and mineral resource estimate indicates a life of asset to 2094 with a subsequent planned relinquishment date of FY2114 following closure and monitoring. At that point in time, all residual mining, processing operations and associated infrastructure (e.g. wellfields) would be closed and rehabilitated, to achieve post-closure landforms and land-uses agreed with regulators and stakeholders.

The purpose of this Closure Management and Rehabilitation Plan is to describe how the Olympic Dam operation will be successfully closed and rehabilitated to achieve the agreed post-closure land-uses and the agreed environmental outcomes for identified values. The plan also outlines the performance criteria that will be used to measure successful closure and rehabilitation.

This plan also addresses the necessary radiological considerations including the safe and secure disposal of the final radioactive processing residues, contaminated plant, soils and equipment.

For closure planning purposes, the site has been broken up into closure domains. The closure requirements and implementation works are similar within each domain, but may vary between domains. The various elements within each domain will be closed and rehabilitated where applicable to a specified/agreed standard. Rehabilitation and closure standard measures, closure design principles and completion criteria are documented.

Post-closure monitoring is also included in this plan to ensure these requirements are appropriately understood and costed. At this stage of planning, the monitoring requirements are generalised, but over time the post-closure monitoring program and schedule will be tailored to suit agreed completion criteria requirements. Ongoing monitoring, data collection and observation during operation are acknowledged as a key component in eventual relinquishment of the site.

This document describes aspects of the planned stakeholder engagement program. Such engagement and consultation on mine closure will only be meaningful closer to the closure date when the implications of closure on the post-closure community can be defined and understood.

This Closure Management and Rehabilitation Plan is supported by risk-based concept level (pre-feasibility) closure engineering designs that use best practice technology. The level of detail in the plan is commensurate with the early stages of planning.

The integrated closure planning system followed within BHP ensures that additional studies (and research where required) will be carried out to provide design data and to increase certainty and confidence in the design and implementation strategy well in advance of closure execution works. Outcomes from the research, study and consultation will be fed into the closure plan review as part of the continuous improvement and development of this Plan.

2 Scope and Purpose

2.1 Purpose and Process

The purpose of this Closure Management and Rehabilitation Plan (CMRP) is to define the closure objectives and commitments of Olympic Dam (OD) and how those will be met over the full life cycle of the mine. The CMRP also supports the closure cost estimate, guides progressive rehabilitation and outlines any knowledge gaps that need addressing throughout the Life of Asset (LoA). This ensures that mine closure is planned and systematic and demonstrates that risk-based closure is fully integrated into LoA planning to achieve successful closure with acceptably low post-closure risks.

The CMRP has been prepared to meet the requirements of:

- BHP’s Our Requirements Closure;
- BHP’s MinAus Closure Planning Standard (Version 1.0; September 2017); and
- OD’s Asset Closure Planning Guideline (ASTCL-000-ENG-GUI-001) (Version 3.0 June 2018)

The CRMP also forms a portion of the approved Olympic Dam Environment Protection and Management Program (EPMP).

The CMRP will be reviewed annually for material changes and updated as required.

2.2 Project Overview

OD is an underground mine, mineral processing plant, copper smelter and refinery producing copper cathode, uranium, gold and silver and is located 16km north of the Roxby Downs township and 570km north-northwest of Adelaide, South Australia (SA) (Figure 2-1).

The orebody was discovered in 1975 by a WMC Resources/BP joint venture and the subsequent operation was named after a livestock watering dam on the Roxby Downs pastoral lease under which the orebody lies. The purpose-built town of Roxby Downs retains the name of the pastoral lease on which it was established. In 1982 the Indenture Agreement between the WMC Resources/BP joint venture and the South Australian Government was ratified.

Mine production at the facility commenced in 1988. A major expansion of the operation to nominal capacity of 200,000 tonnes per annum (tpa) of refined copper was completed in 1999. In 1993 WMC (Olympic Dam Corporation) Pty Ltd purchased BP Group’s share, and in 2005 BHP acquired full ownership of WMC Resources. Once WMC (Olympic Dam Corporation) Pty Ltd became a member of the BHP Group, the name was changed to BHP Billiton Olympic Dam Corporation Pty Ltd. As at FY19, the current Optimised Base Plan (OBP) LoA for OD is until 2094, with a subsequent planned relinquishment date of FY2114 after twenty years of monitoring.

The mineral deposit contains variable concentrations of iron, copper, uranium, gold, silver barium, fluorine and rare earths, although only the extraction and processing of copper, uranium, gold and silver are currently considered commercially viable. The ore body and main mine development occurs to a depth of some 650 m in Precambrian basement rocks. The basement rocks are overlain by a generally horizontally bedded overburden sequence which comprises three main units. The deepest overburden unit is an essentially impermeable shale/mudstone unit (the Tregolana Shale) immediately overlying the ore body. The Tregolana Shale is overlain by approximately 200 m of Arcoona Quartzite, which, although lacking primary porosity, can be fractured in its lower sections and can yield water to ventilation shafts, decline, haulage shafts and drill holes. In turn, the Arcoona Quartzite is overlain by the Andamooka Limestone, between 40 and 100 m thick and occasionally outcropping.

The ore, once extracted, feeds the on-site metallurgical processing plant and has an annual production rate of 10 million tonnes. The metallurgical plant includes a concentrator, hydrometallurgical plant, copper smelter, copper refinery and slimes treatment plant. Process tailings are stored in a series of tailings storage cells, and excess process liquor that cannot be re-used in the process is evaporated in evaporation ponds. The tailings cells and evaporation ponds are collectively referred to as the Tailings Retention System (TRS). Following the completion of the refinery process, product is transported by road to storage facilities at Port Adelaide for export to international markets.

2.3 Current Mining Tenement

Table 2-1 provides detail of the existing authorised mining tenement (SML1) for OD. For the purpose of this CMRP only the Special Mining Lease (SML) and associated external facilities (such as the water supply wellfields and Roxby Downs township) are considered in any detail.

Table 2-1: Olympic Dam Mining Tenements (30 June 2018)

Lease / Area	Grant Date	Expiry Date	Tenure Holder / Applicants	Operational Land
SML 1	09 May 1986	08 May 2036	BHP BILLITON OLYMPIC DAM CORPORATION PTY LTD	Lot S1516 on Plan H833800 (WMC Olympic Dam Corporation) Pty Ltd

Figure 2-1: Olympic Dam Location Plan

2.4 Closure Features and Domains

To facilitate effective mine closure planning, OD operations have been divided into a number of physically distinct domains and features. The domains are comprised of features that have similar closure methodologies, landforms and land-uses (Table 2-2). Section 9 provides further details on the rehabilitation implementation for each domain.

Table 2-2: LoA Domains and Features

Domain	Components
Airport Facilities	• Olympic Dam Airport
Town Facilities	• Olympic Village • Olympic Dam sewage ponds • Roxby Downs town facilities
Metallurgical Plant and Administration Buildings	• Administration buildings • Processing plant and supporting infrastructure (e.g. ponds, bunds, tanks and powerlines) • Roads • Stockpile footprints • Stormwater diversion bunds and channels
Tailings Retention System	• Tailings storage cells • Evaporation ponds • Pipe trace
Pilot Plant	• Pilot Plant • Associated tailings ponds • Haul roads
Open Pit	• Clearing and grubbing area • Excavated area • Dewatering infrastructure • Mine haul roads • Stormwater diversion bunds • Topsoil stockpiles
Rock Storage Facility	• Current Storage Area • Cleared crusher pad area • Separate sand stockpiles
Wellfields and Associated Infrastructure	• Desalination plant • Water storage ponds • Pipelines • Water distribution pipelines and pump stations • Wellfields A and B • Access roads and tracks.
Contaminated Waste Disposal Facility	• Contaminated Waste Disposal Facility (only one cell currently in use)
Miscellaneous (including the underground mine and administration facilities)	• Mine administrative offices • Shafts decline, raise bores and associated surface infrastructure • Core yard • Mine roads • Stormwater diversion bunds and channels • Explosive magazine areas • Mine water settling and evaporation ponds • Stockpile including old mullock pile site • Cement Aggregated Fill (CAF) Plant and associated crushing, screening and backfilling infrastructure • Backfill limestone (for CAF) quarry and haul roads • Quarries and borrow pits • Waste management area • Exploration sites on the SML • Decommission local and regional water monitoring wells and any remaining mineral wells. • Arid Recovery area • Water and wastewater treatment facilities • Residual Infrastructure (powerlines, roads and hardstands)

Domain	Components
	• Transmission lines (Davenport to Olympic Dam) and easement.

2.5 Current Disturbance

Table 2-3 and Figure 2-2 provide a summary of the current disturbance for the mine and town facilities.

Table 2-3: Current Disturbance

Domain	Figure 2-2 legend key	Current Disturbance (ha)
Airport Facilities	Airport	26.4
Contaminated waste disposal facility	CWDF	1.6
Metallurgical Plant and Administration Facilities	Process	108.1
Miscellaneous (including the underground mine and administration facilities)	MISC	2425.5
Open Pit	Open pit	34.0
Pilot Plant	Pilot	12.2
Quarry	Quarry	134.2
Rock Storage Facility	RSF	40.4
Tailings Retention System	TRS	849.3
Town and Village Facilities	Town	510.2
Wellfield Facilities	BF	739.8
Total		**4881.9**

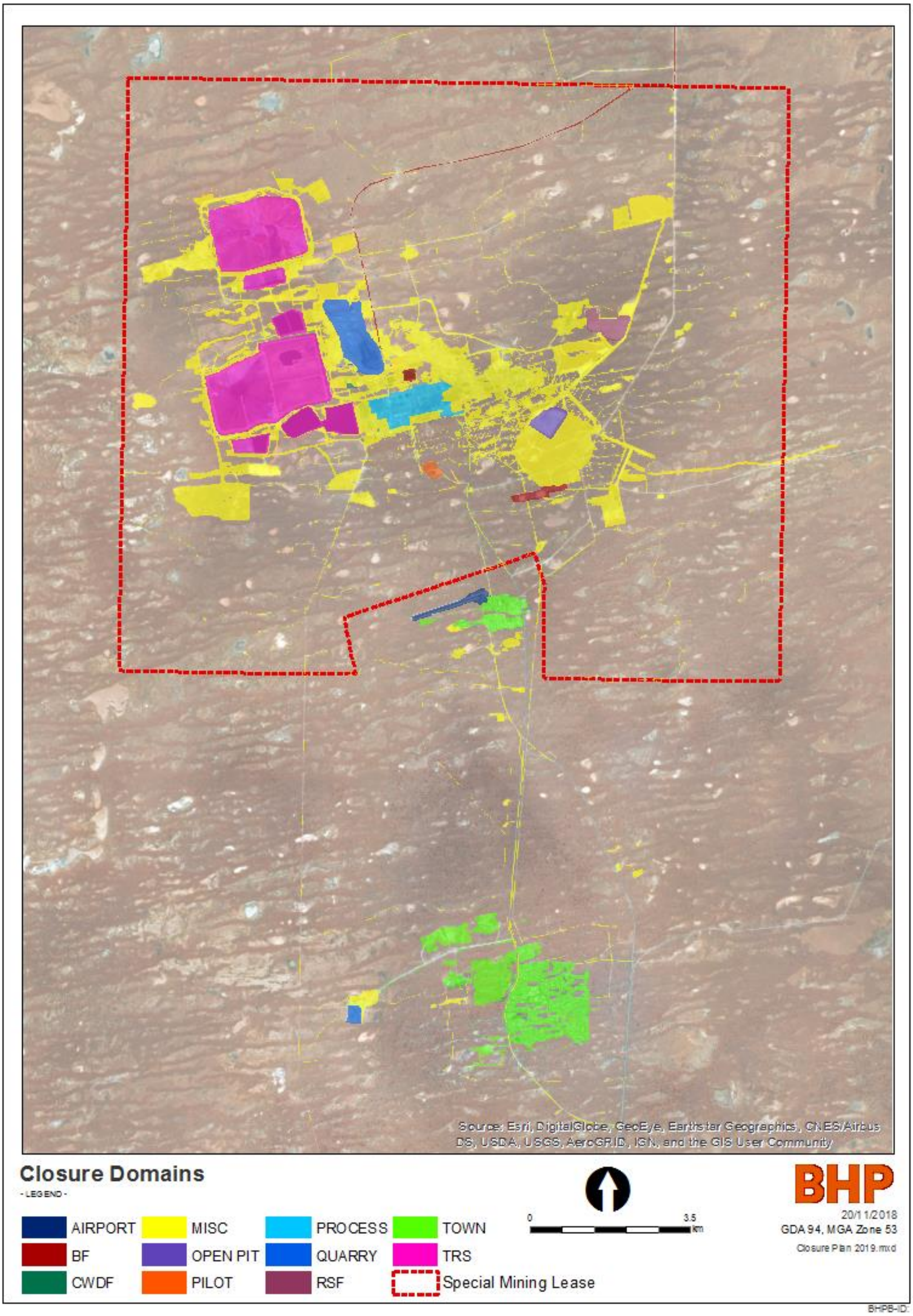


Figure 2-2: **Olympic Dam disturbance as at June 2018**

3 Roles and Responsibilities

The primary roles and responsibilities for deliverables, endorsements and approval of the CMRP are outlined in the BHP Olympic Dam Asset Closure Planning Closure Plan Guideline (ASTCL-000ENG-GUI0001) (Version 3.0 June 2018) and the MinAus Closure Planning Standard (Version 1.0; September 2017) (Table 3-1).

Management accountability for sites and associated facilities is with the operational General Manager/Head of Department, or as otherwise agreed to ensure legal obligations under state legislation are maintained including health and safety.

Table 3-1: Roles and Responsibilities

Deliverables / Roles	Asset Consolidated Closure Mgt. Plan	Closure Mgt. Plan	Regulatory Closure / Rehabilitation Plan	Closure Cost Estimate	Regulatory Closure cost estimate / security	Closure Provision	Sarbanes Oxley Controls (Closure Planning)
Manager Closure Planning	R	R		R	R	A	R
Manager Environment A&I	I	A/C	R		A		
Manager Environment BP	I	A/C	A/C	A	A		
Manager Investment and Evaluation				I		R	R
Finance Global Services				I			
Manager Accounting and Reporting	I			I		A	R
Manager Legal		A/C	A/C				
Head of Environment	C	A/Endorse	A/Endorse	A/Endorse	A/Endorse	I	
Head of RE/Geoscience	Endorse	A/Endorse	A/Endorse	A/Endorse	Endorse	I	
VP P&T	I	I		I	I	I	
VP HSE	Endorse	Approve		I			
VP Accounting and Reporting						Endorse	
General Manager	I	C	Approve	I			
Asset President	Approve	I		Approve		Approve	

R – Responsible A – Accountable C – Consult I - Inform

4 Closure Obligations and Commitments

A critical factor in defining the scope and context of closure is to identify and evaluate applicable legal obligations, guidelines and stakeholder expectations and commitments. Legal obligations for rehabilitation are generally found in legislation and in the mine development approvals and describe 'actions' that must be completed. These legal obligations should be considered as part of the closure planning process. Other commitments and obligations can include company standards, legal and other commitments made to regulators, and internal and external stakeholders with respect to mine closure and tenement relinquishment. The following sections provide an overview of the commitments and obligations considered relevant for OD closure planning.

4.1 Regulatory and Other Requirements

Key regulatory requirements, guidelines, policies and codes of practice that are relevant to the development of this CMRP and which may apply at closure are summarised in Table 4-1**.**

Table 4-1: **Regulatory and Other Commitments and Obligations**

Regulatory Document	Consideration
Aboriginal Heritage Act 1988 (SA)	The Act provides for the protection and preservation of the Aboriginal heritage and may need to be considered during closure for the current and surrounding lands.
Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)	The Code provides for radiation protection in mining and mineral processing industries and for protection of human health and the environment from the effects of radioactive waste from mining and mineral processing.
Environment Protection Act 1993 (SA)	In accordance with the objects of the EP Act, closure activities will need to consider the management of environmental harm.
Environment Protection and Biodiversity Conservation Act 1999 (Cth)	Not to undertake action that may have a significant impact on a matter of national environmental significance or on the environment within Commonwealth land without approval.
Native Vegetation Act 1991 (SA)	Provides for the preservation and enhancement of native vegetation and controls the clearance of native vegetation. Closure activities, including clearing of and rehabilitation outcomes may need to consider these requirements.
Guidelines for calculating a Significant Environmental Benefit Under the Native Vegetation Act 1991 and Native Vegetation Regulation 2017, Department of Environment Water and Natural Resources 2016	The Native Vegetation Act 1991 and Native Vegetation Regulations 2017 allow the clearance of native vegetation under certain circumstances. To prevent the further decline in native vegetation in South Australia, some clearance activities require the establishment of a Significant Environmental Benefit (SEB). An SEB is achieved through the establishment of an area of land to be managed and protected for the growth of native vegetation.
Heritage Places Act 1993 (SA)	Provision for the identification, recording and conservation of places and objects of non-Aboriginal heritage significance. Closure activities need to consider impacts on identified places and objects.
National Parks and Wildlife Act 1972 (SA)	Provides for the establishment, management and conservation of wildlife in a natural environment. Closure may need to consider requirements for surrounding lands.
Natural Resources Management Act 2004 (SA)	Promotes sustainable and integrated management of the State's natural resources; to make provision for the protection of the State's natural resources.
Pastoral Land Management and Conservation Act 1989 (SA)	Provides for the management and conservation of pastoral land. Closure and rehabilitation objectives may need to consider the requirements.

Regulatory Document	Consideration
Minerals Regulatory Guidelines MG2a and MG2b (SA)	Guidance for content related to care and maintenance, rehabilitation strategies and timing and mine completion.
Roxby Downs (Indenture Ratification) Act 1982 (SA)	Requirement for the EPMP and relevant codes.
Radiation Protection and Control Act 1982 (SA)	Provides for the control of activities related to radioactive substances and radiation apparatus, and for protecting the environment and the health and safety of people against the harmful effects of radiation.
'It's your place – A roadmap for managing natural resources in the SA Arid Lands Region 2017-2027', SA Arid Lands Natural Resources Management Board. Regional NRM Plan (Volume 1), 2017	10 year plan for maintaining and enhancing the natural resources of the SA Arid Lands NRM region.
South Australian Public Health Act 2011 (SA)	Promotes and provides for the protection of the health of the public of South Australia and to reduce the incidence of preventable illness, injury and disability.

4.2 Legal and Statutory Commitments and Obligations

A summary of the documents in which legal and statutory commitments and obligations were identified and which may apply at closure are summarised in Table 4-2. All statutory documentation is housed in BHP's *LandAssist* database

Table 4-2: Legal and Statutory Commitments and Obligations

Document	Document(s) Number	Consideration
Environmental disturbance Permits		Provide for the conditions of clearing on site. May contain rehabilitation conditions.
Environmental Impact Statement	1982 / 1997 / 2009 / 2011	Environmental Impact Assessment completed under State and/or Federal requirements. Generally inform the state and federal environmental approvals and contain closure and rehabilitation commitments and obligations.
Environmental Protection and Biodiversity Conservation Approval (EPBC)	EPBC 2005/2270	Federal approval under which mining activities can be completed that have an impact on Matters on National Environmental Significance (MNES). Approval contains rehabilitation and closure related conditions.
Ministerial Approval	ODO0005	Contains conditions permitting the construction of TSF cells 4 and 5. Condition requirements and design information will need to be demonstrated at closure.
Retention Lease and Extractive Minerals Lease (Quarry Permits)	EML5357 / EML5552 / RL76	Provides the conditions that must be met to permit quarry activities. Contains conditions requiring progressive rehabilitation.

4.3 Community Agreements

A review of existing community agreements did not identify any closure related commitments. Social investments (e.g. donations) occurring during operations are managed at an asset level. A review of donations will be undertaken as OD approaches closure.

5 Stakeholder Consultation

5.1 Stakeholder Identification and Approach

Stakeholder engagement is a critical component of successful mine closure planning. Through effective stakeholder engagement, organisational and community perspectives, knowledge is gathered to inform mine closure processes and goals. Effective stakeholder engagement increases the likelihood that mine closure outcomes will be beneficial, for both the operator and the broader community, and should involve all stakeholders. Working with stakeholders throughout the project lifecycle assists in reflecting the needs of stakeholders in the rehabilitation objectives for the site.

BHP has systems in place to identify stakeholder risks and concerns related to the operations, including BHP's 'Our Requirements – Communications, Community and External Engagement', which considers the need for developing a Stakeholder Engagement Strategy. Furthermore, BHP is a signatory to the International Council for Mining and Metals' (ICMM) Sustainable Development Principles and the Minerals Council of Australia (MCA) Enduring Value, both of which require member companies to conform to actions where mines are being operated. Both industry bodies outline sustainable development principles for member companies including the requirement to 'proactively engage key stakeholders on sustainable development challenges and opportunities in an open and transparent manner (ICMM 2015) and consult with interested and affected parties to identify, assess and manage all significant social, health, safety, environmental and economic impacts associated with our activities'.

One of the primary objectives of the OD CMRP is to ensure that stakeholder needs, concerns and aspirations are taken into account for closure planning. The existing stakeholder engagement approach will be reviewed throughout the LoA and if required, adapted to meet the needs of closure planning.

The objectives of the stakeholder engagement strategy with respect to closure will include:

- Ensuring all internal and external stakeholders are identified and interests and concerns understood;
- Keeping identified stakeholders informed of relevant activities and progress at the mine, specific to the LoA and closure;
- Maintain and nurture existing stakeholder relationships;
- Identify stakeholder concerns about rehabilitation and mine closure;
- Consider and address stakeholder concerns where possible, as they arise; and
- Provide timely, accurate and credible information to the identified stakeholders up until relinquishment is achieved.

Owing to the extensive remaining life of the mine and the current consultation processes for the operation, discussions with interested parties and stakeholders about closure planning of the existing operations have not commenced. Stakeholder engagement will be held at appropriate stages during the evolution of the mine and the mine closure.

5.2 Five Year Engagement Goals

In addition to the regular and ongoing engagement with regulatory authorities, Table 5-1 provides a summary of the planned engagement activities with other community stakeholders identified to occur within the next 5 years:

Table 5-1: Five Year Engagement Activities

Stakeholder	Engagement
Olympic Dam employees, contractors and suppliers	Updates on demolition and rehabilitation activities
Roxby Downs, Woomera and Andamooka communities	Updates on demolition and progressive rehabilitation activities

5.3 Community Profile

The resident population of the Roxby Downs Local Government Area (LGA) during 2017 was estimated at 3,979 (Australian Bureau of Statistics, 2018). The major contributor to the Roxby Downs economy is the mining resource sector with mining making up 51.8% of jobs, followed next by education (6.3%) and construction and administrative support services, both making up 5.8% of jobs (Australian Bureau of Statistics, 2018). Table 5-2 provides a summary of the key social and economic features for the Roxby Downs LGA.

Table 5-2: Roxby Downs Local Government Area Economic Features (ABS, 2018)

Economic Measure	Statistic
Resident Population	3,979 (2017)
Median Total Income	$86,357
Industry of Employment	The top five industries of employment: • Mining: 51.8% • Education and Training: 6.3% • Construction: 5.8% • Administrative and Support Services: 5.8% • Accommodation and Food Services: 5.1%
Occupation	The top five occupations of employment: • Technicians and Trade Workers: 26.6% • Machinery Operators and Drivers: 22.4% • Professionals: 13.5% • Labourers: 9.1% • Clerical and Administrative Services: 8.5%
Unemployment	Increasing since 2011 (1.8%) to 3.5% in 2016
Age Groups	The main age groups are: • 0-14 years: 26.7% • 25-34 years: 23.1% • 35-44 years: 16.7%
Education	Post School Qualification (64.6%), Certificate (33.1%), Bachelor Degree (10.3%)
Household Composition	• Total households: 1,177 • Predominantly family households (866) • Lone person households (258)
Dwelling Tenure	Renting (69.8%), Owned with mortgage (22.2%), Owned outright (5.8%),

5.4 Community Exit Strategy

OD operations are located within and near various communities. The major host community supporting OD which will be impacted as a result of OD's closure is Roxby Downs. Roxby Downs major industry of employment is mining, making up 51.8%.

It is recognized that the development of OD included construction and ongoing support of public infrastructure including roads, water supply and airports as well as a range of ancillary services and direct and indirect employment opportunities.

Planned closure activities will include the demolition and removal of all BHP buildings and structures and rehabilitation of the Olympic Village, the Olympic Dam Sewage Ponds, the Olympic Dam Airport and Roxby Downs Town Facilities. The potential to hand these facilities over to an interested party (e.g. government) will be part of the stakeholder/public consultation process leading up to final closure. The closure plan has not considered any areas or facilities which Roxby Council is responsible for operating and maintaining.

As part of the closure planning process, a Social and Economic Impact Assessment (SEIA) will be completed 10 years prior to closure to allow positive and negative impacts to be addressed. The SEIA will aim to address:

- Potential impacts of closure;
- Extent/magnitude of impacts likely to be experienced;
- Resilience of stakeholders and host communities to respond to change (e.g. without support from BHP);
- How negative impacts may be mitigated or beneficial impacts enhanced, to facilitate the closure process (e.g. transitioning ownership of assets or built infrastructure to interested stakeholders, investigating opportunities to transition local employment to closure / post closure monitoring period); and
- Opportunities for transitioning OD's current social investment to sustainable practices post closure.

5.5 Stakeholder Register

Appendix A provides an overview of the identified stakeholders with respect to OD's rehabilitation and closure planning.

6 Rehabilitation Goals, Objectives and Criteria

Rehabilitation is defined as "a process where disturbed land is returned to a stable, productive and self-sustaining condition, taking future land use into account (EPA 2006)". The rehabilitation sequence is normally considered to comprise of the following activities:

- developing designs for appropriate landforms for the mine site;
- creating landforms that will behave and evolve in a predictable manner, according to the design principles established; and
- establishing appropriate sustainable ecosystems (DITR 2006).

6.1 Rehabilitation Goals

The general goals for OD's rehabilitation are to create a post mine land use that is:

- Safe to humans and wildlife;
- Non-polluting;
- Stable; and
- Able to sustain an agreed post mine land use.

6.2 Final Land Use

The proposed final land uses to achieve the closure goals have been defined, as far as is reasonably achievable, as:

- SML Area:
  - land use for rehabilitation at original ground level: revegetated vacant crown land with potential for restricted grazing;
  - above ground tailings retention facilities and below ground open pit: vegetation free (to the extent possible) vacant crown land with restricted public and fauna access;
  - above ground rock storage facility: naturally revegetated vacant crown land with restricted public and fauna access.
- Areas outside of SML: land use consistent with neighbouring properties.

The final closure land uses will be negotiated with the stakeholders and communities throughout the LoA, including the demolition, retention or repurposing of BHP built infrastructure such as Olympic Dam Airport, Roxby Downs Town Facilities, Olympic Village and Olympic Dam Sewage Ponds. It is possible that a variety of land uses will be discussed and negotiated in order to ensure that the post-closure land uses promote and support the viability and sustainability of the post-closure communities that will remain in the region after closure of the mining operation.

6.3 Closure Environmental Outcomes and Assessment Criteria

The high level closure outcomes and assessment criteria for OD are summarised in Table 6-1, from which site-specific, domain-specific and area-specific assessment criteria are derived. The environmental outcomes are based on post-closure, to be achieved in the long term following closure and rehabilitation activities. The activities undertaken during closure would be carried out to comply with the outcomes and compliance criteria in place during the mines operation.

Importantly the proposed indicators and criteria will be refined through ongoing trials, monitoring and investigations and in consultation with key stakeholders and regulatory authorities. A monitoring programme will be established and updated as required to track progress of rehabilitation, inform ongoing management and to demonstrate that the rehabilitation has achieved or is trending toward the rehabilitation goals (Section 10). A review of the completion criteria will be undertaken as required and refined from monitoring results as further information becomes available.

Table 6-1: Closure Outcomes and Criteria

EM Program	Environmental Outcomes	Assessment Criteria	Applicable Domain(s)
Use of Natural Resources			
Land disturbance and rehabilitation	• Rehabilitation provides a geotechnically and geochemically stable and safe environment to reduce the need for long-term monitoring and maintenance	• Rehabilitation of sites and its integration into adjacent land uses occurs as soon as reasonably practical and in accordance with the Leading Practice Sustainable Development Program for the Mining Industry. • Erosion resistant landforms achieved such that post-closure remediation works are not required. • 'Contaminated areas assessed in accordance with NEPM 1999, and assessed and where necessary remediated to SA EPA requirements under the Environment Protection Act 1993 and relevant guidelines criteria at the time of closure. • Monitoring (e.g. ecosystem function analysis) shows satisfactory rehabilitation progress with diversity and structure approaching that observed at appropriate reference areas	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility.
Spread of pest plants and animals	• No significant increase in the areas of infestation or abundance of declared pest plants, plant pathogens or pest animal populations as a result of closure.	• No material difference in abundance of declared pest species compared to appropriate reference areas. • No introduction of new self-sustaining declared pest populations post-closure as a result of BHP activities	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility
Aquifer level drawdown	• No significant adverse impact on third party groundwater users.	• Groundwater quality and yield, for third party users, commensurate with agreed future land use.	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility
Operation of Industrial Systems			
Particulate emissions	• No adverse impacts to public health as a result of particulate emissions from the final landforms achieved.	• NEPM (ambient air) criteria for public exposure, or the relevant criteria at the time of closure, applied to final landforms.	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility

EM Program	Environmental Outcomes	Assessment Criteria	Applicable Domain(s)
Radioactive emissions	• No adverse impacts to public health as a result of radioactive emissions from final landforms. • No significant adverse radiological impacts to ecological communities as a result of radioactive emissions from final landforms.	• A dose limit for radiation doses to members of the public of 1 mSv/y above natural background • Deposition of closed site originated 238U less than 25 Bq/m2/y at non-human biota assessment sites	Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Contaminated Waste Disposal Facility
Generation of Industry Wastes			
Embankment stability of TSF	• Final landforms geotechnically stable.	• No significant TSF embankment failure.	Tailings Retention System
Tailings and Rock Storage Facility (RSF) seepage	• No significant adverse impact on vegetation as a result of seepage from the TSF or RSF post-closure. • No compromise of existing and future land uses on adjoining areas as a result of seepage from the TSF or RSF post-closure.	• Surface and groundwater quality commensurate with agreed future land use (for third party users).	Tailings Retention System and Rock Storage Facility
Stormwater discharge	• No significant adverse impact on local drainage patterns and water quality, arising from discharge associated with the final landform, which would compromise existing water use and water-dependent ecosystems.	• All contact storm water maintained within designated storm water management areas.	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility
Solid waste disposal	• No significant adverse impacts from solid wastes following closure.	• Relevant criteria at the time of closure, for surface water and groundwater and for air quality. • Landfill facility decommissioning and/or rehabilitation in accordance with SA EPA landfill guidelines and requirements.	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility
Radioactive waste	• No adverse impacts to public health as a result of radioactive emissions from final landforms. • No significant adverse radiological impacts to ecological communities as a result of radioactive emissions from final landforms.	• A dose limit for radiation doses to members of the public of 1 mSv/y above natural background. • Deposition of closed site originated 238U less than 25 Bq/m2/y at non-human biota assessment sites	Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Contaminated Waste Disposal Facility
Containment of waste rock	• Maintain structural integrity of the RSF.	• No unplanned structural failure to the RSF resulting in a significant adverse impact to third party surface and groundwater users.	Rock Storage Facility

EM Program	Environmental Outcomes	Assessment Criteria	Applicable Domain(s)
Employment and Accommodation of People			
Community interactions and workplace interactions	• Communities in which BHP operates value their relationship with us.	• Safe conditions and controls to restrict inadvertent access to unsafe environments following rehabilitation	Airport, Town Facilities, Metallurgical Plant and Administration Facilities, Tailings Retention System, Pilot Plant, Open Pit, Rock Storage Facility, Miscellaneous, Wellfields and Associated Infrastructure, Contaminated Waste Disposal Facility

7 Collection and Analysis of Closure Data

The following section provides a summary of the physical and biological environment that influence closure planning and rehabilitation decision making at OD and has been obtained from the baseline assessments completed as part of previous Environmental Impact Statements (EIS) (1982, 1997 and 2009), the Supplementary EIS (2010), operational studies and the Environmental Protection and Management Program. This knowledge base, along with the feedback from key stakeholders will be subject to review and update throughout the LoA to ensure its continued relevance and accuracy. Gaps in the knowledge base and which have the potential to influence the closure outcomes have been identified and preliminary actions identified. These actions will form future studies to close the identified gap. A consolidated list of the identified gaps and preliminary actions is included in Appendix B.

7.1 Climate

7.1.1 Existing Climate

The climate is arid with average annual rainfall of 148 millimetres (mm) and annual average evaporation of approximately 3000 mm recorded at the closest meteorological recording station (Roxby Downs Olympic Dam Aerodrome Site No. 016096). The temperature ranges from cool winters, with mean daily minima and maxima of 5°C and 19°C respectively, to hot summers with mean daily minima and maxima of 20°C and 36°C respectively (Figure 7-1). Rainfall is erratic, and most years Olympic Dam experiences periods of two to three months with no significant rainfall. Long sustained periods of intense rainfall are very rare, but large intensity and short duration storm events associated with thunderstorm activity can occur in any month. The 1-in-100 72-hour annual exceedance probability (AEP) rainfall event is 158 mm and the 1-in-500 AEP is 272 mm (12-hour duration).

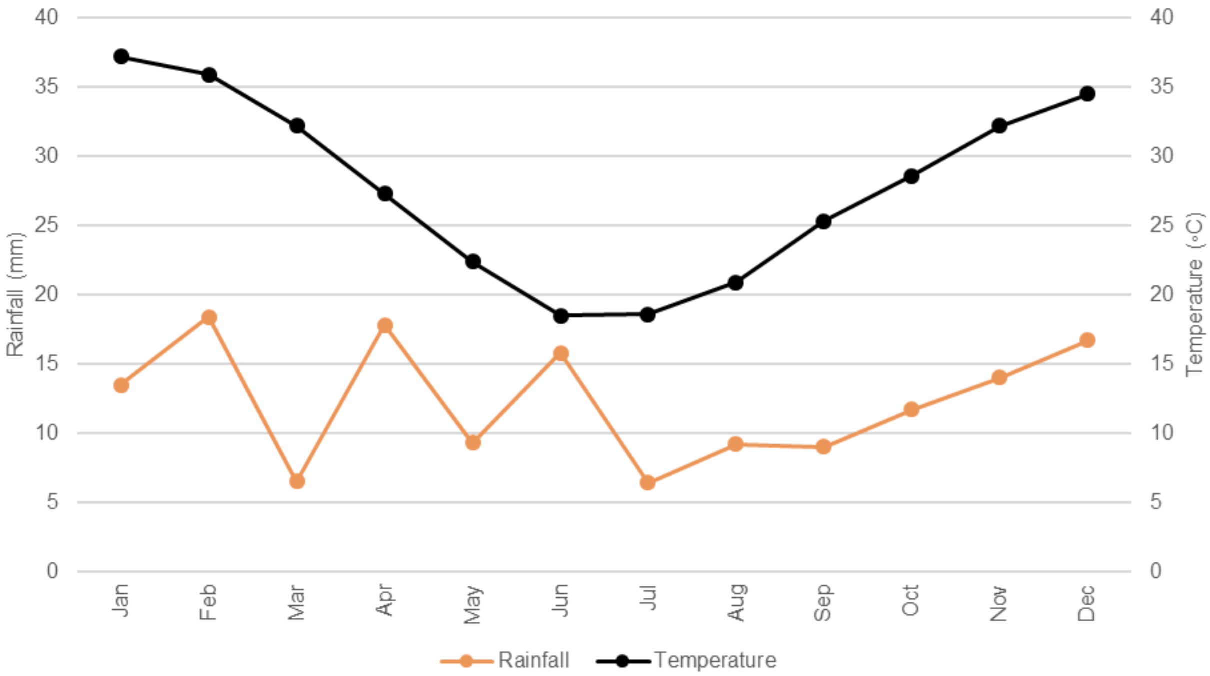


Figure 7-1: **Mean Maximum Temperature and Rainfall (Roxby Downs Olympic Dam Aerodrome Site No. 016096) (BOM 2018)**

7.1.2 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) regularly undertakes an assessment of global climate change literature. BHP accepts the IPCC's current view that warming is unequivocal, human influence is clear and physical impacts are unavoidable. Australia's CSIRO has completed climate change projections to support the planning needs of Australia's natural resource management sector, and to provide information to assist climate adaptation processes. Based on this work, OD lies within the CSIRO modelled Rangelands Cluster (Watterson et al, 2015). The vast Rangelands cluster extends across much of the iconic 'Outback'. It contains varied landscapes, including the Flinders and Pilbara Ranges, salt lakes that flood sporadically (Hope et al., 2004), and the Centre (Watterson et al, 2015). The Rangelands Cluster consists of a wide range of vegetation, from tropical woodlands to shrublands, grasslands and saltbush, and it includes relatively intact ecosystems. Water features are mostly intermittent, and aside from the coastal rivers of the west, most streams drain into salty lakes, in particular Lake Eyre (Watterson et al, 2015). Change in climate conditions for the Rangelands Cluster forecast by CSIRO and which may impact OD include:

- Increase in average mean maximum and minimum temperatures;
- Hotter and more frequent hot days and fewer frosts;
- Rainfall changes are unclear, but likely less rainfall in winter and spring and increased intensity of heavy rainfall events;
- Increased evaporation rates in summer and reduced soil moisture in all seasons; and
- A harsher fire-weather climate.

7.1.3 Knowledge Gaps

Knowledge gaps and preliminary actions with respect to climate and climate change and which may have impacts on closure outcomes are outlined in Table 7-1.

Table 7-1: Climate and Climate Change Knowledge Gaps and Actions

Knowledge Gap	Preliminary Action
Suitability of rehabilitation species selection to sustain hotter and dryer climates with less soil moisture	Observation of trends from rehabilitation monitoring
Ability for landform designs (TSFs and RSF) to withstand increased intensity of extreme rainfall events	Landform evolution modelling of retained landforms Include climate change impacts in any future rehabilitation designs
Ability of capping treatments to withstand increased evaporation rates.	Closure designs to incorporate climate change predictions

7.2 Waste Material Characteristics

At Olympic Dam, material bought to the surface from the underground mine is placed in Run of Mine (ROM) stockpiles and put through the metallurgical processing circuit. The processing of the ore results in the removal of around 2-3% of the rock mass, being the mineralised component. The remainder (excluding a small portion that is used to produce cement aggregate fill (CAF) for mine backfill) comprising primarily of finely crushed rock and clay, is managed in Olympic Dam's TRS.

7.2.1 Overburden (Rock Storage Facility)

To support the proposed open pit expansion described in the 2009 EIS, an RSF was assessed and construction of an RSF commenced within the SML following approval of the project in October 2011. In August 2012 a decision was taken to place the majority of the components of the approved expansion on hold while more cost effective mining and processing technologies were explored, and all RSF construction ceased by June 2013. No potentially reactive waste material was placed and the content is currently limited to benign material extracted from the starter pit, being sands and unconsolidated clays. Although the current LoA plan does not include an RSF, there may be a requirement to store low and medium grade waste rock in long-term (potentially permanent) stockpiles. Closure requirements for these storage facilities will be addressed in future versions of this CMRP, should those storage facilities eventuate.

7.2.2 Tailings Storage Facilities

Tailings are the waste product stream from the metallurgical operations. They consist of a slurry of fine rock particles and acidic liquor from which the economically-recoverable minerals have been extracted. The slurry is pumped to the TRS and deposited within the two operating Tailings Storage Facilities (TSF). These cells are paddock type construction with upstream raises. Within the TSFs, the tailings solids settle and the tailings liquor not evaporated or retained in the tails mass is reclaimed to evaporation ponds. The tailings contain ~70-80% of the radioactive material associated with the original ore. The tailings are deposited as a slurry at about 47% solids concentrations. The tailings liquor is acidic and contains dissolved metals (BHP Billiton, 2009).

Approximately 9.1M tonnes of tailings solids and about 9-10GL of liquor from the processing operations are discharged to the TRS per annum. The individual TSF walls are raised at a rate of less than 2m per annum and are constructed of compacted tailings and local sandy clays, with an outer rock armouring. The cells have been located where there is an underlying layer of superficial clay. The whole site is underlain by a deeper limestone geology. Cells 1-3 were constructed without a geomembrane liner. TSFs 4 and 5 have a centrally located HDPE liner under the decant area in the centre of the cell that is overlain with an underdrain system. Additionally, TSF5 has an internal heel drain sand layer and a downstream toe drain to improve drainage in the embankment and to capture lateral seepage. Some hazardous materials, including process spillage material and low-level radioactive wastes are also disposed of in the TSF into assigned waste finger areas out on the tailings beach.

As of June 2018, the facility consists of five (5) cells covering approximately 640ha within the SML, with only two currently in operation. The individual cells vary in height but have an approved raise height of 30-40m. Upon closure, the TSF will remain as a permanent land feature.

7.2.3 Knowledge Gaps

Table 7-2 outlines the knowledge gaps and preliminary actions with respect to waste material characteristics.

Table 7-2: Waste Material Characteristics Knowledge Gaps and Actions

Knowledge Gap	Preliminary Action
TSF capping and landform suitability	Complete TSF capping trials
Potential for acid forming material to be generated from permanent low and medium grade waste ore storage areas	Ensure that adequate knowledge is gathered to inform design criteria prior to any permanent storage areas being constructed

7.3 Soil Characteristics

7.3.1 Soil and Terrain

Although past erosional cycles have removed varying thicknesses of these materials, the resulting surface remains essentially flat, consisting of an extensive stony tableland. In places where extensive deep erosion has occurred, claypans, swamps and lagoons have formed at the terminal points of the internal drainage systems.

The more recent Quaternary deposits form a thin veneer of aeolian origin over much of the tableland surface. In many places these deposits form the most dominant feature of the landscape, comprising a series of east west oriented red quartz sand dunes. The dunes are highly variable, with heights of up to 10 m, widths to a maximum of 300 m, and dune spacing from about 100 m to several kilometres. When closely spaced, the interdune areas form gentle concave swales covered with sandy soil and are often well vegetated with trees and shrubs. Where dunes are more widely spaced, the tableland surface, with its more silty and clayey sandy soils, gibber and drainage features, is exposed.

The characteristics of the tableland surface vary considerably over the region, and depend on the underlying rock type and the thickness of the Quaternary sediments. In the majority of the Project Area the underlying rock type is Andamooka Limestone. In some areas the bedrock is very shallow, and outcrops occur in some places. The tableland surface is generally undulating, with sandy textured soils and extensive occurrences of gibber in the swale areas. The soils contain large quantities of calcareous material, possibly derived from weathering of the underlying rock. Drainage is into claypans, vegetated shallow depressions or, occasionally, small dolines. Table 7-3 provides a high-level topsoil balance based on the current disturbance footprint.

Table 7-3: **Olympic Dam Topsoil Balance (30 June 2018)**

Topsoil component	Volume
Area requiring topsoil (ha) (excludes TSFs)	3,718
Current topsoil stockpiles (m3)	500,691
Topsoil requirements for current open footprint at 100mm depth (m3)	3,718,000
Deficit based on current stockpiles (m3)	3,217,309

7.3.2 Knowledge gaps

Table 7-4 outlines the knowledge gaps and preliminary actions to with respect to soil.

Table 7-4: **Soil and Post Mine Land Suitability Knowledge Gaps**

Knowledge Gap	Preliminary Action
Long-term viability of topsoil stockpiles	Complete rehabilitation research project to better understand closure liabilities

7.4 Flora

The Olympic Dam Area of Influence extends over three bioregions, including Gawler, Stony Plains and Simpson Strzelecki Dunefields. The vegetation type over these regions range from acacia low woodlands and shrub lands with chenopod shrub lands to hummock grasslands.

The vegetation in the region is determined by the terrain structure and climate. The terrain of the Olympic Dam region consists of low parallel dunes with an east-west orientation. The dunes may be close together or separated by swales which vary in width, the narrowest in the southern parts of the Roxby Downs Municipal Lease and the broadest to the north of the mine.

Three vegetation communities are present within the OD region, namely:

- Dunefield vegetation (dune ridge, slopes and swales);

- Drainage area vegetation;
- Stoney tableland vegetation.

Of the three vegetation communities, the primary vegetation community and which is found on the SML is dunefield vegetation.

Vegetation on the dunes consists of low woodlands or tall shrublands of Northern Cypress Pine (*Callitris glaucophylla*), Horse Mulga (*Acacia ramulosa*), Narrow Leaved Hopbush (*Dodonaea viscosa*) and Sandhill Wattle (*Acacia ligulata*). The understorey consists mainly of grasses and ephemeral herbs. The pines are most common in the vicinity of Roxby Downs, becoming less common north of Olympic Village.

Swale vegetation is dominated by chenopod shrublands of Bladder Saltbush (Atriplex vesicaria) and Low Bluebush (*Maireana astrotricha*), with associated short-lived chenopods, grasses and ephemeral herbs. Some swales also contain low woodlands of Western Myall (*Acacia papyrocarpa*), with either a chenopod or grass understorey. Mulga (*Acacia aneura*) is common at the base of dunes and also on low sand rises, usually with a grassy or herbaceous understorey. The broad swales north of the mine are dominated by Bladder Saltbush, Glasswort (*Sclerostegia tenuis*) and Bristly Sea-Heath (*Frankenia serpylifolia*) with an understorey of grasses and ephemeral herbs.

Four flora species listed under the EPBC Act and 34 flora species listed under the NPW Act are recognised to potentially occur in ODC's Area of Influence. *Eriocaulon carsonii*, listed as Endangered under the EPBC Act and NPW Act, is known to occur on GAB mound springs within ODC's predicted impact zone for water drawdown. Sandalwood (*Santalum spicatum*), listed as Vulnerable under the NPW Act, has been recorded in the Olympic Dam region, however, it is not known on the SML. Similarly, Koch's saltbush (*Atriplex kochiana*) has been recorded in many locations in the Olympic Dam region, however, it is not known to occur on the SML.

Acacia aneura Low Woodland on sand plains are a listed as a threatened ecological community under the NPW Act and are known to exist in small clusters on the SML. While potential impacts to the threatened ecological community may occur on the SML, it is unlikely that this would result in a significant impact to the population and distribution overall. Regardless, the Environmental Disturbance Permit (EDP) process assists to minimise impacts to these threatened ecological communities.

7.4.1 Weeds and Declared Plants

Species declared under NRM Act 2004 (as of January 2015) that are known to be present within the Olympic Dam region are detailed in Table 7-5. The current distribution of priority species is determined during scheduled weed monitoring.

Table 7-5: **NRM Act 2004 Declared Weeds**

Scientific Name	Common Nam
Opuntia spp.	Prickly Pear
Cenchus ciliaris	Buffel Grass
Cenchrus incertus	Innocent Weed
Tribulus terrestris	Caltrop
Echium plantagineum	Salvation Jane
Tamarix aphylla	Athel Pine
Lycium ferocissimum	African Boxthorn

7.4.2 Knowledge gaps

Table 7-6 outlines the knowledge gaps and preliminary actions with respect to vegetation.

Table 7-6: **Vegetation Knowledge Gaps and Actions**

Knowledge Gap	Preliminary Action
Updated impacts on remnant vegetation based on LoA	Re-assess vegetation impacts based on current LoA
Pre-mine planned clearing vs. LoA planned clearing	Review LoA disturbance vs planned disturbance

7.5 Fauna

The mosaic of dunes and interdunal swales, woodland, shrubland, grassland and bare ground habitats in the Olympic Dam region support a diverse fauna community. Over 190 bird species have been recorded in the Olympic Dam region. These are largely bushbirds associated with the Callitris and Acacia woodlands, and chenopod shrublands. Others include waterbirds (including some listed migratory bird species) that are attracted to the natural ephemeral and artificial waterbodies; and some vagrant species such as the Plains-wanderer (*Pedionomus torquatus*).

The local reptile community is diverse by world standards, although the regional pool of 47 species is less than that found in some other Australian arid zone habitats. Several large reptile species, including two venomous elapid snakes, are conspicuous elements of the local fauna.

By contrast, most of the 25 native mammal species recorded in the region (29 if Arid Recovery species are included) are small and nocturnal and hence rarely seen. The Desert Mouse (*Pseudomys desertor*), which has been observed on the SML, was once thought to be rare in South Australia but recent studies suggest that the rodent is widespread and secure. Notably, the Plains Rat (*Pseudomys australis*) and the Hopping Mouse (*Notomys alexis*) were recorded within the SML for the first time in 1998 and the Kultar (*Antechinomys laniger*) in 2008. Red Kangaroos (*Macropus rufus*) are common throughout the region. Introduced species, including the European Rabbit (*Oryctolagus cuniculus*), cats (*Felis. catus*) and foxes (*Vulpes vulpes*) are also common, all of which have a significant adverse impact on the local ecosystem.

The Trilling Frog (*Neobatrachus centralis*) is the only amphibian species recorded from the area, and is only found on the surface following heavy rains during warmer months.

Twenty-eight fauna species listed under the EPBC Act and 52 fauna species listed under the NPW Act are known to occur or could potentially occur in the Olympic Dam Area of Influence. Sixteen of these are listed as Migratory under the EPBC Act and the majority could be potentially impacted by the operation of the TRS. Eight mammal species listed under the EPBC Act have also been identified to potentially occur in the area, five of those have been reintroduced to the Arid Recovery reserve.

The Plains Rat listed as Vulnerable under the EPBC Act has confirmed records located on the SML. However, their population is widespread throughout South Australia and recent data indicates that Arid Recovery may act as a source for Plains Rats due to the predator exclosure fence. Therefore, the species is not likely to be significantly impacted by the Olympic Dam operation. The EDP process assists to minimise impacts to its refuge habitat.

7.5.1 Knowledge gaps

Table 7-7 outlines the knowledge gaps and preliminary actions with respect to fauna.

Table 7-7: **Fauna Knowledge Gaps and Actions**

Knowledge Gap	Preliminary Action
Updated impacts on fauna based on LoA	Re-assess fauna impacts based on current LoA

7.6 Radiation

Pathways of exposure (i.e. the mechanisms by which radiation or radioactive materials can be transported from the operation to people) are described in International Commission on Radiological Protection (ICRP) Publication 29 (ICRP 1979). The primary exposure pathways for members of the public from the operations at Olympic Dam are the inhalation of radon decay products and the inhalation of radionuclides in dust (ODC 1996a). Doses to members of the public are based on these inhalation radiation exposure pathways.

Ingestion of radionuclides from the consumption of local fauna and flora is another pathway but it has not been included in public dose assessments because it has been verified as negligible (ODC 1996b). Similarly, direct gamma radiation from the operation has also not been included because it reduces by many orders of magnitude over a distance of one kilometre and therefore results in negligible public exposure.

Radiation related impacts of the current operations have been monitored for over 25 years and can be summarised as:

- radon from the current operations is not readily discernible above natural background beyond four kilometres (km) from the operations;
- radionuclides in airborne dust at receptor sites show no changes since operations began;
- radionuclides in vegetation from current operations are statistically measurable up to about five km from the operations, but no impacts have been observed;
- a study of kangaroos showed no statistical difference in radionuclide concentrations between samples from inside the mine lease and samples from outside the mine lease;
- radionuclides in soil show no marked variation over time;

- increases in uranium concentrations have been seen in groundwater directly beneath the TSF, although this is very localised with insignificant changes elsewhere.

Overall, the environmental radiation impact is low, with measured increases observed close to the operation that are well within compliance requirements. Doses to residents of Roxby Downs are approximately 0.025 mSv/y, well below the member of the public dose limit of 1 mSv/y.

7.7 Hydrology

7.7.1 Conceptual Baseline Understanding

7.7.1.1 Surface Water

The surface hydrology in the vicinity of the OD is characterised by a mosaic of small catchments, which range in area from 10 to 300 ha. The boundaries are generally defined by the east/west trending sand dunes. Stormwater occurs only after rare heavy rain events, as ponds in inter dune swales from where it evaporates. Groundwater recharge is a very small proportion of rainfall and considered to be 0.01 to 0.06 per cent of annual rainfall which is ~160 to 170 mm per annum. The flat-lying dune field which controls surface water hydrology extends to at least 15 km from the site.

There are no features of any significance within the area of the mine, and the location of the TRS and open cut pit do not interrupt any supply flows or permanent water features (Figure 7-2). The nearest defined surface watercourses more than 15 km to the north and these drain toward saline playa lakes including Lake Torrens, located 45 km to the west. The nearest known permanent natural surface water body is Yarrawurta Spring located 50 km to the northwest and on the north side of Lake Torrens. The spring is saline (60 g/L TDS) and sustained by groundwater flow (BHP Billiton, 2009)

7.7.1.2 Groundwater

There are two important groundwater systems in the Stuart Shelf: the Andamooka Limestone aquifer and the Tent Hill aquifer. These form the overlying cover sequence at Olympic Dam and consist of Cambrian shale and limestone, and Late Proterozoic quartzite, sandstone and shale members, mostly of very low permeability.

The upper Andamooka Limestone aquifer is the shallowest of the aquifers in the Stuart Shelf and forms the regional 'water table' aquifer north of Olympic Dam. The water table typically occurs about 50 metres (m) below ground (i.e. 50 m Australian Height Datum (AHD), with groundwater in the aquifer moving from west of the Stuart Shelf to the northern end of Lake Torrens, where the water table typically occurs less than 10 m below ground. Groundwater salinity is typically in the range of 20,000 to 60,000 milligram per litre (mg/L) on the SML, increasing to as much as 200,000 mg/L closer to Lake Torrens.

The Tent Hill aquifer is extensive and is the most important aquifer within the southern portion of the Stuart Shelf, where the Andamooka Limestone aquifer is either very thin or absent. It includes the lower parts of the Arcoona Quartzite and the Corraberra Sandstone units of the Tent Hill Formation and is therefore sometimes referred to as the Arcoona Quartzite aquifer or the Corraberra Sandstone aquifer. The aquifer occurrences reduce north of the SML due to a deepening of the unit and reduction in permeability.

At Olympic Dam, the Tent Hill aquifer typically occurs 160 to 200 m below ground level (about -60 mAHD to -100 mAHD). The depth increases moderately to the north, west and south, with the base of the unit around 225 m below ground level (-125 mAHD) near the existing underground mine and more than 400 m below ground level (-300 mAHD) north of Olympic Dam.

Groundwater salinity in the Tent Hill aquifer is generally higher than in the Andamooka Limestone aquifer, with reported concentrations ranging from about 35,000 to more than 100,000 mg/L in the vicinity of Olympic Dam, and ranging to around 200,000 mg/L closer to Lake Torrens.

The upper section of the Arcoona Quartzite unit forms an aquitard. This is a low permeability layer that restricts the movement of groundwater between the Andamooka Limestone and Tent Hill aquifers

7.7.2 Change Assessment

Hydro-geochemical modelling of potential impacts on groundwater that may result both during operation and post-closure has been carried out (SRK, 2015). The modelling work included development of appropriate source terms for potential sources of impact on groundwater quality. Primary sources of contaminants include:

- TSF;
- Underground workings;
- Minor waste rock and low grade ore stockpiles;
- Other surface facilities that may remain after closure.

Modelling was conducted to assess mining phase and post-closure groundwater conditions, including sensitivity runs to test a range of model parameters and likely effect. The main focus of the modelling was to assess the potential for solute release and migration off-site (off the SML).

Two separate (but related) modelling assessments, or scenarios, were conducted. The first or initial assessment used a mine configuration representative of the existing site operation, including underground workings and tailings facility, with fate and transport results assessed based on immediate (i.e. “today”) closure. The second assessment extended this initial work and was based on the then (January 2015) life-of-asset plan extending to 2050, including underground workings and tailings storage schedule. For the purposes of this plan only the second scenario results are included.

The modified model was used to predict groundwater behaviour post-closure, including the time to reflood underground workings and the possible long-term groundwater flow paths and flux. Source terms were developed for contaminant sources that may impact on groundwater quality, the two most significant being the TSF and the underground workings. Underground source terms included the exposed wall rocks, and the cement aggregate backfill (CAF; including some tailings sands) used to fill mined-out stopes.

During operations, the modelling predicted that drawdown effects would extend up to a maximum of about 10 km in the Andamooka Limestone. Groundwater mounding would occur beneath the TSF and extending beyond the site to a distance of just under nine km.

Post-closure, the model predicted that:

- the groundwater mound beneath the TSF would dissipate within 20 years of cessation of tailings deposition.
- the time taken for the underground mine to reflood is approximately 400 years, after which time groundwater flows preferentially through the open development and shafts.
- estimated steady-state travel times exceed 10,000 years for affected groundwater to flow beyond the SML boundary, although some TSF cells were outside this boundary in the modelled case.
- long term drawdown at potential environmental receptors (Yarra Wurta Spring) is less than one metre.

In summary, the findings are that few, if any, water quality impacts are expected at the expanded SML boundary for time periods of 10,000 years or above.

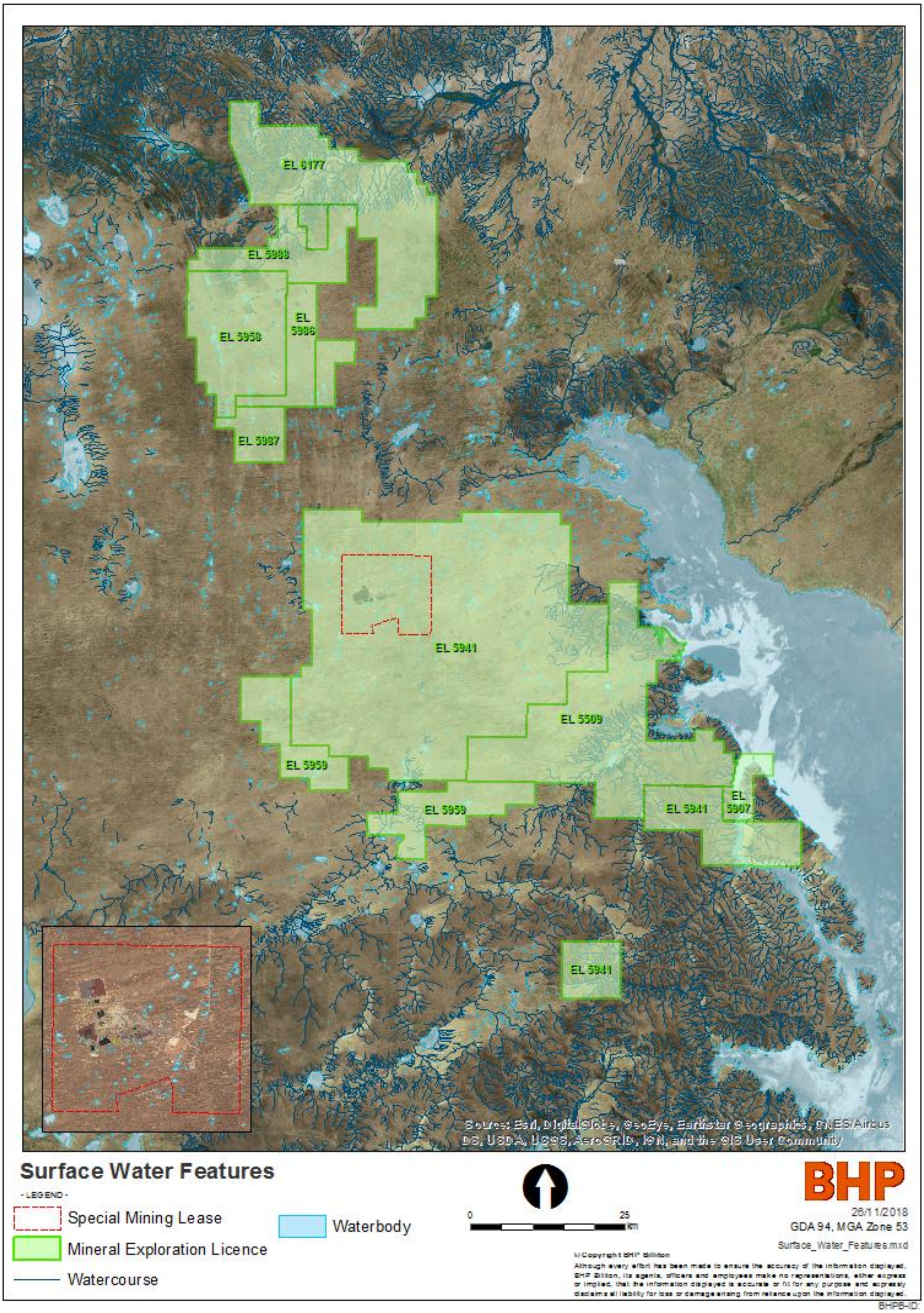


Figure 7-2: **Surface Water Features**

7.8 Site Contamination

OD as part of operations undertakes the storage and handling of ore, fuel (predominantly diesel), lubricants, oils, solvents and acids, and minor quantities of degreasers and domestic cleaning agents. The potential for land contamination from mining projects typically arises from these products.

Three legacy hydrocarbon spill sites exist (one on the SML and two in the wellfields area), with all being actively monitored and managed. The spill on the SML originated from a diesel tank (3ML tank) and was identified in 2002, with the tank being decommissioned shortly thereafter. A groundwater remediation system was installed and commissioned in 2006 and has recovered more than 7000L of light non-aqueous phase liquid (LNAPL). The hydrocarbon plume at the 3ML tank currently shows minor migration in a south easterly direction, and limited natural attenuation of the plume is occurring. A Detailed Site Investigation (DSI) was carried out in FY18 and the results are being assessed.

Diesel spills in the wellfields were identified at both the wellfield A pump station (PS1) and Wellfield B pump station (PS6A) in 2001, with both having undergone several phases of remediation commencing from late 2005. In the latest phase, PS1 remediation has successfully treated a groundwater volume in excess of 4 ML since commencing operation in late 2014, while PS6A remediation has treated groundwater in excess of 12 ML since commencing operation in mid-2014 and recovered approximately 39,800 L of LNAPL).

All three hydrocarbon remediation projects are expected to be completed and meet relevant regulatory requirements within the next 5 – 10 years, and as such are not expected to require any ongoing commitments at closure.

Per- and Polyfluoroalkyl Substances (PFAS) have been used across site historically for firefighting systems and training facilities. A baseline desktop assessment will be completed prior to the completion of mining to identify areas requiring further assessment and any remediation requirements (taking into account the proposed post-closure land use).

7.8.1 Knowledge Gaps

Table 7-8 outlines the knowledge gaps and preliminary actions with respect to contaminated land.

Table 7-8: **Contaminated Land Knowledge Gaps and Actions**

Knowledge Gap	Preliminary Action
Quantity, type and location of contaminants	Complete contaminated land assessment.
Proposed treatment method for contaminants	Outcome of contaminated land investigation reports.

7.9 Visual Amenity

OD lies within a mainly desert landscape of open woodland and shrubland on dunes and sandplains, and low shrubland on inter-dune swales and gibber plains. Much of the area is gently undulating with red sand dunes up to six meters in height, with occasional clay pans in the inter-dune swales. The dunes are orientated in an east-west direction, producing successive low ridgelines that obscure views north and south and create an enclosed visual feature. The existing OD operations are dominated visually by processing infrastructure, TSFs, Rock Storage Facility and the Roxby Downs township and to a lesser extent the small open cut pit remaining following the commencement of the open cut pit.

The largest component of the infrastructure is the constructed TSFs, reaching 20-30 m height (and potentially up to 40m in the case of TSF4). Although this is the largest feature and is visible from up to 5km away, the impact on the natural landscape is minimised by the flat profiled and natural coloured walls. From an aerial perspective however, the TSFs are clearly visible as mine infrastructure within the landscape. At closure the TSF will be capped, reducing the visual aerial impact.

Although smaller in area, the infrastructure footprint of the processing plant is visible from further afield as a result of the smelter stacks, which reach a maximum height of 90m. The stacks create a tall industrial feature on a relatively flat landscape and are visible from Roxby Downs and up to 30km away in Andamooka. The closure plan includes the demolition and removal of this infrastructure, therefore limiting the visual impact

7.9.1 Knowledge Gaps

Table 7-9 outlines the knowledge gaps and preliminary actions with respect to visual amenity.

Table 7-9: **Visual Amenity Knowledge Gaps and Actions**

Knowledge Gap	Preliminary Action
Conceptual post mine landform visualisation (TSFs)	Complete a visual assessment of the conceptual post mine landform.

7.10 Cultural Heritage

Archaeological sites are evidence of past occupation and may include camp sites, quarries or stone tools and scatters. As a result of the archaeological survey work conducted for the 1982, 1997 and 2009 EIS, 437 archaeological sites were recorded within the project area. The archaeological sites recorded in the Olympic Dam region included surface scatters of stone artefacts such as campsites, knapping floors, quarries and stone arrangements.

8 Risk Assessment

Risk assessment is an essential tool to ensure appropriate management of unplanned events that might occur on the mine site during or post closure. A structured risk-based approach allows for a systematic review and analysis of risk and cost benefit in both engineering and environmental terms as well as identification of closure associated opportunities. An iterative approach also assists with eliminating or reducing the likelihood and/or consequence of events to a level considered to be as low as reasonably practicable. For relinquishment of a closed operation, the residual risk must be considered tolerable and acceptable by stakeholders and regulators.

OD's Closure Planning Risk Assessment was reviewed and updated on Monday 23 April 2018. The review considered the current operations and the LoA and included representatives from Risk Management, Closure Planning, Environment A&I, Community Relations, Mine Planning, Legal and Projects.

The risk assessment is managed in Stature (Sphera Solutions).

The purpose of the risk assessment was to identify, analyse and evaluate the risk in line with ISO31000 Risk Management and Our Requirements Risk Management. The risk assessment assumed the following controls are in place and working:

- Management are trained and competent in their area of expertise;
- Management and employees adhere to BHP Our Requirements;
- Compliance with Federal, State and Local Legislation requirements.

The BHP risk evaluation process includes Establishing the Context, Risk Identification, Risk Analysis, Risk Evaluation and Risk Treatment. Impact types assessed include Health and Safety, Environmental, Community, Reputational, Legal / Regulatory and Financial.

Seven risk events were identified during the risk assessment that have the potential to influence the outcomes of achieving OD's closure objectives and outcomes. Within these risk assessments, 37 (non-unique) scenarios were identified as potential contributors to the risk events eventuating. The risk events included impacts related to stakeholder engagement, financial resourcing, inability to relinquish and early closure, post execution and post closure and offsite impacts.

Appendix C provides a summary of the risk assessment and the framework used to assess risk..

9 Closure Implementation

For the purposes of this CMRP and to facilitate effective mine closure planning OD mining operations have been divided into a number of physically distinct domains and features. The domains comprise of features that have similar rehabilitation and closure requirements. Standard design principles relevant to the closure of these domains are outlined in Table 9-1. Domain specific rehabilitation strategies and activities are further discussed in the following sections.

Table 9-1: **Closure Design Principles**

Parameter	Design Principles
Design Life	• Landforms integrity to be maintained in perpetuity.
Design Storm	• Tailings storage surface containment - probable maximum precipitation (PMP) or 1 in 10,000 AEP if PMP data is not reliable. • Restore natural drainage lines.
Post Closure Land-use	• Native Bushland: revegetated land available for grazing e.g. areas outside SML. • Vacant Crown Land: non-revegetated, not suitable for grazing or any access e.g. TSFs, open pit.
Radiation	• All recycled material to be decontaminated (to better than the Mining Code requirements). • Radiation levels returned to levels consistent with pre-mining levels. • Radiation dose to the public < 1.0 mSv/year above natural background. • Deposition of closed site originated 238U less than 25 Bq/m2/y at non-human biota assessment sites
Surface Water	• No unacceptable impairment of surface water quality. • Regional surface flows returned to pre-mining. • Local surface water flows mimic natural analogues as far as practical.
Groundwater	• TSF or RSF seepage will not cause unacceptable off-lease impact. • No unplanned impairment of surface water or groundwater to the extent that it adversely impacts third party users or groundwater dependent ecosystems. • Mounding of groundwater table at edge of TSF will not be higher than 80 metres with respect to the Australian Height Datum (mAHD) (approximately 20 m below natural ground level), with the intent of protecting flora root systems, and will recede in time.
Seismicity	• Post-closure TSF slopes stable for Maximum Design Earthquake (MDE) 1:10,000 years under all load conditions.
Erosion	• Erosion rate on TSF slopes will not affect the cover integrity within the design lifetime. • Landforms mimic natural analogues. • Erosion rates no greater than erosion rate at natural analogue landform.
Air	• Air quality equal to or better than surrounding land-use.
Soil	• Soil quality equal to or better than analogue landform or land-use.
Safety	• Public and wildlife access appropriate to final landform/use of each domain.
Vegetation	• Vegetation in rehabilitated ecosystem sustainable and as comparable as reasonably practicable with analogue landform and land-use. • Tailings storage facilities side slopes and top surfaces will not be revegetated to avoid radiation pathway and/or the creation of concentrated flow channels (stock paths) and breaching of cover by faunal traffic. • Open pit and RSF will not be actively revegetated but rather allowed to revegetate naturally.
Terrestrial and avian wildlife	• TSF runoff and / or standing water quality not toxic to avian fauna. • Stock fencing around TSFs and open pit to minimise (not exclude) fauna visitation

9.1 Domain Closure and Rehabilitation Strategies

9.1.1 Airport Facilities

Closure of the airport will be largely dependent on the requirements for post-mine land use of the town facilities. As such any closure design requirements and activities have not been included here pending future consultation with relevant stakeholders.

9.1.2 Contaminated Waste Disposal Facility

Capping and closure of the contaminated waste disposal facility (CWDF) is expected to be similar in form to that proposed for components of the tailings retention system. Refer to section 9.1.5.

9.1.3 Metallurgical Plant and Administration

The metallurgical plant and administration comprises the administration buildings, processing plant and supporting infrastructure (e.g. tanks and powerlines), roads, stockpile footprints, stormwater diversion bunds and channels, pilot plant area including tailings trial ponds and haul roads. Table 9-2 details the decommissioning and rehabilitation design and primary activities for these areas.

Table 9-2: **Metallurgical Plant and Administration Infrastructure Closure Design Requirements and Activities**

Basis of Design	Activities
• All above ground infrastructure will be decommissioned and removed, unless agreed with the post mine landholder to retain. • Removed infrastructure will be transported off site for re-use or recycling (if considered cost effective and safe). • Retained infrastructure will be made safe and stable prior to handover to the post mine landholder. • All disturbed areas to be assessed and rehabilitated consistent with the proposed post mine land use. • All footings removed to a depth of 500mm. • Buried services >500mm to remain in-situ if they pose no environmental risk. • Road base and other contaminated material removed to a depth of 500mm. • Topsoil respread to a depth of 150mm	• Site contamination assessment • Demolish and remove all minor infrastructure (e.g. pipe racks). • Demolish all structures, buildings and concrete footings unless agreement in writing is obtained from the post mine landholder. • Seek written agreement with post mine landholder for any retained services or infrastructure. • Survey and develop register of any retained services and structures. • Complete risk assessment of any retained services and structures. • Bury demolition waste that is not safe to be taken off site for re-use/recycling in site limestone quarry, underground or TSF. • Remove road base and other obstructions from drainage lines. • Dispose contaminated road base within TSF. Non-contaminated road base disposed of within TSF and/or limestone quarry. • Deep rip compacted soil and hard-stand areas and topsoil, seed, fertilise consistent with the proposed post mine land use.

9.1.4 Miscellaneous (including the underground mine and administration facilities)

Shafts, Raise Bores and Declines

Table 9-3 details the decommissioning and rehabilitation design and primary activities for the shafts, raise bores and decline infrastructure.

Table 9-3: **Infrastructure Area Closure Design Requirements and Activities**

Basis of Design	Activities
• Seal decline portals – seal type and design will depend on inspection and drainage requirements. • Demolish raise bore fans, down casts, and associated structures and infrastructure and dispose. • Cap raise bores and down cast bores. • Remove concrete footings to a depth of around 500 mm. • Cap shafts with concrete cover and cover if appropriate to do so i.e. if inspection of the cap is not required.	• Leave shaft foundations intact. • Complete safety risk assessment. • Install any required safety measures (e.g. signs, fences). • Topsoil, seed and deep rip compacted soil left by access tracks and hard-stand areas.

Exploration Areas

The closure and rehabilitation of exploration disturbance will occur throughout the LoA in accordance with the requirements of operating licences. An exploration audit of all known bore holes and associated disturbance will be completed prior to closure to understand what, if any historic holes require rehabilitation or rehabilitation maintenance at closure. Rehabilitation will include the removal of casing (where appropriate) and the bore holes plugged at the surface with concrete. Ancillary disturbance related to the explorations, such as tracks and pads will be rehabilitated in accordance with the rehabilitation objectives. Any rubbish found during the audit will also be removed and disposed of at the local landfill or the limestone quarry. Table 9-4 details the decommissioning and rehabilitation design and activities for exploration areas.

Table 9-4: **Exploration Design Closure Design Requirements and Activities**

Basis of Design	Activities
• All casing removed. If this is not appropriate, casing is cut down to a depth of 30 cm and removed. • Bore holes plugged at the ground level with concrete.	• Remove and access tracks and road base. • Topsoil, seed and deep rip compacted soil left by access tracks and hard-stand areas.

Water Management - Miscellaneous Ponds

Table 9-5 details the decommissioning and rehabilitation design and activities for miscellaneous ponds.

Table 9-5: **Miscellaneous Pond Closure Design Requirements and Activities**

Basis of Design	Activities
• All remaining liquor evaporated or removed to TSF. • All piping, pumps, liners, scuttle culverts removed.	• Remove contaminated materials and dispose to TSF. • Remove access tracks, push down any raised embankments and backfill base of ponds with uncontaminated material. • Batter slopes to stable erosion slope and rip along contours to relieve compaction. • Complete drainage, topsoil, seed and deep rip compacted areas.

9.1.5 Open Pit

Work on the open pit ceased prior to completion and did not reach a sufficient depth to intersect the underlying groundwater aquifers. As such, the key risk for the open pit at closure is associated with the potential for injury to a member or impacts from geotechnical instability. The open pit is expected to remain at the completion of mining. Any infrastructure located within the open pit at the completion of mining will be decommissioned and removed. The geotechnical assessment will be conducted during the latter stages of the operation to determine the potential for surface subsidence around the perimeter of the open pit and to determine a safety exclusion zone. Based on these studies, safety measures, including the construction of berms and trenches and the installation of fences and safety signs will be completed along the length of the pit perimeter and placed outside the zone of potential pit-wall failure. A summary of the activities is included in Table 9-6.

Table 9-6: **Open Pit Closure Design Requirements and Activities**

Basis of Design	Activities
• Erection of trench/bunding/fencing/warning signs – Bund wall minimum height 2m – Bund wall minimum base 5m – Bund location minimum 10m beyond zone of failure – Security fence minimum height 3.0m – Signage (AS Compliant) minimum 100m apart	• Contoured current slopes for stability and safety. • Geotechnical assessment of high-wall FoS to determine the potential for surface subsidence around the perimeter of the open pit and to determine a safety exclusion zone • Safety risk assessment completed. • Install any required safety measures (e.g. signs, fences). • Remove contaminated road base to 500mm depth and dispose within TSF. Non-contaminated road base disposed of within TSF and/or limestone quarry. • Access roads into the pit and onto the RSF will be deep ripped to discourage vehicle access and encourage revegetation.

9.1.6 Pilot Plant

Closure of the pilot plant will be consistent with the design and activities implemented for the metallurgical plant.

Basis of Design	Activities
• All above ground infrastructure will be decommissioned and removed, unless agreed with the post mine landholder to retain. • Removed infrastructure will be transported off site for re-use or recycling (if considered cost effective and safe). • Retained infrastructure will be made safe and stable prior to handover to the post mine landholder. • All disturbed areas to be assessed and rehabilitated consistent with the proposed post mine land use. • All footings removed to a depth of 500mm. • Buried services >500mm to remain in-situ if they pose no environmental risk. • Road base and other contaminated material removed to a depth of 500mm. • Topsoil respread to a depth of 150mm	• Site contamination assessment • Demolish and remove all minor infrastructure. • Demolish all structures, buildings and concrete footings unless agreement in writing is obtained from the post mine landholder. • Seek written agreement with post mine landholder for any retained services or infrastructure. • Survey and develop register of any retained services and structures. • Complete risk assessment of any retained services and structures. • Bury demolition waste and non-contaminated road base in site waste landfill. • Remove road base and other obstructions from drainage lines. • Deep rip compacted soil and hard-stand areas and topsoil, seed, fertilise consistent with the proposed post mine land use.

9.1.7 Quarry

Closure of the quarry will be consistent with the design and activities implemented for the open pit (i.e made safe and stable)

Table 9-7: **Open Pit Closure Design Requirements and Activities**

Basis of Design	Activities
• Erection of trench/bunding/fencing/warning signs – Bund wall minimum height 2m – Bund wall minimum base 5m – Bund location minimum 10m beyond zone of failure – Security fence minimum height 3.0m – Signage (AS Compliant) minimum 100m apart	• Contoured current slopes for stability and safety. • Geotechnical assessment to determine the potential for surface subsidence around the perimeter of the open pit and to determine a safety exclusion zone • Safety risk assessment completed. • Install any required safety measures (e.g. signs, fences). • Access roads into the quarry will be deep ripped to discourage vehicle access and encourage revegetation.

9.1.8 Rock Storage Facility

Work on the open pit and subsequent RSF ceased prior to completion and no reactive material has been placed within the RSF. As such, the key risk for both of these landforms at closure is associated with the potential for injury to a member of the public or impacts from geotechnical instability. A summary of the key design requirements and activities is included in Table 9-8**.**

Table 9-8: **Rock Storage Facility Design Requirements and Activities**

Basis of Design	Activities
• Side slopes between 20° to 37° • Topsoil respread to a depth of 150mm	• Geotechnical assessment of FoS • Complete risk assessment on final landform. • Install any required safety measures (e.g. signs, fences). • Material characterization of overburden • Water management to minimize/prevent surface water impacts • Seeding conductive for the identified post mine land use • Application of fertilizer and/or ameliorants as deemed necessary

	• Maintenance to achieve the closure objectives and criteria

9.1.9 Tailings Retention System

Tailings Storage Facility

O'Kane Consultants Pty Ltd. was engaged to complete a robust cover system and final landform design for the TSFs. The primary objective of the project was to develop a conceptual cover system and landform designs and to determine locations for full scale cover trials on the existing TSFs. The study included an assessment of erosion to develop the final landforms and cover systems as well as soil-plant-atmosphere numerical modelling to evaluate performance of various TSF cover system designs. A water erosion prediction program was also completed to simulate current and design batter slopes. Assessments were undertaken for the 100-year storm and also extreme events (i.e. the 10,000-year storm). The full text of the report is provided in Appendix D. Table 9-9 summarises the decommissioning and rehabilitation design and primary activities for the TRS.

Table 9-9: **Tailings Retention Closure Design Requirements and Activities**

Basis of Design	Activities
• A design life of 10,000 years for the TSF cover system and final landform, including slope stability and consolidation based on ANCOLD 2012 guidelines. • A 100-year OD climatic data base with an average annual rainfall total of 166mm/year has been used for cover and landform modelling. • An acceptable net annual infiltration rate of approximately 1% of annual rainfall or about 0.3 ML/d (<0.05 m3/ha/d) through the TSF into the foundations. • Maximum TSF height equal to 40m • Breakaway style landform (20° to 37° side slopes/flat top). • No top surface waters allowed to overtop the perimeter bund. • Average erosion on slopes <5t/ha/y. • Peak erosion at any point on the slope <10t/ha/y.	• No reactive material will be placed within the outer slopes. • Decommission and remove tailings mechanical and electrical plant and infrastructure and dispose. • Allow surface pond to drain/evaporate and beaches to dry to strength required for construction vehicles (estimated one to two years on beaches and three to four years in pond areas). • Contaminated soil around TSFs removed and disposed within TSF. • Decant outfall pipes and underdrain outfall pipes grouted/sealed. • Cover tailings with appropriate soil/rock fill cover to: – achieve final radiation, air quality (including radon), surface runoff quality, seepage, erosion and runoff closure performance criteria. – Prevent vegetation growth (to the extent possible) as a radiation pathway. • Complete risk assessment on final landform. • Install any required safety measures (e.g. signs, fences).

Evaporation Ponds

Closure of the evaporation ponds (EPs) is expected to be similar in form to that proposed for components of the tailings retention system, with a cover system and landform design modelled for a design life of 10,000 years, although alternative closure designs may be employed. Some analysis has been undertaken, with further studies to be completed to determine EP closure design requirements and activities. Refer to section 9.1.5 for TSF design requirements.

9.1.10 Town and Village Facilities

Planned closure activities may include the demolition and removal of all BHP buildings and structures and rehabilitation of these areas located within the township of Roxby Downs. The facilities consists a small housing, shopping centres, clubs, libraries schools, medium industrial facilities and community centres. An assessment of infrastructure requirements associated with the post mine land use will be undertaken in consultation with the stakeholders to determine the potential to hand these facilities over to an interested party (e.g. government) or the extent of removal. Similar closure activities will be undertaken for Olympic Dam and Roxby Villages and the Olympic Dam sewage facilities.

If required, infrastructure will be decommissioned and demolished. Materials such as heavy gauge steel and non-ferrous scrap will be cut to size and trucked offsite for recycling if considered cost effective or disposed of in the limestone quarry and/or town landfill. Bitumen surfaces, road base, concrete kerbing and footpaths will be removed and disposed with the limestone quarry and/or Town landfill. Below ground infrastructure that is to be left in place will be made safe (e.g. de-pressurizing, draining and sealing of pipelines) and the location of all infrastructure and other components will be recorded. Contaminated soil assessments will be conducted as required to understand the extent of contamination and any contaminated materials will be removed and disposed of within a suitable landfill or the TSF.

The main rehabilitation treatments will involve de-compacting the surface through deep ripping prior to topsoil application and seeding and the removal of any vegetation that is non indigenous to the area.

The design requirements for infrastructure areas are listed in Table 9-10.

Table 9-10: **Town Facilities Closure Design Requirements and Activities**

Basis of Design	Activities
• Infrastructure removed and / or made safe to be safe for the required post mine land use. • Topsoil placement to a depth of approximately 150mm • Contour ripping to a depth of approximately 500mm • Identification and removal of contaminated material	• Site contamination assessment • Seek written agreement from post mine landholder/stakeholders for retention of infrastructure • Risk assessment for retained infrastructure • Water management to minimize/prevent surface water impacts for rehabilitated areas • Seeding conductive for the identified post mine land use • Application of fertilizer and/or ameliorants as deemed necessary (identified as part of the topsoil testing requirements) • Maintenance to achieve the closure objectives and criteria

9.1.11 Wellfields and Associated Infrastructure

Table 9-11 details the decommissioning and rehabilitation design and activities for the wellfields.

Table 9-11: **Wellfield Design Closure Design Requirements and Activities**

Basis of Design	Activities
• All above ground infrastructure (e.g. including breather valves, pump stations, powerlines and above ground piping) removed and decommissioned, unless agreed with the post mine land holder to retain. • All disturbed areas rehabilitated consistent with the proposed post mine land use. • Production bores decommissioned and capped, unless agreed with post mine land holder to retain. • Below ground infrastructure (pipelines) to remain in ground. • Road base and other contaminated material removed to a depth of 500mm. • Drainage lines reinstated	• Leave monitoring bores in place for post-closure monitoring (if identified as a requirement) • Bury inert demolition debris and pond liners in pond excavation, local landfill, or on site (backfill limestone quarry, underground or TSF). • Remove hard-stand from pumping stations to adjacent borrow pits. • Remove road base and other obstructions from drainage lines and dispose within TSF or limestone quarry. • Backfill ponds with any available wall materials and re-contour to blend with sand dunes or local landforms. • Topsoil, seed and deep rip compacted soil left by access tracks and hard-stand areas.

9.2 Progressive Rehabilitation

The implementation of a successful, planned progressive rehabilitation program of disturbed areas ensures that the obligations and liability associated with completing closure activities is progressively reduced consistent with MAu Closure Planning Principals.

Progressive rehabilitation offers a number of benefits in that it:

- may mitigate existing risk issues associated with the disturbed land (e.g. dust or seepage);
- provides information, data, knowledge and experience that may assist in successfully rehabilitating land;
- reduces the residual disturbance to be rehabilitated at final closure; and
- provides evidence to stakeholders that BHP is committed to, and is capable of, successfully closing and rehabilitating the mining operation to achieve the stated post-closure land use.

The Olympic Dam operation has rehabilitated several disturbed areas that are no longer required by the mining or processing operations as well as exploration sites, and will continue to progressively rehabilitate lesser disturbances as the opportunity arises.

Given the ongoing use of the SML for mining and processing purposes, there is a high likelihood that areas progressively rehabilitated land will be re-used during life of mine to support ongoing mining and processing activities. To accommodate this, progressive rehabilitation will typically be undertaken to a level that is suitable for ongoing industrial use whilst final rehabilitation will be undertaken to support the final land-use.

Table 9-12 outlines progressive rehabilitation and demolition and decommissioning opportunities for the next 5 years. Table 9-13 outlines an indicative rehabilitation schedule for mine closure.

Table 9-12: **5 Year LoA potential progressive rehabilitation opportunities**

Year	Activity	Domain / Location
FY19	Demolition	Mine Area
FY20	Demolition and Rehabilitation (pilot plant)	Mine Area, Pilot Plant, Site Infrastructure
FY21	Demolition and Rehabilitation (pilot plant)	Metallurgical Facilities, Pilot Plant
FY22	Demolition	Metallurgical Facilities
FY23	NA	NA

Table 9-13: **Proposed Rehabilitation Schedule (Based on 2095 mine closure)**

Domain	Year Rehabilitation Commences (Proposed)	Year Rehabilitation Ceases (Proposed)	Year Rehabilitation Monitoring Ceases (Proposed)[1]	Years of Rehabilitation Monitoring
Airport Facilities	2095	2097	2114	20
Contaminated Waste Disposal (CWDF)	2046	2097	2065	20
Metallurgical Plant and Administration Facilities	2095	2097	2114	20
Miscellaneous	2095	2097	2114	20
Open Pit	2095	2097	2114	20
Pilot Plant	2020	2023	2040	20
Quarry	2095	2097	2114	20
Rock Storage Facility	2095	2097	2114	20
Tailings Retention System				
• TSF 1,2 and 3	2028	2029	2047	20
• TSF 4	2036	2038	2056	20
• TSF 5	2039	2041	2058	20
• Evaporation Ponds	2028	2090	2047	20
• Subsequent TSFs and associated facilities as per schedule.				
Town and Village Facilities	2095	2097	2114	20
Wellfield Facilities	2095	2097	2114	20

1. Based on years of rehabilitation monitoring from year of commencement of rehabilitation. For some facilities ongoing monitoring will likely extend beyond this date.

9.3 Implementation Schedule

Detailed planning for final mine closure execution (i.e. residual demolition, disposal and earthworks) will commence 5 years before the scheduled closure date for the mining and processing operations.

The current closure plan nominally allows for a post-closure care and maintenance and monitoring period leading up to relinquishment of 20 years. While this may appear to be a short duration in terms of demonstrating the stability of landforms and tailings closure covers, it is reasonable given that evidence for these will be gathered from the studies, research, implementation and monitoring throughout the LoA as progressive rehabilitation is implemented.

Table 9-14 provides an overview of the proposed schedule of closure works, including progressive rehabilitation of identified closure domains over the life of mine.

Table 9-14: **Proposed Closure Works Schedule (Based on LoA)**

Activity	Start	End
Progressive Rehabilitation	Ongoing	2090
Closure Works Pre-Planning	2090	2094
Contractor Mobilisation	2095	2097
Decommissioning, Demolition and Disposal	2095	2114

10 Post Closure Monitoring and Maintenance

The following section describes monitoring and maintenance activities planned to be undertaken post closure. Information collected during the operational life of OD will be used to support the data collected post closure. The data collected during operations and throughout the post closure monitoring period will ensure:

- sufficient and appropriate monitoring is in place to be able to track and demonstrate the achievement of closure performance criteria for the various closure landforms;
- management plans are in place to model the post-closure performance to provide predictive assessments of the post-closure landforms e.g. drain-down of the TSFs;
- sufficient resources are allocated to ensure that all required inspections and monitoring is carried out, and that any care and maintenance activities required are carried out promptly and to the desired standard;
- adequate financial provisions to carry out the above activities, with a contingency allowance for post-closure 'risk events' (i.e. as per those discussed in Section 8).

The post-closure monitoring timeframe will depend on the complexity of the closure landforms, the post-closure land-use, and the completion criteria. The current proposed post closure monitoring is estimated to occur for 20 years.

Post-closure monitoring activities and the proposed monitoring schedule are detailed in Appendix E**.**

10.1 Rehabilitation Monitoring

Post closure rehabilitation monitoring will employ an amended Ecosystem Function Analysis (EFA) methodology encompassing soil profile reconstruction and nutritional status, vegetation, and erosion. EFA monitoring will be completed annually for the first three years then 5 yearly until relinquishment. Seven monitoring events will occur during the post closure period (1^{st}, 2^{nd}, 3^{rd}, 5^{th}, 10^{th}, 15^{th} and 20^{th} years).

10.2 Tailings Retention System

Post closure monitoring and inspection of the TRS will be completed annually for the first three years then 5 yearly until relinquishment. Seven monitoring events will occur during the post closure period (1^{st}, 2^{nd}, 3^{rd}, 5^{th}, 10^{th}, 15^{th} and 20^{th} years).

The post-closure monitoring will include:

- geotechnical inspections and assessment of the TSFs and EPs by a competent geotechnical engineer to validate:
    - medium-term and long-term stability of the TSF and EP slopes;
    - long-term integrity of the tailings cover.
- groundwater levels and quality (i.e. to ensure the groundwater mound beneath the TSF is reducing); and
- radiation levels.

An inspection and monitoring report will be compiled after each inspection, including follow up of any care and maintenance work recommended in previous reports. The report will be submitted to the appropriate regulatory agency responsible for the confirmation of TRS closure completion criteria.

10.3 Open Pit and Rock Storage Facility

A geotechnical assessment will be conducted prior to closure to determine the potential for surface subsidence around the perimeter of the open pit and to determine a safety exclusion zone. Based on these studies, an abandonment bund and/or fencing will be constructed around the perimeter of the pit outside the zone of potential pit-wall subsidence.

Post closure geotechnical assessments of the RSF and open pit will be completed annually for the first three years then 5 yearly until relinquishment. Seven monitoring events will occur during the post closure period (1^{st}, 2^{nd}, 3^{rd}, 5^{th}, 10^{th}, 15^{th} and 20^{th} years).

10.4 Surface Water Monitoring

Surface water monitoring will be completed annually for the first three years then 5 yearly until relinquishment. Seven monitoring events will occur during the post closure period (1^{st}, 2^{nd}, 3^{rd}, 5^{th}, 10^{th}, 15^{th} and 20^{th} years).

The monitoring program will include an assessment of rainfall runoff from TSFs and rehabilitation to demonstrate:

- No unacceptable impairment of surface water quality;
- Regional surface flows returned to pre-mining; and
- Local surface water flows mimic natural analogues as far as practical.

An assessment of the current operational surface water monitoring program will be completed as OD approaches closure to ensure it meets the closure monitoring requirements. Any data available from the operational monitoring program will also be reviewed and used for closure if considered suitable.

10.5 Groundwater Monitoring

Groundwater monitoring will be completed annually for the first three years then 5 yearly until relinquishment. Seven monitoring events will occur during the post closure period (1st, 2nd, 3rd, 5th, 10th, 15th and 20th years).

The monitoring program will be conducted to demonstrate deep drainage from the rehabilitated areas, including that the TSFs meet the water quality objectives, including:

- TSF or RSF seepage will not cause unacceptable off-lease impact.
- No unplanned impairment of surface water or groundwater to the extent that it adversely impacts third party users or groundwater dependent ecosystems.
- Mounding of groundwater table at edge of TSF will not be higher than 80 metres with respect to the Australian Height Datum (mAHD) (approximately 20 m below natural ground level), with the intent of protecting flora root systems, and will recede in time.

An assessment of the current operational groundwater monitoring program will be completed as OD approaches closure to ensure it meets the requirements for closure monitoring. Any data available from the operational monitoring program will also be reviewed and if considered suitable, used for closure.

10.6 Fauna Monitoring

Fauna monitoring will be completed annually for the first three years then 5 yearly until relinquishment. Seven monitoring events will occur during the post closure period (1st, 2nd, 3rd, 5th, 10th, 15th and 20th years).

Fauna monitoring will be undertaken to demonstrate the recolonization of fauna species, where appropriate and that there are no adverse impacts to fauna from the rehabilitated landscape, including the TSFs. Fauna monitoring will also assist in the identification and management of pest populations as a result of OD' activities.

10.7 Weed and Feral Animal Monitoring

Weed and feral animal monitoring and control will be conducted quarterly for the first 12 months then twice yearly until relinquishment and will be completed in all parts of the SML and adjacent land covered by the CMRP. A total of 42 monitoring events will occur during the post closure period.

The objective of the weed and feral animal control is to manage the land in accordance with the requirements of relevant legalisation and to ensure the rehabilitation objectives and criteria are achieved. The existing site pest and weed management plan will be used at closure or modified as required.

10.8 Radiation

Radionuclide monitoring will be completed annually (20 monitoring events) until relinquishment to demonstrate the rehabilitation objectives of no adverse impacts to public health as a result of radioactive emissions from final landforms and that no significant adverse radiological impacts to ecological communities as a result of radioactive emissions from final closure.

An assessment of the current operational Radionuclides monitoring program will be completed as OD approaches closure to ensure it meets the requirements for closure monitoring. Any data available from the operational monitoring program will also be reviewed and if considered suitable, used for closure.

10.9 Air Quality

Continuous air quality (dust) monitoring will be undertaken for first 5 years, coinciding with the major demolition, decommissioning and rehabilitation activities. The monitoring program will be used to demonstrate the post closure rehabilitation objectives, that air quality is equal to or better than surrounding land-use.

10.10 Great Artesian Basin (GAB) Recovery Monitoring

The GAB water supply for Olympic Dam, and the associated townships and accommodation villages (including Andamooka), is obtained from wellfields located on the south-western edge of the GAB. Most of the recharge to the GAB aquifer is from distant rainfall, and apart from springs, natural discharge in SA is by diffuse upward flow and eventual evaporation. There are numerous GAB springs in the vicinity of the Olympic Dam Wellfields A and B, which support an array of important flora and fauna adapted to these aquatic habitats. GAB springs occur near the margins of the basin where the aquifer is shallow and the shale aquitard is thin, enhanced by structural weaknesses (faults) providing low-conductivity conduits that transmit the pressurised GAB groundwater upwards. Several pastoral properties, which rely on the GAB for water supply, also operate in the vicinity of the wellfields. These properties rely on artesian pressure to distribute water along extensive piping systems. Management of the GAB is closely aligned with the management of aquifer pressure of the GAB, pastoral bore flow and flow at GAB springs.

The aim of the current monitoring program is to measure and assess the environmental impacts associated with water abstraction from the wellfields by:

- Delineating the drawdown induced by the wellfields, and particularly any impact on pastoral water supplies and environmental flows;
- Identifying possible changes in water chemistry that may occur;
- Enable assessment of compliance with legal requirements for the operation of the GAB water supply in the annual Wellfield Report;
- Enable assessment to ensure that impacts are within predictions and expectations in the annual Wellfield Report;
- Increase the understanding of the hydrogeological dynamics of the GAB in the wellfields region.

An assessment of the current GAB monitoring program will be completed as OD approaches closure to ensure it meets the requirements for closure monitoring. Any data available from the operational monitoring program will also be reviewed and if considered suitable, used for closure.

GAB monitoring will be completed quarterly for the first 12 months, then annually until relinquishment (23 monitoring events).

10.11 Safety Monitoring

Periodic inspections will be conducted during mine closure to verify that the safety measures identified and installed as part of the risk assessment process are maintained and effective. Inspections may include, but not be limited to, safety bunds and/or fences erected around final voids, sealing of underground working entrances, boundary fences and infrastructure that has been retained.

11 Unplanned or Temporary Closure

11.1 Unplanned Closure

There are many reasons why mines may close prematurely, that is, they have closed for reasons other than the exhaustion or depletion of reserves (Australian Government, 2016). Some common examples listed by the Australian Government (2016) why mines may close unexpectedly include:

- Economic reasons, such as low commodity prices or high costs that may lead a company into voluntary administration or receivership;
- Geological reasons, such as an unanticipated decrease in grade or size of the ore body;
- Technical reasons, such as adverse geotechnical conditions or mechanical or equipment failure;
- Regulatory direction, due to safety or environmental breaches;
- Policy changes, which occur from time to time, particularly when governments change;
- Social or community pressures, particularly from NGOs;
- The closure of downstream industry or markets;
- Unforeseen flooding of the mine.

Unexpected closure, combined with inadequate or immature closure planning practices can have significant impacts on the business, not only financially, but also on the company's reputation and can also lead to poor environmental outcomes. The impacts may lead to ongoing challenges for the company including gaining access to new land or developments, or the expansion of existing assets. In addition to company impacts, industry impacts can include (Australian Government, 2016):

- Reputational;
- Reactive and unreasonable implementation of regulations;
- Political reaction in response to community outrage, resulting in bad publicity.

In the event of unexpected or unplanned closure, the mining operations would continue to be treated as an operational asset under the BHP Group Standards, with the necessary resources being provided to meet all existing health, safety, environment and community standards until closure, rehabilitation and relinquishment are complete.

As part of this CMRP and by addressing BHP's Our Requirements Closure, a range of risks including unexpected or unplanned closure are addressed in the closure risk assessment (Section 8) and closure provision (Section 12).

11.2 Temporary Closure (Care and Maintenance)

In the unlikely event that the operation is required to be shut down on a temporary basis (i.e. there is an assumption that the operation would recommence once economic or other issues had been resolved) similar management controls would be put in place as described for unplanned closure. Temporary closure would also trigger a thorough risk assessment, the development of a care and maintenance plan, and a full review of the Mine Closure and Rehabilitation Plan in the light of an increased risk of early closure.

12 Closure Provision

BHP recognises that where mining and processing activities give rise to an obligation for site closure and rehabilitation, financial provision for the closure activity must be recognised at the time that the environmental disturbance is made. The basis by which BHP accounts for closure provisions and the Group wide closure provision is described in the publically accessible BHP Annual report.

The main objective of financial provisioning for closure is to ensure adequate funds are assigned for closure to satisfy relevant legal and other requirements and to mitigate future risks associated with an inaccurate accounting provision. The development of closure plans and related financial provisions are required from the outset of a mining development. The OD closure cost estimate has been completed in accordance with all BHP requirements.

BHP implements several key controls to ensure that all assets and operations within the Group are able to meet their closure obligations and commitments including the integration of closure planning into LoA planning. If the asset (project) is shut suddenly, BHP would be fully aware of the obligations and costs required to keep the site in care and maintenance or to close and rehabilitate the site. As part of this CMRP and by addressing BHP's Our Requirements Closure, a range of risks including unexpected or unplanned closure are addressed in the closure risk assessment (Section 8) and included in the cost estimate.

13 References

Australian Bureau of Statistics (ABS) (2018), Statistics Data by Region http://stat.abs.gov.au/itt/r.jsp?databyregion (viewed October 2018)

Australian Government (2016), *Leading Practice Sustainable Development Program for the Mining Industry: Mine Closure*, September 2016

BHP (2017), *Minerals Australia Planning Standard,* Version 1.0, Document Number 0133179, September 2017

BHP (2018), *Our Requirements Closure*, Version 7.2, 4 April 2018

BHP (2018), *Olympic Dam Planning and Technical FY18 Asset Closure Basis of Estimate – Current Disturbance* (August 2018)

BHP Billiton (2009), *Olympic Dam Expansion Draft Environmental Impact Statement (December 2008)*

BOM (2018), Australian Government Bureau of Meteorology http://www.bom.gov.au/ (accessed August 2018)

Department of State Development 2015. Preparation of a mining proposal and/or management plan metallic and industrial minerals (excluding coal and uranium) in South Australia, Minerals Regulatory Guidelines MG2a, Mineral Resources Division. November 2015. Department of State Development, South Australia, Adelaide, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/MRGMG2A.pdf (accessed July 2019)

Department for Energy and Mining 2018. Preparation of a program for environment protection and rehabilitation (PEPR) for metallic and industrial minerals (excluding coal and uranium) in South Australia, Minerals Regulatory Guidelines MG2b, Mineral Resources Division. August 2018. Department for Energy and Mining, South Australia, Adelaide, https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/MRGMG2B.pdf (accessed July 2019)

DITR (2006), *Mine Rehabilitation Handbook – Leading Practice Sustainable Development Program for the Mining Industry*, Department of Industry, Tourism and Resources, Canberra.

EPA (2006), *Guideline for the Assessment of Environmental Factors: Rehabilitation of Terrestrial Ecosystems*, Guidance No. 6, Environment Protection Authority, Perth.

Hope, P. K., Nicholls, N. & McGregor, J. L. 2004. *The rainfall response to permanent inland water in Australia*. Australian Meteorological Magazine, 53, 251-262.

ICRP 1979, Publication 29, (ICRP 29). 'Radionuclide Release into the Environment: Assessment of Doses to Man'.

International Council for Mining and Metals (ICMM) (2015), *Sustainable Development Framework: ICMM Principles*

ODC 1996a (Olympic Dam Corporation) Pty Ltd 1996a, 'Environmental Management and Monitoring Plan, 1996'.

ODC 1996b (Olympic Dam Corporation) Pty Ltd 1996b, 'Justification for Changes to the Environmental Management and Waste Management Programmes 1996'.

SRK, 2015; 'Olympic Dam Operations Assessment of Potential Groundwater Impacts Life of Mine Operation', BHP146_2, July 2015.

Watterson, I. *et al.* 2015, *Rangelands Cluster Report, C*limate Change in Australia Projections for Australia's Natural Resource Management Regions: Cluster Reports, eds. Ekström, M. *et al.,* CSIRO and Bureau of Meteorology, Australia

14 Appendices

Appendix A: Stakeholder Engagement Register

Stakeholder
Internal
BHP Board
MAu Corporate Employees
OD Site Employees
Roxby Downs and Surrounds
Roxby Downs and Olympic Village Communities
Roxby Downs Council
Woomera Community (including Woomera Board, Defence)
Andamooka Community
Service Providers (Health, Police and Education)
Roxby Downs and Woomera Community Board
Andamooka Progress and Opal Miners Association
Outback Areas Authority (Andamooka governance body)
Arid Recovery partners (the South Australian Department for Environment & Natural Resources, the University of Adelaide and Friends of Arid Recovery)
Non-Government Organisations
SA Chamber of Mines and Energy
Australian Uranium Association
Friends of the Earth
South Australian Conservation Council
Wilderness Society
External – suppliers and contractors
Transport and Freight Companies
Local contractors (small, medium and large)
Investors, Banks, Financial Institutions
Government Entities
State Government Elected Representatives
Federal Government Department responsible for the Environment
Federal Government Elected Representatives
Relevant Australian and South Australian Government Departments and Agencies
Great Artesian Basin Coordinating Committee
South Australian Arid Lands NRM Board
Northern and Yorke NRM Board
Eyre Peninsula NRM Board
Indigenous Groups
Arabana Aboriginal Corporation

Barngarla Aboriginal Corporation
Dieri Aboriginal Corporation
Kokatha Aboriginal Corporation
Kuyani Aboriginal Corporation
Nukunu Aboriginal Corporation
Andamooka Aboriginal Corporation
Port Augusta Native Title Working Group.
Native Title Parties Representative Corporation (NTP-RC)
Upper Spencer Gulf
Regional Development Australia – Far North
Regional Development Australia – Whyalla and Eyre Peninsula
Regional Development Australia – Yorke and Mid North
Upper Spencer Gulf Common Purpose Group
City of Port Augusta
City of Whyalla
Pt Pirie Regional Council
Pastoral Communities
SA Pastoral Board
Anna Creek Station
Arcoona Station
Billa Kalina Station
Bosworth Station
Callanna Station
Cariewerloo Station
Clayton Station
Dulkaninna Station
Etadunna Station (BHP)
Farina Station
Hesso Station
Kootaberra Station
Millers Creek Station
Mt Arden Station
Muloorina Station
Mundowdna Station
Murnpeowie Station
Oakden Hills Station
Parakylia Station
Roopena Station
South Gap Station
External – media

Media – Local, State and National

Appendix B: Knowledge Gaps and Preliminary Actions

Knowledge Gap	Preliminary Action
Suitability of rehabilitation species selection to sustain hotter and dryer climates with less soil moisture	Observation of trends from rehabilitation monitoring
Ability for landform designs (TSFs and RSF) to withstand increased intensity of extreme rainfall events	Landform evolution modelling of retained landforms Include climate change impacts in any future rehabilitation designs
Ability of capping treatments to withstand increased evaporation rates.	Closure designs to incorporate climate change predictions
TSF capping and landform suitability	Complete TSF capping trials
Potential for acid forming material to be generated from permanent low and medium grade waste ore stockpiles	Ensure that adequate knowledge is gathered to inform design criteria prior to any stockpiles being constructed
Long-term viability of topsoil stockpiles	Complete rehabilitation research project to better understand closure liabilities
Updated impacts on remnant vegetation based on LoA	Re-assess vegetation impacts based on current LoA
Pre-mine planned clearing vs. LoA planned clearing	Review LoA disturbance vs planned disturbance
Updated impacts on fauna based on LoA	Re-assess fauna impacts based on current LoA
Quantity, type and location of contaminants	Complete contaminated land assessment
Proposed treatment method for contaminants	Outcome of contaminated land investigation reports.
Conceptual post mine landform visualisation (TSFs)	Complete a visual assessment of the conceptual post mine landform

Appendix C: Risk Assessment

The following table defines the actual and/or credible potential impact events associated with closure and post closure activities. The risk analysis identifies the:

- Risk Event – the aspect of the closure planning or closure activities that may cause an undesirable or unforeseen impact, e.g. groundwater contamination.
- Cause – the reason for the risk event being realised.
- Preventative controls – controls that are or will be in place that reduce the chance of the risk event occurring or the severity of the impact.
- MFL – maximum foreseeable loss. The MFL is the impact sustained in a worst case scenario assuming that all preventative control are ineffective. The MFL is assessed on a scale of 1 to 7 (where 7 is the most severe) against a number of impact criteria (health and safety, environment, community, reputation, legal and financial).
- MFL impact description – the assessed worst case scenario leading to the MFL rating.
- Severity rating – the severity rating is assigned based on the assessed MFL (Table 14-1)
- Likelihood rating – the chance of the MFL impact occurring, taking into account the effectiveness of existing preventative controls.
- RRR – residual risk rating. Represents the level of residual risk associated with the risk after taking into account the preventative controls. The RRR is calculated as the product of the severity rating and likelihood rating.

Table 14-1: **MFL and severity rating table**

MFL	Severity rating
7	1000
6	300
5	100
4	30
3	10
2	3
1	1

Table 14-2: **Likelihood rating table**

Uncertainty	Example assessment	Likelihood factor
Almost certain	Could be incurred more than once in a year.	10
Likely	Could be incurred over a 1 - 2 year period.	3
Possible	Could be incurred within a 5 year period.	1
Unlikely	Could be incurred within a 5 - 20 year timeframe.	0.3
Rare	Could be incurred in a 20 - 50 year timeframe.	0.1
Very rare	Has not happened in the industry in the last 50 years, or for natural hazards the predicted return period for a risk of this strength/magnitude is one in 100 years or longer.	0.03

Risk Event and Contributing Scenarios

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
1	Financial resourcing requirements are insufficient	CA1. Inadequate or poor closure planning, stakeholder engagement, engineering & design, pre-& post-closure risk management CA2. Uncertainty around TSF closure CA3. Uncertainty around evaporation pond closure CA4. Inadequate/poor closure execution &/or post-closure cost estimates CA5. Change of internal mining or design requirements	1. Engage regulators to understand & document closure & relinquishment process (CA9, CA12) 4. Stakeholder Engagement Plan (CA1, CA12) 5. Update Mine Closure Plan and submit to regulators in the event of any material changes (CA1, CA5, CA9, CA12) 6. Closure Management and Rehabilitation Plan as per Our Requirements Closure (CA1, CA5, CA6, CA9, CA10, CA12) 7. Active engagement in policy and regulation change to manage new policy requirements (CA1, CA9, CA12) 8. Document closure commitments & obligations (CA9) 11. Progressive Rehabilitation (CA10) 12. Historic waste placement knowledge (CA2) 13. Integrated Closure Planning (CA1, CA5)	5	Health and Safety: During the C&M period, despite security measures, interaction with underground facilities (e.g. portals/shafts) occurs by general public access resulting in a potential multiple fatality.	100	0.3	30

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
		CA6. Inadequate provision for indirect closure costs e.g. HR redundancies CA7. Quantity/cost of suitable TSF cover materials underestimated CA8. Quantities of contaminated solids to be excavated & disposed underestimated CA9. Closure commitments and/or obligations not adequately considered or known. CA10. Early closure - unplanned issues CA11. Inability to use current landfill facilities in township to dispose demolition debris leading to cost increase CA12. Change in regulatory requirements or changing stakeholder expectations	14. Pre-closure costs include engineering and design work, test work, studies & associated management (CA1, CA4) 15. Conservative design assumptions for TSF cover (SRK) (CA2, CA7) 16. TSF cover trials and progressive rehabilitation of TSFs to prove up cover design, construction & performance (CA2, CA7) 17. Climate change included in hydrological modelling predictions (CA2) 18. Geochemistry stability impacts input into geotech analysis (CA2) 19. Waste characterisation (CA2) 20. Tailings closure design in accordance with ANCOLD guidelines (CA2) 21. Track cost for rehabilitation and closure execution and use to inform cost estimates (CA2, CA4) 22. Ranging used to quantify potential scope and rate (CA2, CA4, CA5, CA7, CA8, CA10, CA11) 23. Design and implementation of TSF capping trials (CA2) 24. Risk assessment completed on post mine landform designs (CA2) 25. Evaporation pond rehabilitation and closure design study (CA3) 26. Evaporation pond operating strategy (CA3) 27. Compliance with" Our Requirements Major Capital Projects - Scope Definition, Schedule and Cost Estimating Classifications" (CA4) 28. Include cleaning where required & all study, project management & execution costs in closure provision (CA4) 29. Calculations audited against BHP project cost estimating requirements (CA4) 30. SOX Controls (CA4, CA6, CA10) 31. Corporate and external finance governance and auditing (CA4, CA6, CA10) 32. Closure commitments and obligations register (CA4) 33. Identification & management of material closure risks (CA5) 34. Post closure costs include ongoing community costs, monitoring and maintenance (CA6) 35. Maintain contaminated and hazardous waste registers for classifying and quantifying different wastes requiring treatment &/or disposal (CA8) 36. Cost estimate includes allowance for post-closure events - clean up & repairs by BHP (CA8) 37. Contaminated land assessment (CA8) 38. CAP cycle to review closure risk (cost curve) (CA10)					

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
			39. Price TARP for each operation reviewed quarterly (CA10)					
2	Closure studies and execution works are not managed adequately	CA1. Poor or inadequate closure planning. CA2. Closure planning not integrated into LOA planning. CA3. Closure risks not well understood or managed. CA4. Inadequate progressive closure planning and/or execution. CA5. Inadequate or poor management of closure planning.	4. Stakeholder Engagement Plan (CA5) 5. Update Mine Closure Plan and submit to regulators in the event of any material changes (CA1, CA2, CA4) 6. Closure Management and Rehabilitation Plan as per Our Requirements Closure (CA1, CA2, CA3, CA4) 11. Progressive Rehabilitation (CA3) 13. Integrated Closure Planning (CA1) 16. TSF cover trials and progressive rehabilitation of TSFs to prove up cover design, construction & performance (CA3) 24. Risk assessment completed on post mine landform designs (CA3) 40. Closure plan - schedule, closure actions etc. - aligned with the LoA Optimised Base Plan (CA1, CA2) 41. Preliminary closure designs and materials or specifications for key closure cost driver - TSF cover (CA1) 42. Closure design and performance criteria defined in Closure Plan (CA1) 43. Address BHP Our Requirements, Corporate Alignment Planning, Appendix 1 Closure Plan Scope (CA1, CA2, CA4) 44. 5YP CAP process for rehabilitation (CA2, CA4) 45. Closure provision funding model (CA2, CA4) 46. Annual closure planning workshop with quarterly risk/action review & tracking meetings (CA3) 47. Regular state government disclosure/reporting (CA3) 48. Consideration of specific risks in Our Requirements, Corporate Alignment Planning, Appendix 1 Closure Plan Scope (not achieving closure plan objectives; adverse post-closure events; potential changes to regulations; immediate or unplanned closure) (CA3) 49. Annual review of closure planning risks (CA3) 50. Progressive rehabilitation plans (CA4) 51. Preliminary monitoring & care & maintenance plan - cost provision in estimate (CA4) 52. Preliminary relinquishment plan (CA4) 53. Deconstruction, demolition and demobilisation cost estimate/quotation for plant and equipment (CA5)	5	Community: Closure execution not completed according to agreed plan resulting in impact to Roxby Downs community.	100	0.3	30
3	Early closure is not considered in closure planning.	CA1. Poor or inadequate closure planning. CA2. Poor or inadequate closure risk management i.e. risk management does not include early closure. CA3. Incorrect assessment of asset value and/or life.	1. Engage regulators to understand & document closure & relinquishment process (CA4) External – media 5. Update Mine Closure Plan and submit to regulators in the event of any material changes (CA1, CA4) 6. Closure Management and Rehabilitation Plan as per Our Requirements Closure (CA1, CA2, CA4) 11. Progressive Rehabilitation (CA2) 13. Integrated Closure Planning (CA1)	5	Reputation: Loss of social licence would likely result in national and international negative media attention	100	0.3	30

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
		CA4. Loss of licence to operate through major HSEC incident or breach of operating licence.	16. TSF cover trials and progressive rehabilitation of TSFs to prove up cover design, construction & performance (CA2) 24. Risk assessment completed on post mine landform designs (CA2) 30. SOX Controls (CA3) 31. Corporate and external finance governance and auditing (CA3) 39. Price TARP for each operation reviewed quarterly (CA3) 43. Address BHP Our Requirements, Corporate Alignment Planning, Appendix 1 Closure Plan Scope (CA1) 44. 5YP CAP process for rehabilitation (CA1) 45. Closure provision funding model (CA1, CA3) 46. Annual closure planning workshop with quarterly risk/action review & tracking meetings (CA2) 48. Consideration of specific risks in Our Requirements, Corporate Alignment Planning, Appendix 1 Closure Plan Scope (not achieving closure plan objectives; adverse post-closure events; potential changes to regulations; immediate or unplanned closure) (CA2) 49. Annual review of closure planning risks (CA2) 54. Provision for early closure incorporated into LoA cost estimate as a risk event (CA1) 55. Early closure risk assessment using early closure risk bowtie - risk associated with early closure is low (CA2) 56. Risk status reviewed annually in consideration of Tier 1 asset requirements - long life, large, low-cost, high-margin, expandable (CA3) 57. Community relations plan (CA4) 58. Engagement of regulators in closure trials & progressive rehabilitation observations, monitoring & continuous improvement (CA4) 59. Public consultation an engagement - demonstration of success of progressive rehabilitation (CA4)					
4	BHP is unable to relinquish the mining tenements and leases	CA1. Poor or inadequate closure planning CA2. Poor or inadequate closure risk management i.e. risk management does not include early closure. CA3. Incorrect assessment of asset value and/or life. CA4. Loss of licence to operate through major HSEC incident or breach of operating licence	1. Engage regulators to understand & document closure & relinquishment process (CA4) 2. Engage stakeholders prior to closure to agree on post-closure land-uses & to address any gaps or uncertainties in closure objectives and criteria (CA4) 3. Develop plans for community programs leading up to and after closure. (CA4) 5. Update Mine Closure Plan and submit to regulators in the event of any material changes (CA4) 6. Closure Management and Rehabilitation Plan as per Our Requirements Closure (CA1, CA2, CA4) 11. Progressive Rehabilitation (CA2) 13. Integrated Closure Planning (CA1)	2	Legal: Closure ultimately completed per the approved closure plan but legal negotiations required to resolve matter.	3	1	3

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
			16. TSF cover trials and progressive rehabilitation of TSFs to prove up cover design, construction & performance (CA2) 24. Risk assessment completed on post mine landform designs (CA2) 30. SOX Controls (CA1, CA3) 31. Corporate and external finance governance and auditing (CA1, CA3) 39. Price TARP for each operation reviewed quarterly (CA3) 45. Closure provision funding model (CA1, CA3) 46. Annual closure planning workshop with quarterly risk/action review & tracking meetings (CA2) 48. Consideration of specific risks in Our Requirements, Corporate Alignment Planning, Appendix 1 Closure Plan Scope (not achieving closure plan objectives; adverse post-closure events; potential changes to regulations; immediate or unplanned closure) (CA1, CA2) 49. Annual review of closure planning risks (CA2) 55. Early closure risk assessment using early closure risk bowtie - risk associated with early closure is low (CA2) 56. Risk status reviewed annually in consideration of Tier 1 asset requirements - long life, large, low-cost, high-margin, expandable (CA2, CA3) 58. Engagement of regulators in closure trials & progressive rehabilitation observations, monitoring & continuous improvement (CA4) 59. Public consultation an engagement - demonstration of success of progressive rehabilitation (CA4) 60. Established baseline information e.g. natural radiation levels (CA1) 61. Closure plan contains detailed proposed completion criteria to be used in progressive and final closure (CA1) 62. Research, studies, closure trials and progressive rehabilitation demonstrating achievement of closure performance objectives and criteria (CA2)					
5	Failure of TSF cover resulting in exposure & release of tailings	CA1. Inadequate planning - design, trials, improvements CA2. Poor/inadequate cover design: CA3. Inadequate drying/dewatering of tailings before placement CA4. Cover constructed poorly/incorrectly CA5. TSF cover thickness not adequate for long term radiation safety &/or tailings containment	12. Historic waste placement knowledge (CA1, CA2) 15. Conservative design assumptions for TSF cover (CA1, CA2) 16. TSF cover trials and progressive rehabilitation of TSFs to prove up cover design, construction & performance (CA1, CA2) 17. Climate change included in hydrological modelling predictions (CA1) 18. Geochemistry stability impacts input into geotech analysis (CA1, CA2) 20. Tailings closure design in accordance with ANCOLD guidelines (CA1, CA2)	4	Financial:	30	1	30

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
			63. Progressive rehabilitation planning - research, design, execution planning 2 to 5 years before execution due to commence - is integrated into LoA & 5 year planning & 2Y budget (CA1, CA5) 64. Studies and planning includes cover trials - prior to full scale cover works (CA1) 65. Regulatory engagement in short, medium and long term observation / monitoring / improvement of trials, construction, leading indicators (erosion, seepage, stability etc.) (CA1) 66. Geotechnical review to understand FOS of post mine landform (CA1, CA2) 67. Design criteria set to highest standards (CA2) 68. Post TSF filling drying/consolidation period - 2 to 4 years - monitor and verify tailings consolidation prior to cover placement (CA3) 69. Material characterisation (CA4) 70. Compliance to plan (CA4) 71. Ensure clear communication of requirements (CA4) 72. Design execution survey control (CA4) 78. Trials and monitoring of progressively rehabilitated TSFs (CA5) 83 Use suitably qualified and experienced personnel in the design and construction of TSF capping (CA5).					
6	Post closure risk events - earthquakes, storms, droughts	CA1. Post-closure earthquake beyond design parameters (e.g. Richter Magnitude 9) causes slumping of embankments CA2. Post closure event exceeds TSF design parameters CA3. Post-closure flood events CA4. Climate change	15. Conservative design assumptions for TSF cover (CA2) 17. Climate change included in hydrological modelling predictions (CA2, CA4) 18. Geochemistry stability impacts input into geotech analysis (CA2) 20. Tailings closure design in accordance with ANCOLD guidelines (CA2) 66. Geotechnical review to understand FOS of post mine landform (CA2) 73. Risk assessment completed on post mine landform designs (design failure mode analysis) (CA1. CA3) 74. Conservative design assumptions (CA2) 75. Monitoring of physical stability (CA2) 76. Cover design to promote drain down of TSG water & strength gain of tailings (CA2) 77. Monitoring of progressively rehabilitated TFSs (CA2)	5	Reputation: Despite having relinquished the tenement and having completed capping and rehabilitation of the TSFs per the required standards, a TSF failure would likely result in national and international negative media attention and public and NGO adverse reaction. Likely also result in interest from regulators with respect to reviewing evidence of rehabilitation standards.	100	0.1	10
7	Off-lease ground water seepage originating from TSF or other	CA1. Model underestimates or incorrectly predicts post closure seepage and movement/migration of seepage plume	78. Trials and monitoring of progressively rehabilitated TSFs (CA1, CA3) 79. Closure groundwater model correlated to many years of pre-closure groundwater level and quality data (CA1)	4	Reputation: Although the groundwater aquifer is known to be localised and with limited beneficial use,	30	1	30

	Risk Event	Cause name	Preventative controls	MFL level	MFL Impact description	Severity rating	Likelihood rating	RRR
	contaminated sources.	CA2. Incorrect estimate of water seepage and infiltration into tailings from water on beaches and pond. CA3. Inappropriate TSF design and operation prevents adequate closure outcomes (i.e. low evaporation and high seepage).	80. Groundwater model rechecked in 2015 confirming very low probability of off-lease migration of solutes (CA1) 81. Design and management of TSFs to minimise seepage (CA2) 82. Cover design (shedding) to minimise post closure infiltration of incident water (CA2) 83 Use suitably qualified and experienced personnel in the design and construction of TSF capping. (CA3)		the perception of causing environmental harm to a groundwater aquifer would likely result in national media attention.			

Appendix D: Tailings Investigation

BHP Billiton Olympic Dam

Tailings Storage Facility –

Cover System and Landform Design 2013

Report No. 809/5-01

Prepared for:

bhpbilliton
resourcing the future

Prepared by:

O'Kane Consultants Pty Ltd

Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

May 2013

EXECUTIVE SUMMARY

O'Kane Consultants Pty Ltd. (OKC) was retained by BHP Billiton Olympic Dam Corporation Pty Ltd (ODC) to complete a robust cover system and final landform design for the TSF at Olympic Dam. The primary objective of this project was to develop conceptual cover system and landform designs and to determine locations for full scale cover trials on the existing Olympic Dam TSFs. OKC seconded the services of Landloch Pty Ltd. (Landloch) to aid in erosion assessments to be used by OKC to develop the final landforms and cover systems. This report details the work completed by the Project Team.

Material characteristics used for this assessment was based on current pit waste material characteristics and photographs supplied by ODC. Is it important to emphasise that due to the lack of site-specific data for future waste rock, the designs and recommendations presented in this report are conceptual.

Soil-plant-atmosphere numerical modelling was completed to evaluate performance of various TSF cover system designs for the Olympic Dam site. The soil-plant-atmosphere modelling was carried out to elucidate the following aspects of cover performance:

- Seasonal and annual water balance fluxes including net percolation rates;
- Available water holding capacity; and
- Propensity for upward migration of solutes in the tailings mass into the cover profile (through examination of hydraulic head gradients predicted at the cover / tailings interface).

The models indicate that a cover system consisting of 1 m of overburden waste rock limit net percolation to below 1% of rainfall. The largest risk for increased net percolation is preferential flow especially in areas where ponding will occur. Adding landforms (hammocks) to the TSF top surface will attenuate the runoff water, thereby reducing pressure heads on the cover and increasing evaporative efficiency.

The Water Erosion Prediction Program (WEPP), was used to simulate current and design batter slopes which are understood to be the same for the existing and expansion TSFs. Simulations assessed current design batter slopes and also reduced slope angles for erosion within acceptable levels. Assessments were undertaken for the 100-year storm and also extreme events, i.e. the 10,000-year storm.

To achieve reasonable certainty of long-term erosion control (at current expansion design heights and slopes for a design life of 100 years), D_{50} of at least 60mm will be required. To achieve reasonable certainty of long-term erosion control (at current expansion design heights and slopes for a design life of 10,000 years), D_{50} of at least 125mm will be required. These materials will have to be selected or crushed from future waste rock.

A suitable rock size will have to be selected based on risk profile, cover materials available, detail design accuracy and construction precision.

Slope stability and consolidation assessments were completed for the post closure landform including the design cover and found to be within acceptable design parameters required by TSF closure guidelines.

The landform design must include perimeter bunding on the top surface of the TSF cells to rule out top surface runoff flowing over outer batters uncontrolled. Each cell must include a dedicated spillway and associated drainage channel to convey surface waters (that cannot be accommodated on the inward draining top surface cover system during very large storm events) to the surrounding natural ground level.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF DRAWINGS

1 INTRODUCTION

BHP Billiton Olympic Dam is a world-class mining and mineral-processing operation, owned by the BHP Billiton Group through its wholly owned subsidiary BHP Billiton Olympic Dam Corporation Pty Ltd (ODC). The ore body at Olympic Dam was discovered in 1975 with production commencing in 1988. The operation is located 564 km north of Adelaide in South Australia. A producer of high quality copper, uranium, gold, and silver, ODC produces over 200,000 tonnes of refined copper and 4,300 tonnes of uranium oxide annually. ODC has a very significant ore reserve with a mining life in excess of 50 years.

BHP Billiton is proposing to significantly expand its existing mining and processing operations at Olympic Dam. The Olympic Dam Expansion Project (ODP) is centred on the creation of a new open pit mine that would operate simultaneously with the existing underground mine. The proposed expansion would be built progressively over several stages, increasing production of copper to about 750,000 tonnes per annum over the next 30 years. Government approvals were received in the second half of 2011, and the ODP is now subject to BHP Billiton board approval.

A site closure plan for the proposed ODP is required to be submitted for regulatory approval by October 2013. This site closure plan must encompass the commitments made in the Olympic Dam Expansion Draft and Supplementary Environmental Impact Statements (EISs), and conditions stipulated in regulatory approvals for the EIS (10 October 2011). Within the site closure plan, the Tailings Storage Facility (TSF) cover system would require minimal ongoing monitoring or care and maintenance, and would ensure that all key risks would be well controlled in the very long term. These risks include:

- Landform instability,
- Cover integrity,
- Release of radioactive tailings into the environment,
- Erosion,
- Flora and fauna impacts,
- Dust generation,
- Groundwater contamination, and
- Radiation doses to members of the public.

ODC requires a cover system engineering design/s for the TSF based on the results of various numerical modelling programs. In addition, ODC also requires a plan for implementation of field trials during operations to verify modelling predictions from this cover system design, which will lead to selection of the preferred full-scale cover system design for the TSF.

O'Kane Consultants Pty Ltd. (OKC) was retained by ODC to complete a robust cover system and final landform design for the TSF at Olympic Dam. OKC seconded the services of Landloch Pty Ltd. (Landloch) to aid in the design of the TSF final landform and complete landform erosion modelling. This report details the work completed by the Project Team based on the objectives and scope outlined below.

1.1 Project Objectives and Scope

The primary objective of this project is to design a cover and final landform for the ODC TSF that will not impact the receiving environment in excess of acceptable levels post closure.

The scope of this project involved completion of the following tasks:

- Review of historical investigations and other pertinent background information;
- Defined TSF closure cover criteria and design parameters;
- Developed cover system and final landform design alternatives based on required performance criteria and economically available cover materials at ODC;
- Conducted numerical analyses of the various design alternatives, including soil-plant-atmosphere, consolidation, seepage, landform erosion / evolution, and slope stability analyses;
- Finalised design of the TSF closure cover system and landform based on the results of numerical analyses as well as a Failure Modes and Effects Analysis (FMEA); and
- Designed a cover system field trial program including recommendations for trial footprint, location, construction methods, and monitoring program.

1.2 Report Organisation

For convenient reference, this report has been subdivided into the following sections:

- Section 2 – provides background information pertinent to this study;
- Section 3 – outlines proposed closure criteria and design parameters as well as cover system and final landform design alternatives considered in this study;
- Section 4 – details the approach and findings of cover system design numerical analyses;
- Section 5 – details the approach and findings of landform design numeric analyses including erosion and slope stability modelling;
- Section 6 – outlines the preferred ODP TSF closure design as well as findings of the FMEA and key issues for construction;
- Section 7 – details the proposed TSF cover system field trial including design layout, location, recommended monitoring program, construction methods, timing for construction and monitoring; and
- Section 8 – details the proposed TSF outer embankment field trial including design layout, location, recommended monitoring program, construction methods, timing for construction and monitoring.

2 BACKGROUND

2.1 *Definition of Net Percolation*

The term 'net percolation' is used throughout this report and is defined as follows (refer to Figure 2.1). Meteoric water that reaches the cover surface will either be intercepted by vegetation, run off, or infiltrate into the cover surface. A portion of the water that infiltrates will be stored in the 'active zone' and subsequently exfiltrate back to the surface and evaporate or be removed by transpiration. The infiltration can also move laterally downslope within and below the active zone. A percentage of the infiltrating water will migrate beyond the active zone as a result of gravity overcoming the influence of atmospheric forcing (i.e. evaporation) and result in net percolation to the underlying waste.

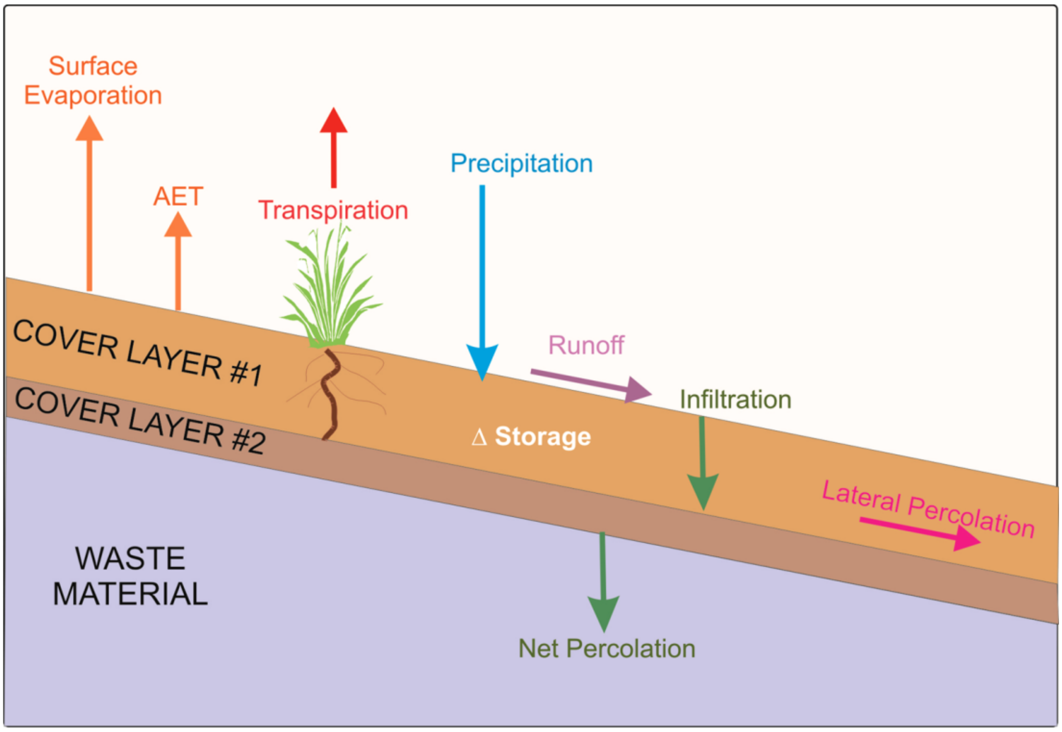


Figure 2.1 Schematic of hydrologic processes that influence performance of sloping mine waste cover systems.

2.2 *Overview of ODP TSF Proposed Design*

The ODP TSF design is described in detail in the Draft and Supplementary EISs, with a synopsis provided below for completeness of this proposal. The proposed TSF design includes seven or eight cells each with a footprint of 2,000 m by 2,000 m (400 ha). The cell embankments would be centre-line raised using competent rock. The embankment height for the FY13 Closure Plan will be 65 m, although it is envisaged that the TSF cells will be raised above this once adequate operational supporting information can be gathered. Each cell would have a central decant area, the base of which would be underlain by a liner (HDPE) and drainage system. The square-shaped decant area is a rock, flow-through wall designed to minimise the size of the pond and support bird netting. In order to minimise seepage and excess unusable process water, each cell will be filled at a very slow rate of rise (~1.5 m/year). Therefore, the majority of the TSF surface will be accessible soon after completion of filling, with no requirement for enhanced consolidation drainage or construction support.

The proposed closure plan for the ODP TSF as detailed in the Draft and Supplementary EISs involves construction of an engineered cover system to ensure long-term containment of the tailings. It is understood that the primary design objective of the TSF cover system is to reduce net percolation and thus seepage rates to a level that matches the seepage rate used in post-closure groundwater flow modelling for the ODP EIS. The long-term seepage rate estimated for the TSF post-closure is around background infiltration, which is approximately 1% of annual rainfall or ~0.3 ML/d (<0.05 m3/ha/d). This is required in order to ensure that all tailings seepage flow is directed to the open pit (sink) over the long term such that a seepage plume does not escape the lease boundary. It is also stated in the ODP EIS that the surface of the rehabilitated TSF will be constructed in a manner to discourage vegetation growth, thereby minimising the potential for metal uptake by plants.

Two different final landform alternatives were considered for the ODP TSF in the 2009 EIS. The first is a ‘water-shedding’ landform that would direct incident rainfall to the cell perimeters and via drop-down structures into the surrounding natural environment. The second is a ‘water-harvesting’ landform where the majority of incident rainfall would be stored in the cover profile and subsequently released via evaporation. It is envisaged that the TSF outer embankment slopes would be left at their constructed slope (2H:1V) at closure to minimise the length of slope that would be susceptible to erosion; however, the final cover design and landform erosion / evolution modelling will lead to the appropriate slope and material prescription for the outer embankment slopes.

Sequential cell closure will provide the opportunity for continual improvement of the TSF closure design during operations. This will be accomplished through performance monitoring of early TSF cell closure designs and potentially field trials using various cover sequence materials stockpiled for this purpose.

2.3 Minimising Radiological Impacts at the TSF Post-Closure

Three potential pathways exist for human radiation exposure at the ODC TSF. The first is inhalation of radon daughters; Radon (Rn^{222}) produced from Radium (Ra^{226}) present in the tailings emanates from the surface of the TSF. The extent of emanation is dependent on the concentration of Ra^{226} in the tailings and *in situ* water contents in the upper tailings / cover profile. The second pathway is inhalation of long-lived radioactive dust (LLRD); however, placement of any type of cover system over the tailings surface will eliminate this pathway. The third and final pathway for occupational radiation exposure at the TSF is external irradiation by gamma rays. ODC is legally obliged to ensure that public exposure to radiation resulting from their operations is not more than 1.0 mSv per year above background level.

The Project Team anticipates that an earthen cover system of sufficient thickness will be required for closure of the TSF in consideration of soil erosion and required low seepage rates over the long term. This same cover system will also reduce potential radiological impacts of the tailings to acceptable site-specific requirements and other regulatory standards. As an approximation, an earthen cover will reduce radon flux by about a factor of two (2) for each 0.5 m of thickness (COGEMA, 2001). If necessary, compaction of a portion of the cover system, which will lead to higher retention of *in situ* moisture, can be carried out to further reduce radon gas emissions. Assuming that the ultimate TSF cover system has a minimum thickness of 1.0 m, the radon flux would be reduced by about a factor of four (4). The gamma fields are generally reduced by about a factor of two (2) for each 100 mm thickness of cover (COGEMA, 2001); therefore, placement of an appropriate earthen cover system on the TSF should reduce gamma fields to near background levels.

3 TSF CLOSURE CRITERIA AND DESIGN ALTERNATIVES

3.1 TSF Closure Criteria

OKC conducted a desktop review of available data and information pertinent to the design of a TSF closure cover. Based on this information OKC was able to identify several design parameters that would be affected by closure criteria stated within the Draft EIS (Arup/ENSR, 2008), legislated by regulating bodies, or dictated by best practice. When closure criteria are explicitly stated they provide a basis for measuring the field performance of a cover system and ultimately, determination of whether the cover system is ‘working’ (O’Kane and Ayres, 2012). The specific closure criteria will guide the design of all facets of the TSF cover system. The following tables present specific closure criteria for evaluating the performance of the TSF cover system and final landform design.

Table 3.1
General closure criteria for the TSF cover system

Design Parameter	Closure Criteria	Source
Environmental Impact	Adverse existing and residual environmental impacts must be assessed and minimised to statutory or acceptable levels and positive effects are maximised.	ANCOLD Guidelines (2012)
	The physical and chemical stability of the storage and the durability of control structure is such that risk to any environmental aspect can be maintained at an acceptable level.	ANCOLD Guidelines (2012)
Post-Closure Mine Use	TSF must be able to remain functionally compatible with the agreed post mining land use.	ANCOLD Guidelines (2012)
Monitoring	Records should be kept on an annual audit.	ANCOLD Guidelines (2012)
	Monitoring and auditing requirements should include monitoring objectives, variables to be measured, sampling frequency, sampling and testing protocols, reporting and auditing frequency, conditions precedent to cessation of monitoring, specifications for visual inspections and a checklist of aspects which should be assessed and reported, reporting to regulating authority.	ANCOLD Guidelines (2012)
	Monitoring should continue until the information obtained proves that a steady state has been reached or an acceptable level of confidence is achieved.	ANCOLD Guidelines (2012)
Safety	Access to dangerous areas should be limited by appropriate barriers and signs and through communication and training.	ANCOLD Guidelines (2012)
	The health of humans and fauna, and the integrity of property and infrastructure are safeguarded.	ANCOLD Guidelines (2012)
Stakeholder Needs	All the procedural and substantiative needs of the involved parties/role-players/stakeholders are addressed	ANCOLD Guidelines (2012)
	The cover design is to utilise “water shedding” and “store and release principles.	Arup/ENSR (2009)
Time	Closure approval can be obtained by a mine within a reasonable time scale.	ANCOLD Guidelines (2012)
Wildlife	The proposed TSF should ensure free tailings liquor is not accessible to fauna.	Arup/ENSR (2009)

Table 3.2
Landform closure criteria for the TSF cover system

Design Parameter	Closure Criteria	Source
Erosion Control	TSF must be able to remain resistant to erosion.	ANCOLD Guidelines (2012)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover that provides erosion protection for any intermediate cover layer materials and the underlying tailings	Arup/ENSR (2009)
	Erosion modelling would extend to at least 10,000 years.	BHP Billiton RFP (2012)
Stability	TSF must be able to remain structurally stable.	ANCOLD Guidelines (2012)
	Records should be kept on monitoring of dam movements or cracking.	ANCOLD Guidelines (2012)
	The final land-use or land capability adopts suitable land forms and can be achieved on a sustainable basis.	ANCOLD Guidelines (2012)
	TSF must achieve factor of safety of 1.1 for earthquakes. Using a return period of 500 years for peak ground acceleration of 0.1g.	ANCOLD Guidelines (2012)
	A peak ground acceleration of 0.075 applies to the maximum design earthquake with an average return period of 1000 years.	Knight Piesold (2004)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover that maintains the stability and integrity of the embankment and crests into perpetuity.	Arup/ENSR (2009)
Visual Amenity	TSF must be able to remain compatible with the surrounding landform.	Arup/ENSR (2009)
Vegetation	The visual impact of the TSF should be minimised by creating suitable conditions for vegetation growth around the base of the TSF.	Arup/ENSR (2009)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover that does not encourage deep rooted vegetation and has sufficient thickness of rock cover such that borrowing animals cannot access tailings	Arup/ENSR (2009)
Cover Thickness	The final rock cover is nominally 0.5 to 1.5 m thick.	BHP Billiton RFP (2012)

Table 3.3
Surface water management closure criteria for the TSF cover system.

Design Parameter	Closure Criteria	Source
Runoff	An operator of an extractive industry must ensure that stormwater that has been contaminated by extracted material on the premises has had as much material removed from is as is reasonably practicable before it is discharged into any waters.	Water Quality Guidelines (2003)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover that minimises seepage by shedding excess rainfall from higher ARI event safely into the adjacent environment.	Arup/ENSR (2009)
Erosion	The cover will be able to withstand a 1 in 100 year storm of 155mm as well as a probable maximum precipitation of 800mm.	Arup/ENSR (2009)
Water Quality	Records should be kept on surface water monitoring.	ANCOLD Guidelines (2012)
	Surface water pollutant levels should not exceed values listed in Schedule 2 under agricultural livestock levels.	Water Quality Guidelines (2003)

Table 3.4
Seepage and ground water management closure criteria for the TSF cover system.

Design Parameter	Closure Criteria	Source
Net Percolation	Seepage from the TSF should not exceed 3.2 ML/d post closure.	Arup/ENSR (2009)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover with appropriate surface area store/release zones that will safely store and release the incident rainfall from average annual rainfall and event up to and around 1 in 25 years.	Arup/ENSR (2009)
	At all times, the cover would seek to keep the net average seepage into the underlying tailings below an infiltration level that matches the assumed infiltration rates (1% rainfall recharge) used in post-closure groundwater mound dissipation modelling predictions (consistent with the RSF seepage rates).	Arup/ENSR (2009)
Water Table	Groundwater levels are required not to rise above 80 m AHD.	Arup/ENSR (2009)
Groundwater Quality	Records should be kept on groundwater monitoring.	ANCOLD Guidelines (2012)
	Groundwater pollutant levels should not exceed current background levels.	Water Quality Guidelines (2003)
	Naturally occurring calcareous clays and Andamooka Limestone beneath the TSF should neutralise acidic seepage and attenuate metals naturally.	Arup/ENSR (2009)

Table 3.5
Closure criteria for **emissions** from the TSF.

Design Parameter	Closure Criteria	Source
Emission	During operations to release acceptably low emissions to air and water from TSF.	Arup/ENSR (2009)
	Post closure to have a stable landform with a final surface that ensures ongoing acceptably low emissions to air and water.	Arup/ENSR (2009)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover that minimises dust by preventing the uncontrolled erosion and release of fine tailings material.	Arup/ENSR (2009)
Radiation	Potential exposure from radon emissions and dust will be effectively controlled by covering the exposed tailings with a suitably thick cover of inert mine rock. The cover design will aim to ensure that exposures are low enough to be consistent with future land uses and conform to the principles of ALARA.	Arup/ENSR (2009)
	Design will provide a hard, durable, non-oxidising and non-radioactive cover that provides a barrier to ensure radiation exposures remains below accepted closure limits into perpetuity. The thickness, type and grading of cover material will be trialled in developing an optimal barrier.	Arup/ENSR (2009)

3.2 TSF Closure Design Parameters

The design of the TSF closure has been based on the following parameters:

a) A design life of 10,000 years for the TSF cover system and final landform, including slope stability and consolidation based on ANCOLD 2012 guidelines;
b) A 100-year OD climatic data base with an average annual rainfall total of 166mm/year has been use for cover and landform modelling;
c) An acceptable net annual infiltration rate of approximately 1% of annual rainfall or about 0.3 ML/d (<0.05 m3/ha/d) through the TSF into the foundations has been used;
d) Maximum TSF height equal to 65m;
e) Outer batter slope (current and new design) at 26.56 degrees (1 vertical : 2 horizontal);
f) No top surface waters will be allowed to overtop the perimeter bund;
g) Average erosion on slopes to be <5t/ha/y; and
h) Peak erosion at any point on the slope to be <10t/ha/y.

3.3 Cover System Design Alternatives

The Project Team selected two cover system alternatives with varying particle size distributions (i.e. hydraulic material properties) to assess for compliance with cover design requirements. The cover systems analysed consisted of a 1.0 m or 1.5 m monolithic layer of waste rock that relies on the moisture store-and-release concept to achieve low net percolation rates.

3.4 Final Landform Design Alternatives

The Project Team investigated two broad top surface cover system alternatives. The first being a water shedding landform that will drain all top surface waters off the TSF via a channel and outer embankment drop structures. The second being a seasonal water containment design that will direct all top surface waters to the centre low point of the TSF with no outer embankment drop structures. The two systems are described below:

Top Surface Water Shedding including Moisture Store-and-Release Concept:

- Install a cover maintaining the top surface topography with water draining to the centre of each cell of the TSF;
- Construct a surface drainage channel from the centre of the TSF cell to the outer embankment along the waste rock decant access roadway; and
- Construct lined drop structures/channels from the top of the outer embankment to natural ground.

Top Surface Water Containment including Moisture Store-and-Release Concept:

- Install a cover maintaining the top surface topography with water draining to the centre of each cell of the TSF;
- Design the cover in the centre of the TSF to hold seasonal standing water without increased infiltration above the 1% NP;
- Construct perimeter bunding to ensure compliance with ANCOLD guidelines for closure and to prevent top surface waters from flowing over outer embankments; and
- Utilise TSF access ramp vehicle carriageways as emergency overflow routes. Carriageways will be designed to accommodate rainfall design events in accordance with ANCOLD guidelines for closure.

Outer Batter Profile and Armour including Moisture Store-and-Release Concept (applicable to both Top surface Alternatives):

The existing outer batters of TSF 1-5 were assessed and it has been concluded that there is very limited benefit modifying batter height or gradients. The same design has been proposed for the ODP TSF. Therefore, alternatives focussed on ways to establish or manage batter surfaces to restrict erosion to acceptable levels.

Based on communication with ODC, onsite materials are believed to be similar to that expected from the expansion pits. Site photographs of these materials were used to classify the potential available materials.

Initial indications are that various D_{50} sized (>30 mm) material appear to be suitable for upper layers of outer batters. Application of 2 layers varying in material size is likely to be less prone to erosion and gully forming than single layers. Runoff on outer batters must be limited to direct rainfall; no top surface waters to overtop the crest. Constructing perimeter bunding will prevent top surface waters from flowing over outer batters.

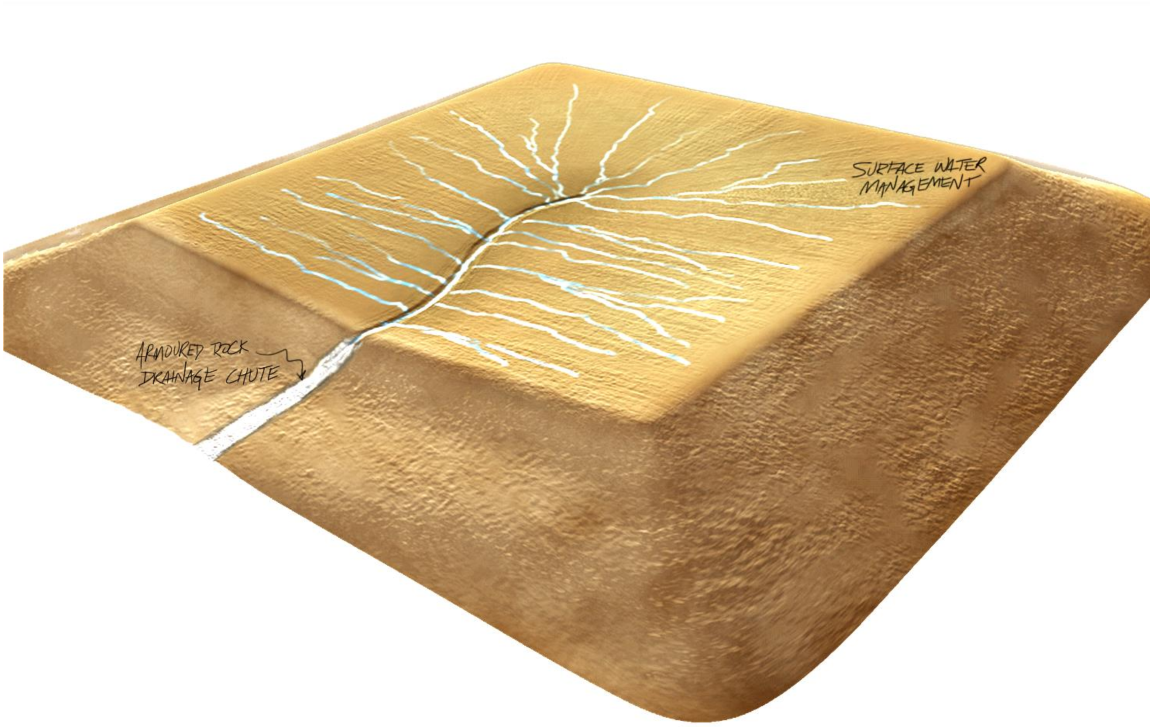


Figure 3.1 Rendering of water-shedding landform design option including moisture store-and-release concept.

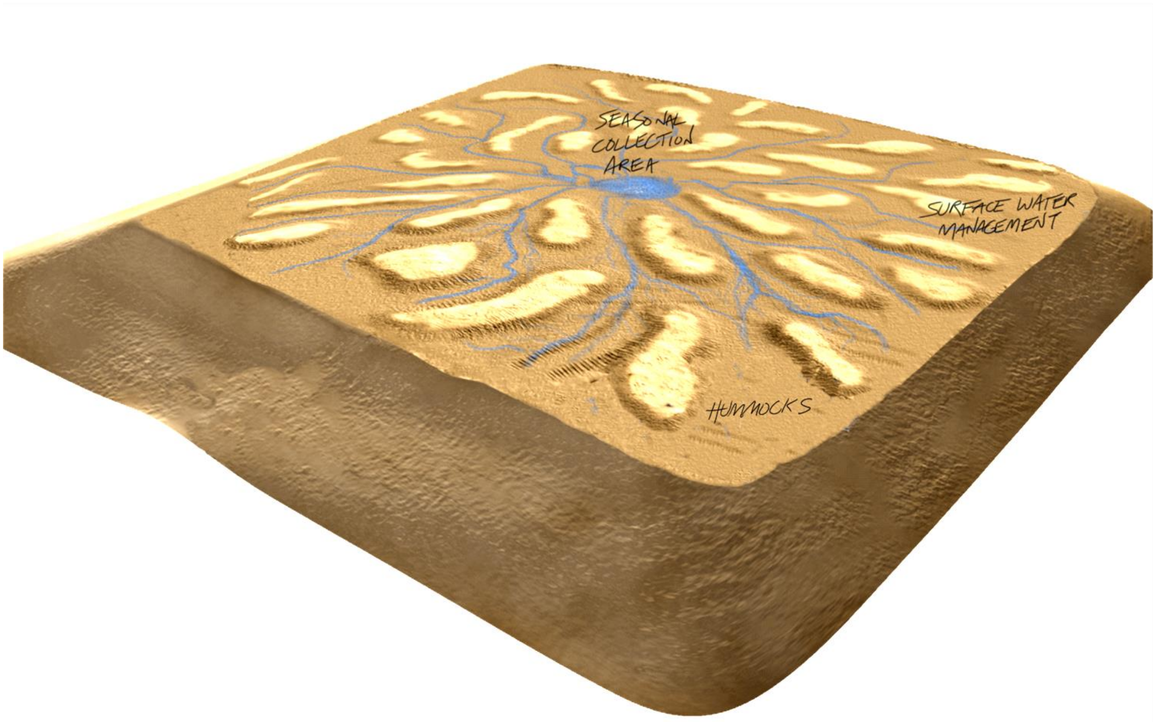


Figure 3.2 Rendering of water-containment landform design option including moisture store-and-release concept.

**note: perimeter bund and emergency spillway and channel to natural ground level not shown*

4 COVER SYSTEM DESIGN NUMERICAL ANALYSES

4.1 Soil-Plant-Atmosphere Numerical Modelling

The numerical modelling report is included in Appendix A

4.1.1 Purpose and Approach

Soil-plant-atmosphere (S-P-A) numerical modelling was completed to evaluate performance of various cover system designs for the ODP TSF. VADOSE/W (Krahn, 2004), a two-dimensional (2-D) saturated-unsaturated numerical model that is fully coupled to the atmosphere, was used in this study. The soil-plant-atmosphere modelling program was carried out to elucidate the following aspects of cover performance:

- Seasonal and annual water balance fluxes including net percolation rates;
- Available water holding capacity (AWHC – important for the climax vegetation community); and
- Propensity for upward migration of solutes in the tailings mass into the cover profile (through examination of hydraulic head gradients predicted at the cover / tailings interface).

One-dimensional (1-D) numeric simulations were completed to predict performance of various cover system designs including two moisture store-and-release cover systems as well as a reduced permeability geosynthetic clay liner (GCL) cover system. All of the simulations are one-dimensional (1-D); however, options are available in the VADOSE/W software to remove ponded surface water following a storm event when running a 1-D simulation, to mimic a rehabilitated landscape that incorporates positive drainage. A 100-year climate database, comprised of site-measured climate records, and estimates of key vegetation characteristics were developed for the 1-D modelling program. A sensitivity analysis of key model inputs on predictions of net percolation was included in the 1-D modelling program.

4.1.2 Model Description and Inputs

VADOSE/W is a finite element model that predicts pressure head (suction) and temperature in the soil profile in response to climatic forcing (such as evaporation) and lower boundary conditions (such as a water table). A key feature of VADOSE/W is the ability of the model to predict actual evaporation and transpiration based on potential evaporation and predicted soil suction, as opposed to the user being required to input these surface flux boundary conditions. The actual evapotranspiration rate is generally well below the potential rate during prolonged dry periods because the suction, or negative water pressure, in the soil profile increases as the surface desiccates. VADOSE/W is a fully coupled (through the vapour pressure term) heat and mass transfer model which is capable of predicting water vapour movement.

VADOSE/W is a physically-based model although modelling of vegetation is based on an empirical formulation. The potential transpiration rate is based on the leaf area index (LAI). The model user can apply ‘excellent’, ‘good’, or ‘poor’ LAI values (that change during the growing season), which are based on agricultural crops, or rooting characteristics and transpiration rates indicative of native species can be input. The potential transpiration rate predicted by the LAI method is limited based on the negative water pressure predicted by VADOSE/W. This is a physically-based positive aspect of the VADOSE/W vegetation module.

Information is provided below for the following items highlighting the key inputs of the proposed S-P-A numerical modelling program:

- Climate database,
- Material properties,
- Lower boundary conditions, and
- Geometry.

4.1.2.1 Climate Data

A historic 100-year climate database developed for this project was estimated from climate data obtained from the Bureau of Meteorology (BoM) for the following stations: Roxby Downs (Olympic Dam Aerodrome); Andamooka; Roxby Downs Station; Woomera (Purple Downs); Roxby Downs (Parakylia Station); and Woomera Aerodrome (BoM, 2013). Appendix B contains details of how these datasets were used to develop the 100-year climate database. The monthly and yearly average climate conditions are summarised in Table 4.1.

Table 4.1
Summary of average climate parameters for the 100-year ODP climate database

Month	**Temperature** (ºC)		**Relative Humidity** (%)		**Wind** (m/s)	**Rainfall**	
	Maximum	Minimum	Maximum	Minimum		(mm)	(# days/month)
January	36	20	37	18	5.1	15	2
February	35	20	42	21	4.8	24	2
March	32	16	45	22	4.4	10	2
April	27	12	45	27	3.7	12	2
May	22	8	58	34	3.4	14	3
June	18	5	70	41	3.3	14	4
July	18	4	68	39	3.4	10	4
August	20	5	58	32	4.1	11	3
September	24	8	46	25	4.8	12	3
October	28	12	39	21	5.0	15	3
November	31	26	39	21	5.0	12	3
December	34	18	38	19	5.1	17	2
Annual	***27***	***12***	***49***	***27***	***4.3***	***166***	***33***

4.1.2.2 Material Properties

Material properties (expressed as a function) required for each material in the VADOSE/W model are as follows:

- moisture retention curve (MRC; suction versus volumetric water content);
- hydraulic conductivity function (suction versus hydraulic conductivity);
- thermal conductivity function (volumetric water content versus thermal conductivity); and
- volumetric specific heat function (volumetric water content versus volumetric specific heat).

Table 4.2
Key material properties input to VADOSE/W for soil-plant-atmosphere cover design simulations

Material	Porosity	Saturated Hydraulic Conductivity (cm/s)	Air Entry Value (kPa)
Overburden Waste Rock – Base Estimate	0.35	1×10^{-3}	0.1
Overburden Waste Rock – Alternate Estimate	0.28	5×10^{-4}	0.4
Tailings – Base Estimate	0.39	5×10^{-6}	7
Tailings – Alternate Estimate	0.28	1×10^{-6}	9

4.1.2.3 Lower Boundary Conditions

The lower boundary of all the models was simulated as a unit hydraulic gradient at the base of the waste material. This boundary condition simulates the water table to be well below the base of the cover system. A unit hydraulic gradient boundary condition assumes that at the lower boundary the soil suction (and, as a result, water content and hydraulic conductivity) are constant with depth. When this is the case, the total head equals the gravitational head causing a unit hydraulic gradient. In other words, a unit hydraulic gradient represents a location in the modelled profile where water movement is controlled mainly by gravity.

4.1.2.4 Geometry

All models (except where stated) consisted of 1 m of overburden waste rock overlying tailings.

4.1.3 Model Results

The S-P-A and seepage modelling was completed in three parts:

- 1D S-P-A modelling to determine cover system thickness and general net percolation rates, and establish actual evaporation to potential evaporation (AE:PE) ratios for the 2D quasi-S-P-A model completed using SEEP/W;
- 2D quasi-S-P-A modelling to ascertain the implications of lateral water movement (i.e. runoff and interflow) on the performance of the TSF cover system and to analyse the sensitivity of the cover system design; and
- 2D seepage modelling to show the seepage pattern through the tailings.

Each part is described in its own section below.

4.1.3.1 1D Soil-Plant-Atmosphere Numerical Modelling

Two, 1D S-P-A models were simulated of cover systems consisting of 1 m and 1.5 m of overburden waste rock overlying tailings using the 100-year climate database. The average annual water balances are presented in Table 4.3. The results indicate that 0.7% of rainfall (just over 1 mm/yr) will infiltrate deep enough to result in net percolation for both cover system alternatives. This result assumes that no runoff is allowed to leave the surface of the cover system.

Additional cover thickness does not provide additional benefit. The modelling actually shows that additional thickness may be detrimental to cover system performance as the underlying tailings act as a barrier slowing percolation to depth and keeping the water stored in the cover system within reach of evaporative forces. However, increasing the cover thickness also increases the depth to which water can infiltrate within the cover system away from the surface, thereby increasing the evaporative force required to remove the infiltrated water.

Table 4.3
Predicted average annual water balance components for the modelled cover system alternatives

Cover Alternative	Rainfall (mm/yr)	PE (mm/yr)	AE (mm/yr)	NP (mm/yr)
1.0 m Overburden Waste Rock	166	2013	165	1.2
1.5 m Overburden Waste Rock	166	2013	165	1.2

Given the measures required to get the model to allow water to infiltrate the cover system (as explained in Section 3.1 of Appendix A) and the high intensity of rain events anticipated on the ODP site, more focus was placed on the 2D quasi-S-P-A modelling.

4.1.3.2 2D Quasi-Soil-Plant-Atmosphere Numerical Modelling

Ten, 20-year, 2D quasi-S-P-A models were completed to determine the effects of runoff and ponding on cover system performance, and to analyse the sensitivity of the performance results to variations in material properties. The list of quasi-S-P-A models is presented in Table 4.4 along with the resultant overall net percolation rate.

Table 4.4
Input parameters evaluated with the 2D-quasi S-P-A models

Key Parameter	Values Incorporated in Numerical Model	NP (mm/yr)
Overburden Waste Rock Material	**Base case material properties**	**1.2**
	Alternate material properties	1.2
Tailings Material	**Base case material properties**	**1.2**
	Alternate material properties	1.2
Saturated Hydraulic Conductivity of Overburden Waste Rock Material	**k_{sat} = 1 x 10^{-3} cm/s**	**1.2**
	k_{sat} = 1 x 10^{-2} cm/s	1.0
Saturated Hydraulic Conductivity of Tailings Material	**k_{sat} = 5 x 10^{-6} cm/s**	**1.2**
	k_{sat} = 5 x 10^{-5} cm/s	1.6
Preferential Flow within Overburden Waste Rock during Rainfall Events	**With Preferential Flow**	**1.2**
	Without Preferential Flow	0.3

The results indicate that variations in the range of material properties estimated for the waste rock and tailings will cause minimal changes in to cover performance. Increasing the saturated hydraulic conductivity of the overburden waste rock results in a decrease in the amount of net percolation. A higher hydraulic conductivity allows the cover to lose water more readily to evaporation during times of drying. However, increasing the saturated hydraulic conductivity of the tailings material allows water to permeate more quickly to depth within the tailings, thereby increasing net percolation.

Decreasing the hydraulic conductivity at high suctions of the overburden waste rock (i.e. simulating less macroporosity and/or cracking) decreases the net percolation. However, this result is misleading as lower conductivity during rainfall events means larger runoff amounts and a larger pond in the middle of the TSF. This is shown in Figure 4.1; the pond size is much larger and does not evaporate during the year when preferential flow is not simulated. Ponding will take advantage and magnify any weaknesses (i.e. macropores and/or cracks) in the cover system, substantially increasing the potential for net percolation. This issue can be solved in three ways:

1) Adding landforms to the TSF to attenuate the runoff water so that runoff water is distributed over a larger area, thereby reducing pressure heads on the cover and increasing evaporative efficiency.
2) Lining the anticipated pond area to block preferential flow paths into the tailings.
3) Removing runoff for the surface of the TSF.

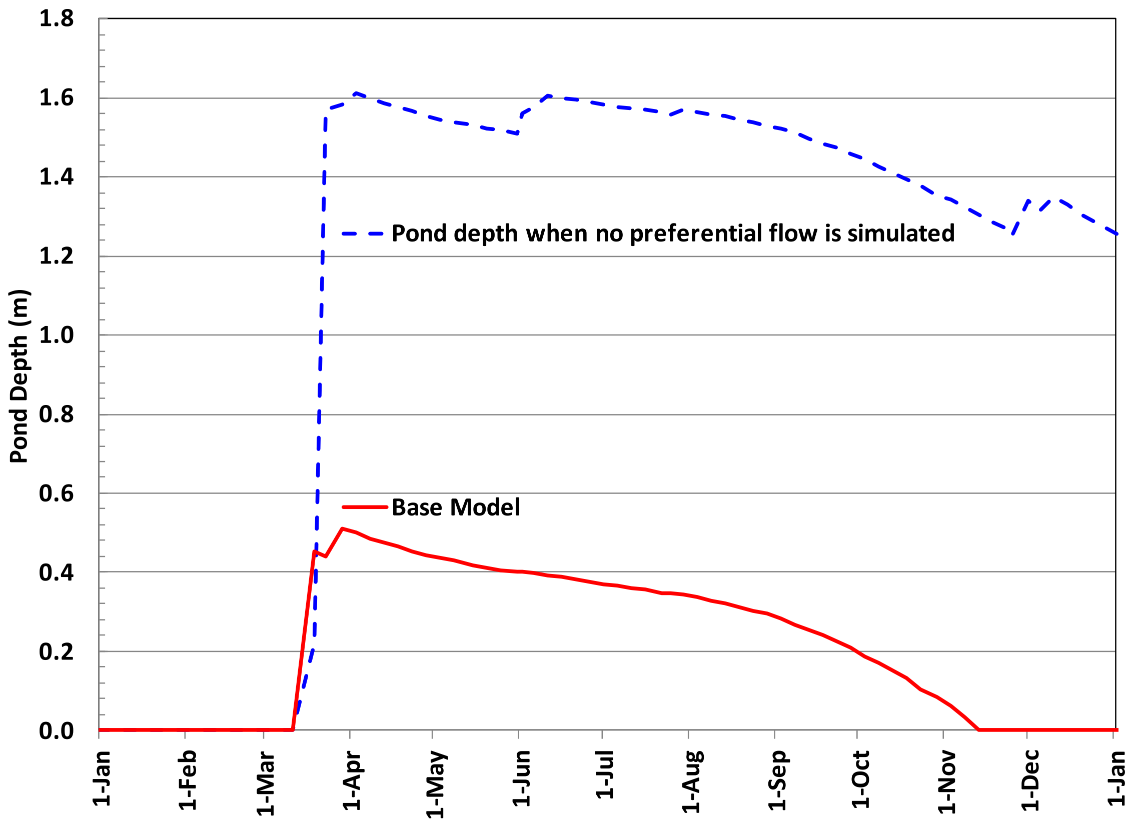


Figure 4.1 Pond depths simulated during year of largest rainfall event with and without preferential flow paths considered.

4.1.3.3 Seepage Modelling

Once the covered TSF comes into equilibrium with local hydrogeologic conditions, the long-term net percolation rate will equate to the long-term seepage rate (i.e. what comes in the roof must come out the floor). This assumes that the TSF under-drainage system will not operate for an extended period post-closure. However, the length of time required for the phreatic surface in the TSF to equilibrate with local hydrogeologic conditions depends on the final closure scenario. In addition, the long-term pore-water pressure conditions for the tailings mass will influence the long-term geotechnical stability of the TSF outer embankments. Therefore, the Project Team conducted a transient, 2-D seepage analysis for the preferred TSF closure design (in progress).

The Project Team used SEEP/W v2012 (GEO-SLOPE, 2012b) for this task. SEEP/W simulates 2-D steady-state or transient saturated / unsaturated flow as well as mass and heat transport. All available reports pertaining to the design and performance of the ODC TSF were reviewed. Long-term net percolation rates predicted from S-P-A modelling was used as input to the SEEP/W model as the upper boundary condition.

The seepage models simulate a complete cross-section of the ODP TSF. The models have a plan length of 2000 m, with a thickness of 45 m at the centre of the cross-section and increasing linearly to 65 m thick at the outer boundaries (Figure 4.2). The rock ring walls and central decant area are simulated assuming both have properties similar to the overburden waste rock.

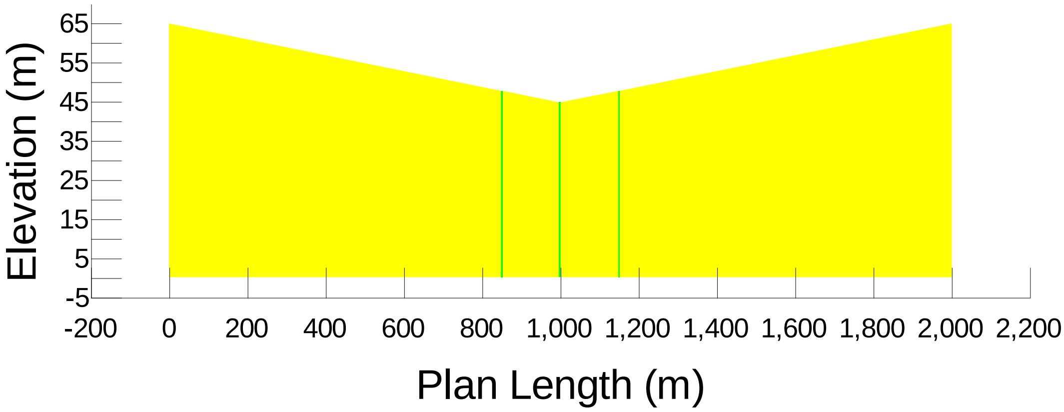


Figure 4.2 Geometry used to simulate seepage models.

Two net percolation scenarios were considered:

- A uniform flux rate equivalent to 1.2 mm/yr across the entire surface of the tailings; and
- A flux rate equivalent to 2.2 mm/yr applied to the centre 100 m of the tailings surface and flux equivalent to 1.2 mm/yr for remaining tailings surface. This scenario simulates the presence of a central pond

Initial suction conditions of 200 kPa and 250 kPa were applied across the entire cross-section to initiate the seepage models. 200 kPa and 250 kPa were chosen as they made the TSF slightly wetter and slightly drier, respectively, than the final steady-state conditions.

The four seepage simulations developed using the above scenarios and seepage conditions (i.e. each net percolation scenario simulated with each initial suction condition), were run transiently until the system came into equilibrium (i.e. the flux entering the top of the model (net percolation) equalled the flux exiting the base (basal seepage).

The results of these seepage models are presented in Figures 4.3 and 4.4. Figure 4.3 shows that in all four scenarios it takes approximately 200 to 300 years for the surface flux to start influencing the basal seepage and almost 2000 years for the system to reach equilibrium (i.e. flux entering the top equals flux exiting the base).

Figure 4.4 shows that, as anticipated, additional net percolation due to a central pond results in increased seepage at the base of the dump directly below the pond. The three points of slightly increased basal seepage represent the locations of the rock ring walls and central decant area. However, it must be noted that the seepage model does not account for heterogeneity in the tailings, rock walls and central decant materials. Therefore, in reality, the increase in seepage at the centre of the TSF would be much less acute (but the overall basal seepage rate would still be as shown in Figure A4.3).

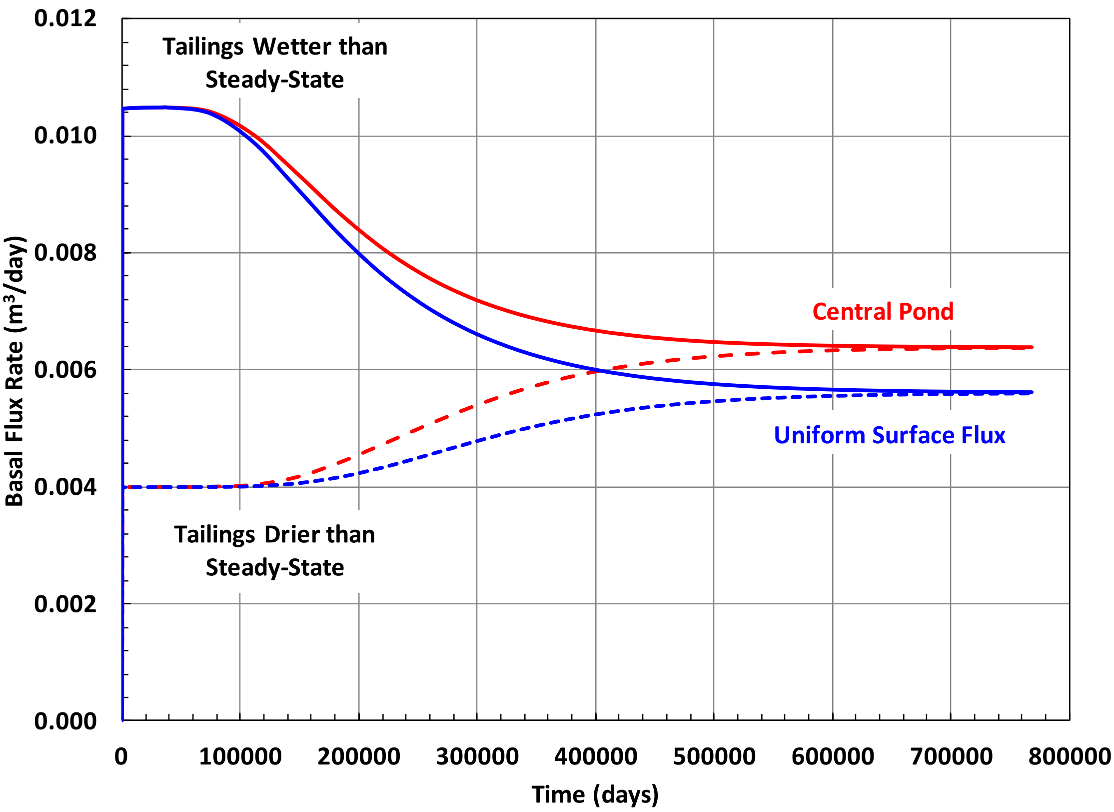


Figure 4.3 Change in basal flux rate with time for four seepage models.

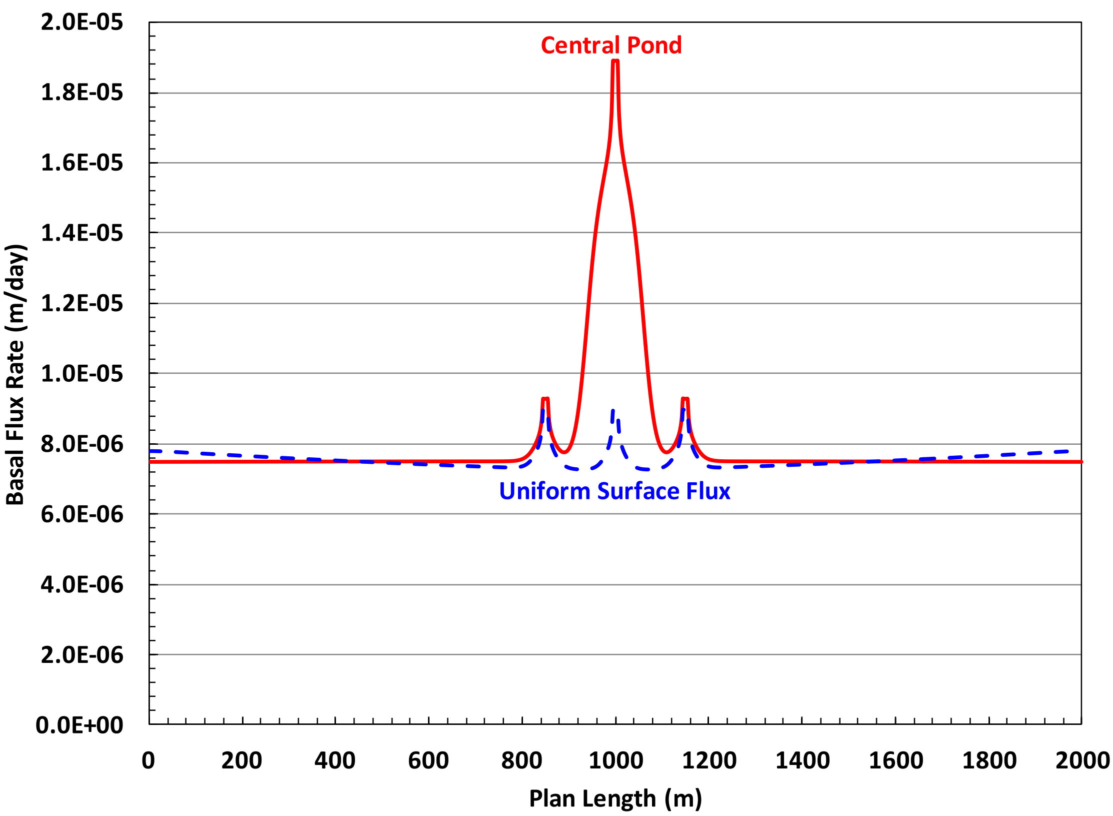


Figure 4.4 Final basal flux rates across base of TSF for two seepage scenarios.

4.1.4 Model Limitations

The S-P-A model presented in this section is a mathematical representation of moisture and heat transport within the cover system alternatives examined for the ODP TSF. The model was constructed to develop an understanding of the performance of cover system designs in limiting net percolation to the underlying tailings material. The complex hydrogeology of the TSF had to be simplified into a conceptual model that could be represented in a mathematical model. The numerical model is thus limited by the accuracy and detail of the conceptual model.

The following limitations should be noted when interpreting the results of the model predictions for the S-P-A numerical modelling program.

- The conceptual model assumes that movement of water in the unsaturated zone can be represented as Darcian flow in a porous media. The model does not accurately account for any potential non-Darcian flow in macropores and/or cracks within the cover system alternatives.

- The conceptual model assumes that the cover system alternatives can be represented by various material types with homogeneous material properties. The potential influence of local heterogeneity (within a given material type) was not investigated.

- The moisture movement within the cover systems is defined by the unsaturated hydraulic conductivity versus matric suction relationship. This relationship is extremely difficult to measure *in situ* in a field condition and consequently is derived by a theoretical algorithm based on the value input for k_{sat}. The theoretical relationship defines the hydraulic conductivity function over several orders of magnitude, while a single or half order of magnitude change can greatly affect the predicted net percolation results from a simulation.

The key advantage to the numerical modelling results summarised herein is the ability to enhance judgment, rather than to lend predictive accuracy. Hence, instead of focusing on the absolute results predicted, it is recommended that the modelling results be viewed as a tool to understand key processes and characteristics that will influence performance of the potential cover designs, and develop engineering decisions based on this understanding.

4.2 Tailings Consolidation Modelling

4.2.1 Purpose and Approach

A key issue in TSF landform stability is the potential for differential tailings mass settlement due to changes in pore-water pressure (effective stress; typically associated with drawdown of the water table) and additional loading from cover material placement. Differential settlement can result in failure of the surface water management system and lead to ponding conditions on the TSF after closure. Based on the design and planned operation of the new TSF cells, it is anticipated that the majority of tailings consolidation will occur prior to placement of the closure cover system. However, from a due diligence perspective, the Project Team recommends that a numerical analysis be completed to predict tailings consolidation due to pore-water dissipation and cover material placement for the preferred TSF closure design.

The Project Team uses several commercial software packages to evaluate consolidation of tailings deposits, including both small- (SIGMA/W) and large-strain (CONDES0) consolidation. The Project Team would first review all available reports pertaining to the strength and consolidation of the tailings mass. 1-D models of representative sections of the ODC TSF and underlying materials would then be developed. It is assumed that historic geotechnical investigations as well as available survey data or design drawings will provide the necessary information to construct reasonable models of the TSF. A sensitivity analysis of key input parameters would be conducted to provide insight on the dominant factors controlling consolidation of ODC tailings mass.

The key outcomes from this modelling program will be threefold. First, the predicted consolidation and settlement of the tailings mass, particularly in fine-textured tailings (i.e. slimes) areas, will aid in the design of the final contouring plan in terms of managing rainfall runoff from the cover surface over the long term. Secondly, the predicted dissipation of excess pore-water pressures will enable a transient analysis of seepage to be completed for this project (Task 4.3). Finally, the results of the consolidation analysis, coupled with the seepage analysis, will provide an indication of how long the TSF under-drainage system should operate following cessation of tailings deposition.

The Tailings Consolidation Analysis report is attached as Appendix B. Five base scenarios were modelled to determine the consolidation behaviour of the bulk tailings once active tailings deposition ceases. The scenarios included having no cover, a 1 meter and 2 meter cover constructed on top of the TSFs. In addition to base scenarios, sensitivity analyses were also conducted to consider tailings spatial variation along the tailings flow pathway during deposition.

4.2.2 Model Results

The implications of tailings settlement on cover design can be summarised as follows:

- Rate of consolidation will be the highest for the no cover and unsaturated tailings scenarios
- The maximum differential settlement for the field trial (achieved over decades) was calculated to be 0.57 m with a resulting slope of 0.6% over a length of 97.5 m
- The 4 year cover trial will not be exposed to differential settlement due to the short monitoring period
- The maximum differential settlement for new proposed TSF cells was calculated to be 1.20 m with a slope change from 1% to 1.2% over a length of 1000 m
- This margin of increase in slope will not generate substantial impacts on the integrity of the final cover system

4.3 Summary of Numerical Analyses

4.3.1 Soil-Plant-Atmosphere

S-P-A and seepage modelling were completed to evaluate potential cover systems for the ODP TSF. These models indicate that a cover system consisting of 1 m of overburden waste rock will be sufficient to limit net percolation below 1% of rainfall. The largest risk for increased net percolation is preferential flow especially in areas where ponding will occur. This issue can be solved in three ways:

1) Adding landforms to the TSF to attenuate the runoff water so that runoff water is distributed over a larger area, thereby reducing pressure heads on the cover and increasing evaporative efficiency.
2) Lining the anticipated pond area to block preferential flow paths into the tailings.
3) Removing runoff for the surface of the TSF.

The first method is the simplest and most sustainable.

It is anticipated that it will take at least 200 years for net percolation entering the surface of the tailings to start influencing the basal flux rate, and almost 2000 years for the system to reach equilibrium (i.e. flux entering the top equals flux exiting the base).

5 LANDFORM DESIGN NUMERICAL ANALYSES

5.1 Erosion / Landform Evolution Modelling

5.1.1 Purpose and Approach

The Project Team used the WEPP runoff/erosion model to predict the long-term erosion of the TSF landform design alternatives developed in Task 3. The Water Erosion Prediction Program (WEPP), developed by the United States Department of Agriculture, will use available data on (a) site materials and (b) from similar materials at other sites to assess outer batter slope erosion. Using WEPP, the Project Team has developed relatively simple approaches that can be applied to estimate erodibility parameters even when direct measurements are not possible.

WEPP explicitly considers rill and interrill erosion and is therefore better able to consider interactions of slope length and gradient than other models. WEPP estimates net soil loss for an entire hillslope or for each point on a slope profile on a daily, monthly, or average annual basis. Basic inputs required for the WEPP model include climate data, slope configuration, soil properties, and soil management (vegetation) properties. However, WEPP does not consider potential effects of erosion and deposition on landform development, nor does it deal specifically with gully development but it is well suited to assess extreme events like the 10,000 year storm event required for the assessment of the Olympic Dam TSF.

5.1.2 Model Description and Inputs

WEPP simulations were carried out by Landloch for the OD TSF current and design batter slopes which are understood to be the same. Not only did the simulations consider alterations of the current batters but focussed on ways to maintain or establish slopes with erosion restricted to acceptable levels. Assessments were undertaken for the 100-year storm and also extreme events, i.e. the 10,000-year storm. The Landloch assessment reports are attached in Appendix C.

The design parameters for the TSF were taken as being 65 m high with outer batters at 1 Vertical : 2 Horizontal. The project 100-year OD climate data with an average 166mm/y was utilised. Allowance was made for 5 m rill spacing in the models.

It was assumed that the TSF top surface waters will not overtop over outer batters and outer batters will be stabilised by spreading waste rock over the existing batters. Material parameters were derived from site photographs of the current batter materials at the existing TSFs.

5.1.3 Model Results (100-year)

For 5 m rill spacing and for a D_{50} of 40mm, the predicted average erosion rate is slightly lower than the “acceptable” rate of 5 t/ha/y. In slight contrast; for D_{50} of 50mm, the predicted peak erosion rate is lower than the acceptable peak rate of 10 t/ha/y.

To achieve reasonable certainty of long-term erosion control (at current design slopes), D_{50} of at least 60mm will be required.

5.1.4 Model Results (10,000-year)

As can be expected, there is a considerable increase in rock size for the 10,000-year storm event. There are significant potential benefits if detail design and precision construction shaping are implemented for the closure of the TSF.

To achieve reasonable certainty of long-term erosion control (at current design slopes and for a design life of 10,000 years), D_{50} of at least 125mm will be required.

A suitable rock size will have to be selected based on risk profile, cover materials available, detail design accuracy and construction precision.

5.2 Slope Stability Modelling

5.2.1 Purpose and Approach

Slope stability analyses were completed for the expanded TSF as part of the ODP Draft and Supplementary EISs. These analyses were in support of the proposed design and operation of the new TSF cells. Slope stability analyses are required as part of this project in order to verify that the preferred closure cover and landform design will result in acceptable slope stability factors of safety post-closure.

The Project Team used SLOPE/W v2012 (GEO-SLOPE, 2012a) for this task. Using limit equilibrium, SLOPE/W can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure conditions using a large selection of soil models. The approach used for the post-closure slope stability analysis followed that used in the EIS study for TSF operations. Analyses were carried out for static loading conditions as well as post-earthquake conditions immediately following the Maximum Design Earthquake (MDE) event. Pore-water pressure conditions input to the model came from seepage analyses for the preferred closure scenarios. Shear strength parameters were derived based on historical investigations and available test data.

5.2.2 Model Results

The factor of safety for all modelling scenarios is greater than 1.5 indicating that the landform is stable at a slope of 1V:2H (26.6°) with the proposed rock cover.

6 TSF CLOSURE PREFERRED DESIGN

The final cover system design for the ODP TSF should be based on performance required to achieve acceptable impacts to the receiving environment post-closure (O’Kane and Wels, 2003). In particular, the long-term net percolation rate for the cover system must be adequate to attenuate peak concentrations for contaminants of concern in natural watercourses, to levels that can be assimilated without adverse impact to the aquatic ecosystem. The cover system also needs to be thick enough to reduce gamma radiation exposure and radon gas emissions from the stored tailings to acceptable levels. Finally, the chosen cover system should be designed to mitigate the effects of various physical, chemical and biological processes specific to the Olympic Dam site, to ensure performance of the cover system will be sustainable over the long term (see Figure 6.1).

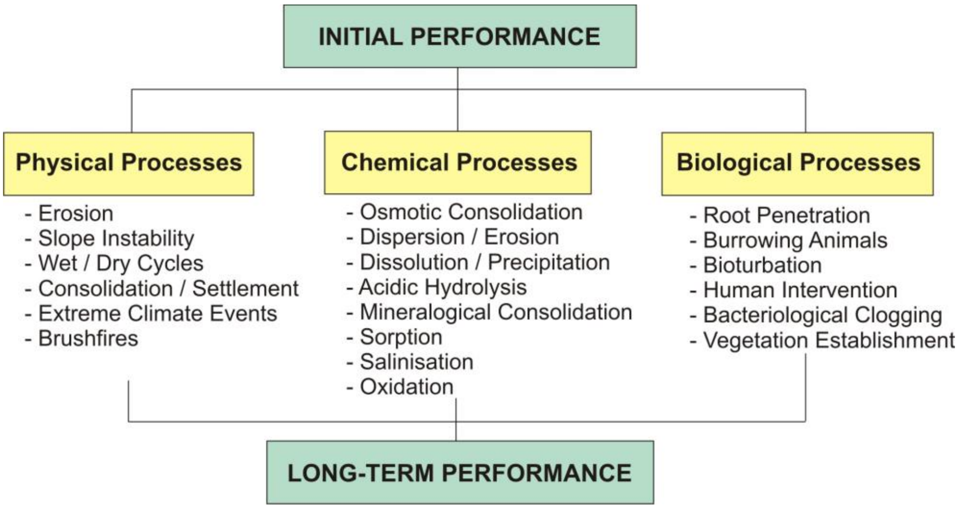


Figure 6.1 Processes that could impact the sustainable performance of mine waste cover systems (adapted from INAP, 2003).

Based on closure criteria and design parameters outlined in Section 3, numerical analyses completed for this study, and various processes identified in Figure 6.1, the preferred closure cover system and landform design are shown in Figure 6.2 and 6.3, respectively. The proposed cover material is ROM overburden waste, which has sufficient fines to provide adequate moisture retention plus sufficient gravel and cobble size particles to provide adequate resistance to soil erosion. From a net percolation perspective, there would not be a considerable difference in performance between a 0.5 m thick and 1.0 m thick cover system comprised of ROM overburden waste material. However, the placement of an additional 0.5 m of cover material over the tailings surface provides greater protection over the long term against various processes such as soil erosion and radiological exposure to humans. To further reduce net percolation rates over the long term, the proposed TSF cover system should incorporate positive surface drainage in order to promote runoff of storm event waters.

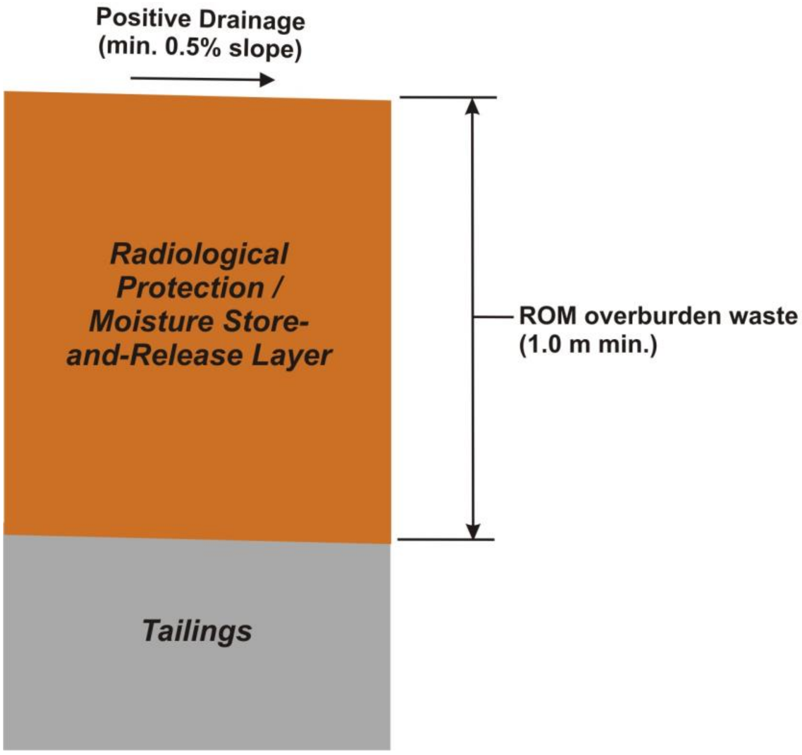


Figure 6.2 Preferred closure cover system design for the ODP TSF.

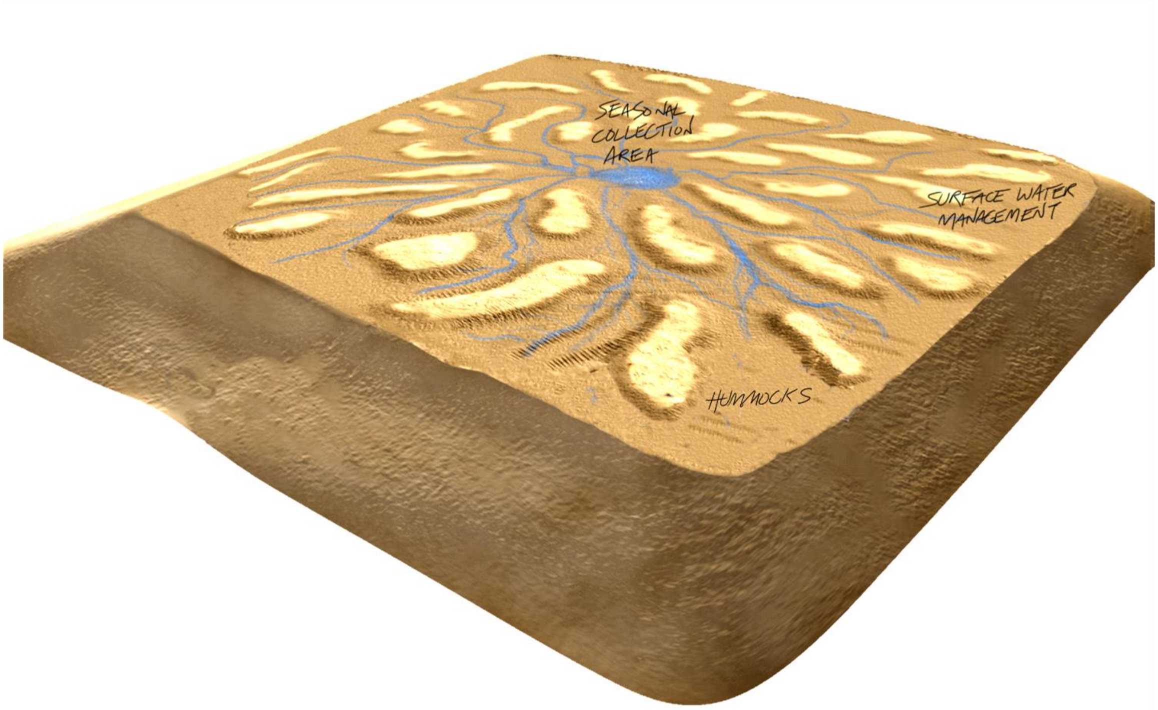


Figure 6.3 Preferred closure landform design for the ODP TSF.

**note: perimeter bund and emergency spillway and channel to natural ground level not shown*

6.1 Risk Assessment (FMEA)

A failure modes and effects analysis (FMEA) was completed on the preferred closure cover system and final landform for the ODP TSF. A FMEA is a top-down / expert-system approach to risk identification and quantification, and mitigation-measure identification and prioritisation. Its value and effectiveness depends on having experts with the appropriate knowledge and experience participate in the evaluation during which failure modes are identified, risks estimated, and appropriate mitigation measures proposed. The goal is to provide a useful analysis technique that can be used to assess the potential for, or likelihood of, failure of the proposed design and effects of such failures on human health and the surrounding ecosystem. Robertson and Shaw (2006) describe the FMEA approach in greater detail.

The completed FMEA table is attached in Appendix E. One critical and two high TSF cover system failure modes were identified during the analysis. They are:

- Segregation of ROM overburden waste upon placement (Critical)
- Inadequate QA/QC during cover construction (High)
- Cover system constructability (High)

With the implementation of the correct mitigation measures the risk rating of these failure modes may be reduced to within acceptable standards. Proposed mitigation measures have been included in the FMEA table.

6.2 Key Construction Issues

Key issues pertaining to construction of the proposed cover design for the TSF are as follows:

- Placement of cover material on undrained, less-consolidated tailings;
- Placement of cover material on contaminated waste;
- Placement of cover material in a manner that minimises segregation;
- Gamma radiation levels at the surface of the as-built cover system; and
- Provision of emergency overflow routes.

It is presumed the TSF cells that are ready for rehabilitation will have sufficiently drained to facilitate placement and spreading of cover material. The central portion of a given cell near the decant area may possess tailings that are not sufficiently drained to support construction equipment. It is recommended that ponded water in the decant area be pumped down to the greatest extent possible before cover construction commences. It is also recommended that cover material be placed starting along the perimeter and progressing towards the decant area. As cover construction progresses towards the decant area, excess pore-waters will be expressed from the tailings mass; therefore, the decant pond should remain operational throughout cover construction. It is anticipated that sufficient bearing capacity would exist for hauling and spreading equipment provided the equipment travels on cover material already placed. If necessary, a geo-grid or geotextile product can be used to provide additional strength for construction equipment. Traffic compacted areas in the cover profile should be ripped or scarified at the end of construction; these compacted areas, if left intact, could lead to higher than anticipated runoff volumes and consequently erosional features.

The predicted long-term net percolation rates for the 1.0 m ROM overburden waste cover system are based on the subgrade material being tailings, with a k_{sat} of 5 x 10^{-6} cm/s. As shown in the sensitivity analysis, increasing the tailings k_{sat} by one order of magnitude results in a 37% increase in the predicted mean annual net percolation rate. Therefore, in order to achieve the lowest possible net percolation rates for the proposed 1.0 m cover system, it is recommended that the subgrade material possess a k_{sat} similar to that of the upper tailings material. For areas where the cover system is constructed on top of contaminated waste or other fill (i.e. not tailings), it is recommended that the top 0.5 m (minimum) of subgrade material consist of well-graded, silty-sand material (similar texture to the tailings). This will reduce the potential of localised differential settlement as well as preferential flow of infiltrated meteoric waters.

Gap-graded materials, which are typical of ROM wastes, have a greater propensity for segregation compared to well-graded materials, particularly when they are placed using large haul trucks. The segregated zones of coarser textured material can result in macro-pore flow, and as described above will lead to preferential flow during higher intensity and longer duration rainfall events, and ultimately higher than expected net percolation rates. The key issue is that rapid and deep infiltration occurs via the coarser textured segregated material, and the only manner in which this water can ‘report’ back to the atmosphere via evaporation and/or transpiration is via the finer textured material (O’Kane and Ayres, 2012). This is typically a slower and more dampened response, and if a subsequent lower intensity rainfall event occurs, unsaturated piston flow can ‘push’ the original water deeper in to the profile; again, ultimately resulting in higher than expected net percolation rates. In short, some additional mixing of placed cover material with dozers may be required to insure that a homogeneous layer has been created.

It is presumed that the gamma radiation levels measured at one metre above the tailings surface would be relatively low. Nonetheless, upon completion of cover system construction, a gamma survey should be conducted to confirm the reclaimed surface possesses an average dose rate less than 1 µSv/hr above background (averaged over a 100 m by 100 m surface, or a 10,000 m^2 surface), and a maximum spot dose less than 2.5 µSv/hr above background.

The preferred design will incorporate emergency overflow routes to satisfy ANCOLD guidelines. As the design intent is contain incident rainfall on the landform surface, the emergency overflow routes are not expected to be utilised over the landform design life. In this design, landform overflows will be routed via access ramp carriageways, which (with only minor modification to the carriage bunding) provide a hydraulically consistent route for overflows.

7 COVER SYSTEM FIELD TRIAL

The Project Team was tasked with designing a cover system field trial program to demonstrate the feasibility and improve the viability of the proposed TSF remediation strategy. The field trial program would utilise non-operational (filled) tailings cells (e.g. existing TSF cells 1, 2 and 3) to verify:

1) Proposed construction methods using the selected waste materials;
2) Erosion rates of different cover materials on the plateau area and embankment slopes;
3) Net annual infiltration and seepage rates into the tailings foundation; and
4) Long-term adequacy of dropdown structures under extreme flow conditions.

7.1 General Approach

Cover trials need to be large enough to properly evaluate construction methodologies and equipment that would be used for full-scale construction. In addition, cover trials need to be large enough to minimise edge effects on instruments installed to monitor performance.

A ‘watershed’ approach as opposed to a ‘trial plot’ approach is preferred in order to gain a better understanding of cover system performance under site-specific conditions (O’Kane, 2011). The rationale for utilising a watershed approach is such that it allows for the complexity and challenges of cover system performance monitoring, which are apparent given the scale increase of a cover system from a point-scale (e.g. a trial plot) to a macro-scale (e.g. a watershed). Although most monitoring techniques used in point-scale cover system monitoring can be applied for macro-scale cover system monitoring, the extent of performance monitoring for a macro-scale cover system is much broader than that for a point-scale cover system. The performance monitoring and evaluation of a macro-scale cover system considers the temporal and spatial variability of the field measured datasets. The monitoring frequency (scale) for obtaining sufficient data, which is associated with spatial instrumentation and temporal data acquisition, must be understood in order to deploy a cost-effective monitoring system. In short, a watershed approach to designing cover system field trials allows for thought in regards to the interaction of key processes, mechanisms, and characteristics that will be operational on a full-scale cover system, but which can be studied at a manageable size.

From a practical perspective, stakeholders will gain more confidence in the cover system design process if trial areas cover a larger portion of the final reclaimed landscape. In addition, watersheds are the ‘building blocks’ of landscapes, and if performance is understand on a watershed scale, this understanding can be extended to the landscape scale, which is the scale required for mine closure.

Several factors need to be considered when designing a cover performance monitoring program. Cover system performance will be different in upslope versus downslope areas due to differences in runoff and infiltration across a sloping surface. Heterogeneity in the particle size distribution of cover material will also result in slight differences in cover system performance. Cover performance monitoring systems should be automated to the extent possible to avoid missing collection of field response data during key times of the year (e.g. during and following storm events). In addition, the use of automated systems for data collection greatly reduces the need for human intervention and in particular, demands placed on mine site personnel. Finally, a key purpose of cover trial monitoring programs is to develop a database of moisture and thermal field responses for calibration of a soil-plant-atmosphere numerical model and ultimately predictions of long-term cover performance.

7.2 Proposed Location and Layout

The location of the proposed TSF cover system field trial should take into account the following factors, at a minimum:

- An area of an existing TSF cell that will not receive any future deposition of tailings;
- Tailings texture representative of the majority of tailings at Olympic Dam;
- Overall gradient of the tailings surface representative of surface gradients upon cessation of tailings deposition;
- Ease of access for construction equipment;
- Distance to cover material borrow source(s); and
- Minimal potential for meteoric or process waters to run into the cover trial area to prevent outside influences on the cover trial water balance.

Based on the above factors and discussions with ODC personnel, the proposed location of the cover system field trial is the southwest corner of TSF Cell #1 (see Dwg. No. 809/5-100). Drawings are attached as Appendix F.

A proposed layout for the TSF cover system field trial is shown in Dwg. No. 809/5-101. The cover profile is indicative of the preferred cover system design for closure (minimum 1.0 m of ROM overburden waste rock). Additional cover material is included near the outer perimeters for landform design purposes and in particular, to direct storm runoff waters to a common point for flow and erosion measurements (see Dwg. No. 809/5-102 and -103). Table 7.1 outlines pertinent design details for the proposed cover trial layout.

Table 7.1
Overview of key design attributes of proposed TSF cover system field trial

Minimum cover thickness	1.0 m
Maximum cover thickness	2.7 m
Footprint of cover trial	8.5 ha
Volume of cover material	133,000 BCM
Slope of drainage path (avg.)	0.75%

Key aspects that should be considered during construction of the cover system field trial are:

- *Over-compaction of cover material* – due to the confined area and requirement for construction equipment to operate on previously placed fill material, a material placement plan will be needed to prevent over-compaction of cover material, particularly in the central drainage path area.
- *Segregation of cover material* – due to the gap-graded nature of ROM waste material, thicker fills may need to be placed in two lifts to minimise the potential development of preferential flowpaths through the cover profile.
- *Installation of instrumentation* – where feasible, instruments will be installed following cover material placement to minimise the potential for damage to the instruments; however, some instruments to be installed in the upper tailings profile will need to be installed prior to cover material placement.

7.3 Recommended Monitoring Program

The proposed monitoring program for the cover system field trial has been designed to quantify two critical aspects of cover system performance; namely, net percolation and erosion. The types and locations of proposed monitoring instruments are shown on Dwg. Nos. 809/5-101 and -102. The proposed monitoring parameters are as follows:

- Net percolation,
- Meteorological parameters,
- Actual evapotranspiration,
- Changes in soil water storage,
- Runoff volumes, and
- Erosion rates.

7.3.1 Net Percolation

Net percolation can be directly measured with a lysimeter or indirectly calculated using the water balance equation. In general, the design and installation of lysimeters to monitor evaporative fluxes as well as net infiltration is well understood and implemented in the soil science discipline; however, the design of lysimeters for field monitoring programmes in the mining industry have typically not included fundamental aspects of lysimeter design as established in the soil science literature (MEND, 2004). The design of a lysimeter for one site is generally not transferable to another site due to potential differences in climatic conditions, hydraulic properties of the cover and waste materials, and slope of the cover system at the location of the lysimeter. Bews *et al.* (1997) and O'Kane and Barbour (2003) showed that bypass flow around a lysimeter is common if the lysimeter is improperly designed. Based on OKC's experience with installing lysimeters below a tailings cover system, it will be extremely challenging to measure representative net percolation rates with a lysimeter. In addition, net percolation rates for the proposed TSF cover system are expected to be very low (~1% of annual rainfall). As such, OKC recommends that lysimeters not be used in this study as the primary method for estimating net percolation rates through the cover system field trial.

The water balance method is proposed as the primary method for estimating seasonal and annual net percolation rates through the trial cover system. All water balance parameters would be continuously monitored with the exception of net percolation. Net percolation volumes would be determined based on measured AET rates and solving the water balance equation on a daily basis.

As a backup to the water balance method, OKC recommends that a Decagon drain gauge Gee passive capillary lysimeter (Gee lysimeter) be installed at each of the primary soil monitoring sites. Gee lysimeters will help define sub-surface flow dynamics including determining the magnitude and timing of flow from the cover system into the underlying tailings. Gee lysimeters are automated in that they measure the amount of percolation without the aid of an external tipping bucket and can be installed *in situ* without the need for periodic calibrations. In addition, Gee lysimeters collect a volume of water which can be sampled though a flexible hose that extends to the surface using a peristaltic pump.

7.3.2 Meteorology

Site-specific measurements of rainfall and net solar radiation are critical for evaluating performance of a mine waste cover system. Rainfall is a key element of the cover system water balance, and directly related to net percolation realised through the cover system. Net solar radiation is a dominant factor in the surface energy balance and resulting evapotranspiration from the cover profile. Potential (or theoretical maximum) rates of evaporation from the cover surface can be determined through measurements of net solar radiation, air temperature, relative humidity (RH), and wind speed.

A portable, fully-automated station supplied by Campbell Scientific Australia (CSA) is proposed for site-specific monitoring of various climatic parameters. The proposed station would be located near the centre of the cover trial, and would include sensors to measure air temperature, relative humidity, wind speed and direction, net solar radiation, and rainfall. These sensors would be controlled by a Campbell Scientific Inc. (CSI) CR800 datalogger powered by a 12-volt battery recharged with a solar panel.

7.3.3 Actual Evapotranspiration

Actual evapotranspiration (AET) will be estimated using an Eddy Covariance system (ECoV). The ECoV directly measures the transfer of water vapour from the ground surface by measuring the exchange rates of trace gasses, in this case water vapour (H_2O) and carbon dioxide (CO_2) over a given study area. Air flow can be compartmentalized as horizontal and vertical rotating eddies (turbulent vortices of different sizes). Each eddy is comprised of vertical and horizontal components. At a given time interval, the eddy moves a parcel of air in a certain direction at a certain speed which is recorded using a sonic anemometer. Each eddy has a gas concentration, temperature, pressure, and humidity. Using these factors in combination with wind speed and direction, eddy flux can be determined. For instance, if the number of water molecules travelling downward is known at Time A and travelling up at Time B at the same location, the vertical flux of water over time can be calculated at this location. Therefore, vertical flux can be presented as a covariance of the vertical wind velocity and the concentration of the gas of interest over time.

CSA distributes portable ECoV stations that are equipped with an automated data acquisition system (DAS). One of these stations is recommended for the centre of the cover trial. A key requirement for installation of an ECoV station is that a minimum 100 m by 100 m area (minimum fetch length of 100 m) is necessary to measure conditions representative of the surface being monitored.

7.3.4 Changes in Soil Water Storage

Three primary soil monitoring stations are proposed for the TSF cover system field trial. A total of six secondary soil monitoring sites are proposed to ensure cover performance at the primary sites is representative of the cover system as a whole. Sensors installed at the secondary monitoring sites would be controlled by the primary monitoring station data acquisition system (DAS). Two different types of sensors are proposed for monitoring changes in soil water storage and direction of water flow within the cover / upper tailings profile.

CSI model CS616-L time domain reflectometry (TDR) sensors are recommended for continuous monitoring of *in situ* volumetric water content at the primary and secondary sites. These sensors consist of two 30 cm long stainless steel rods connected to measurement electronics. The CS616-L sensor is supplied with a factory calibration curve based on agricultural / loam type soils, which can be used for monitoring relative changes in moisture storage. However, in order to obtain accurate *in situ* volumetric water content data, material-specific calibration curves must be developed in the laboratory. OKC is capable of developing such calibration curves in its laboratory.

CSI model 229-L heat dissipation or thermal conductivity sensors are recommended for continuous monitoring of matric suction and temperature in the cover / upper tailings profile at the primary and secondary monitoring sites. The model 229-L sensor consists of a heater and temperature sensor in a porous ceramic block that equilibrates with the surrounding material. The sensor is heated for a fixed time period, and the measured heat dissipation is related to the matric potential of the sensor through laboratory calibration. A nest of 229-L sensors allows hydraulic head gradients to be determined across the cover / waste interface, which will aid in assessing net percolation through the cover system, and coupled with *in situ* volumetric water content measurements, will facilitate development of field moisture retention curves. The latter is important for tracking evolution of the cover system due to processes such as wet/dry cycling (INAP, 2003).

An automated DAS comprised of CSI equipment is proposed for each primary soil monitoring station. A CSI CR1000 datalogger is recommended for each DAS, which will be powered by a 12-volt rechargeable battery / solar panel source. Two AM16/32B multiplexers and one constant current interface are also required for each DAS.

7.3.5 Runoff Volumes

A flume or V-notch weir would be used for continuous monitoring of meteoric waters running off the cover trial at the down-gradient collection point. A flow measurement device would be sized to handle a certain design storm event, and would be designed to freely pass eroded sediments. The station would be equipped with a pressure transducer for continuous monitoring of stage across the flume or weir.

7.4 Detailed Design, Construction Specifications and Quality Control

Many cover systems fail or behave differently to what was modelled and designed due to poor construction specifications and actual construction. Detailed design construction drawings including construction specifications must be prepared for the construction of the cover system trial. The construction must be monitored and sufficient quality control implemented to ensure proper construction.

7.5 Construction and Monitoring Schedule

Table 7.2 outlines anticipated timeframes for activities associated with construction and monitoring of the proposed TSF cover system field trial.

Table 7.2
Anticipated timeframes for construction and monitoring of TSF cover system field trial

Task	Estimated Timeframe
1) Pre-construction work (analyse samples of ROM waste, finalise construction drawings and technical specifications, order/calibrate/deliver instrumentation)	3-4 months
2) Construction of cover trial (load/haul/place/grade cover material)	1-2 months [1]
3) Installation / commissioning of instrumentation	2-3 weeks
4) Monitoring of cover trial and interpretation of performance	4 years (minimum 2) [2]

NOTES: 1) Duration for construction depends largely on availability of cover material from operations and size of equipment fleet.
2) 3-4 years of monitoring is preferred in order to compile a wider range of field responses under local climatic conditions; this will enable a more robust calibration of the preliminary numerical models for improved predictions of long-term cover system performance.

8 OUTER EMBANKMENT COVER SYSTEM TRIAL

The outer embankment trial comprises four adjacent trial plots, which have been chosen to simulate a variety of final embankment configurations. Sediment yield is measured from each of the trial plots so that the relative performance of the cover configurations may be compared. Results will also be used to verify and calibrate SIBERIA (or similar) landform evolution modelling. The calibrated models will be used to confirm the design of the much higher new TSFs.

8.1 General Approach

The trial plots are proposed at four adjacent locations on the southern outer embankment of TSF3. Trial plots are approximately 25m long and 10m wide with each having different cover material grading and slope configurations. The trial plots will be bounded by timber (or similar) boundaries, which protrude from surface approximately 0.15m, this allows clear delineation of the trial plot boundary and prevents surface water flows from adjacent sub catchments. The foot of the slope flattens to horizontal, to mimic the transition of the TSF embankment to ground over a length of 2m.

Sediment is collected in a timber (or alternative) sediment sump, and is measured downstream of the foot of the slope by allowing surface water runoff to flow through the sump, with an overflow weir on the downstream side, sediment will be collected from the sump after rainfall events. This sump will also house a low level outlet comprising a slotted PVC outlet pipe surrounded with a permeable geofabric (to act as a filter).

A polyethylene (or similar) surface water collection sump is located immediately downstream of the sediment sump. This sump includes a v-notch weir on the downstream side and a pressure transducer located within the sump. This enables real-time measurement of surface water flow rates (and volumes) derived from the surface of the test-plot.

Four trial plots are proposed for comparison, which have been based on material grading and slopes recommended in a previous modeling study (Landloch, 2013). The cover configurations proposed for the trial plots are summarised in Table 8.1

Table 8.1

Outer embankment cover system trial – trial plot configurations

Test Plot Id	Cap description	Embankment Slope
1	0.7m uncompacted coarse waste rock (D_{50} =40mm) underlain by 0.3m finer material (D_{50} = 30mm)	1V in 2H
2	0.7m uncompacted coarse waste rock (D_{50} =60mm) underlain by 0.3m finer material (D_{50} = 30mm)	1V in 2H
3	0.7m uncompacted coarse waste rock (D_{50} =125mm) underlain by 0.3m finer material (D_{50} = 30mm)	1V in 2H
4	0.7m uncompacted coarse waste rock (D_{50} =60mm) underlain by 0.3m finer material (D_{50} = 30mm)	1V in 3H

NB: D_{50} refers to the sieve size at which 50% of all material passes.

8.2 Measurements

The following measurements/logs will be recorded during the testwork programme:

Climatic conditions**:** log date/time, temperature, humidity, weather conditions (wind, wet, dry) when sediment samples are collected.

Cover configuration**:** the cover configuration will be logged and photographed. Key parameters to record include cover description, cover materials and thickness, shape and slope angles, length of slopes, placement and compaction (if any). XRD analysis of cover samples will be required of the materials constituting the cover (for geochemical characterisation).

Rainfall measurement**:** the depth of rainfall on the trial plot, as a function of time. This will be recorded with a pluviograph located centrally, and logged at five minute increments.

Sediment yield: the volume of sediment will be measured (after individual rainfall events), and samples taken for physical and geochemical analysis. Water discharging over the V-notch weir will be sampled, which will include suspended solids to compliment the settled sediment yield.

Sediment characteristics**:** sediment removed from the trap will be sampled and sent to a laboratory for physical and chemical characteristics, including bulk density, PSD, EC, metals suite, cation exchange capacity, XRD. *In situ* tests will include temp, pH, EC (to be confirmed). Sample will be taken of sediments (materials) not eroded during testing.

Runoff measurement**:** runoff is to be measured by collecting overland flow and directing the water to a sediment trap (to remove sediment) followed by a V-notch weir at the outlet. A float level or pressure transducer will be used to measure the depth of flow over the V-notch weir over time. One minute increments will be used to log flow data.

8.3 Proposed Location and Layout

The proposed location and layout of the trial plots are provided in Drawing 809-5-104.

8.4 Construction and Monitoring Schedule

Table 8.2 outlines anticipated timeframes for activities associated with construction and monitoring of the proposed TSF cover system field trial.

Table 8.2
Anticipated timeframes for construction and monitoring of TSF cover system field trial

Task	Estimated Timeframe
1. Pre-construction work (analyse samples of ROM waste, finalise construction drawings and technical specifications, order/calibrate/deliver instrumentation)	3-4 months
2. Construction of cover trial (load/haul/place/grade cover material)	1 month [1]
3. Installation / commissioning of instrumentation	2-3 weeks
4. Monitoring of cover trial and interpretation of performance	4 years (minimum 2) [2]

NOTES: 1) Duration for construction depends largely on availability of cover material from operations and size of equipment fleet.
2) 3-4 years of monitoring is preferred in order to compile a wider range of field responses under local climatic conditions; this will enable a more robust calibration of the preliminary numerical models for improved predictions of long-term cover system performance.

9 REFERENCES

Ayres, B., Dobchuk, B., Christensen, D., O'Kane, M. and Fawcett, M. 2006. Incorporation of natural slope features into the design of final landforms for waste rock stockpiles. *In* Proc. of 7th International Conference on Acid Rock Drainage, St. Louis, MO, March 26-29, pp. 59-75.

Bews, B.E., O'Kane, M.A., Wilson, G.W., Williams, D., and Currey, N. 1997. The design of a low flux cover system, including lysimeters, for acid generating waste rock in semi-arid environments. *In* Proc. of 4th International Conference on Acid Rock Drainage, Vancouver, BC, May 31-June 6, pp. 747-762.

BHP Billiton 2011. Olympic Dam Expansion Supplementary Environmental Impact Statement 2011, pp 129-139 & 787.

COGEMA Resources Inc. 2001. Cluff Lake Project Comprehensive Study Report: Main Document, Section 5. January.

de Vries, D.A. 1963. Thermal properties of soils. Physics of Plant Environment, W.R. Van Wihk (ed.), North Holland Pub. Co., pp. 382.

INAP (International Network for Acid Prevention). 2003. Evaluation of the long-term performance of dry cover systems, final report. Prepared by O'Kane Consultants Inc., Report No. 684-02, March.

Johansen, O. 1975. Thermal Conductivity of Soils. Ph.D. Thesis, (CRREL Draft Translation 637, 1977), Trondheim, Norway.

Krahn, J. 2004. Vadose Zone Modelling with VADOSE/W 2007 – An Engineering Methodology. Second Edition, GEO-SLOPE International Ltd., May.

Maidment, D.R. 1993. Handbook of Hydrology. McGraw-Hill Inc., New York, NY.

MEND (Mine Environment Neutral Drainage). 2001. Dry covers. *In* G.A. Tremblay and C.M. Hogan (eds), MEND Manual, Volume 4 – Prevention and Control, pp. 155-232. Canadian Mine Environment Neutral Drainage Program, Project 5.4.2d, February.

MEND (Mine Environment Neutral Drainage). 2004. Design, construction and performance monitoring of cover systems for waste rock and tailings. Canadian Mine Environment Neutral Drainage Program, Project 2.21.4, July.

O'Kane, M. 2011. State-of-the-art performance monitoring of cover systems – Moving from point scale to macro scale approaches. *In* Proc. of 7th Australian Workshop on Acid and Metalliferous Drainage (AMD), Darwin, NT, 21-24 June 2011.

O'Kane, M. and Ayres, B. 2012. Cover systems that utilise the moisture store-and-release concept – do they work and how can we improve their design and performance? *In* Proc. of Mine Closure 2012, Brisbane, AUS, 25-27 September.

O'Kane, M. and Barbour, S.L. 2003. Field performance of lysimeters used to evaluate cover systems for mine waste. *In* Proc. of 6th International Conference for Acid Rock Drainage, Cairns, Qld., Australia, July 12-18, pp. 327-339.

O'Kane, M. and Wels, C. 2003. Mine waste cover system design – linking predicted performance to groundwater and surface water impacts. *In* Proc. of 6th International Conference on Acid Rock Drainage, Cairns, QLD, Australia, July 12-18, pp. 341-349.

Robertson, A. and Shaw, S. 2006. Mine Closure. InfoMine E-Book, pp. 55.

Smith, C.D. 1995. Hydraulic Structures. University of Saskatchewan Printing Services, Saskatoon, SK.

USDA (United States Department of Agriculture). 1986. Urban hydrology for small watersheds. Technical release 55 (TR-55), Natural Resources Conservation Service, June.

van Genuchten, M.T. 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Science Society of America Journal, Vol. 44, pp. 892-898.

Willgoose, G.R. 1994. A physical explanation for an observed area-slope-elevation relationship for declining catchments. Water Resources Research, Vol. 30, pp. 151-159.

APPENDIX A

Preliminary Soil-Plant-Atmosphere and Seepage Modelling of Cover System Design Alternatives

BHP Billiton Olympic Dam

Tailings Storage Facility
Cover System and Landform Design 2013

Appendix A:

Preliminary Soil-Plant-Atmosphere and Seepage Modelling of Cover System Design Alternatives

Report No. 809/5-01

Prepared for:

bhpbilliton
resourcing the future

Prepared by:

O'Kane
Consultants Pty Ltd
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

February 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

A1 INTRODUCTION

O'Kane Consultants Pty Ltd. (OKC) was retained by BHP Billiton Olympic Dam (BHPB-OD) to complete various tasks in support of designing a robust cover system and final landform for the TSF at Olympic Dam. This appendix details the soil-plant-atmosphere (SPA) and seepage modelling completed by OKC to analyse various cover system design options.

A1.1 Objectives and Approach

The main objective of the SPA and seepage modelling is to determine the most effect cover system design to limit net percolation into tailings. The 1D SPA modelling was completed to determine cover system thickness and general net percolation rates, and establish the AE:PE ratio for the 2D quasi-SPA model completed using SEEP/W. 2D quasi-SPA modelling was completed to ascertain the implications of lateral water movement (i.e. runoff and interflow) on the performance of the TSF cover system and to analyse the sensitivity of the cover system design. Finally, 2D seepage modelling showed the basal seepage pattern at the base of the tailings.

A1.2 Report Organisation

For convenient reference, this report has been subdivided into the following sections:

- Section A2 – provides a description of the numerical models used for the work described in this appendix;
- Section A3 – outlines inputs required for the SPA and seepage modelling programs;
- Section A4 – presents the results of the SPA and seepage modelling programs; and
- Section A5 – provides a summary and recommendations based on the SPA and seepage modelling programs.

Tables and figures referenced hereinafter are located in the main body of this document. This report also has the following appendices:

- Appendix A-1 – Development of Material Properties; and
- Appendix A-2 – Development of a Climate Database.

A2 DESCRIPTION OF NUMERICAL MODELS

VADOSE/W (Geo-Slope International, 2012a) is a two-dimensional (2D) finite element model (which can also perform 1D simulations) that predicts pressure head (suction) and temperature profiles in the soil profile in response to climatic forcing (such as evaporation) and lower boundary conditions (such as a water table). A key feature of VADOSE/W is the ability of the model to predict actual evaporation and transpiration based on potential evaporation and predicted soil suction, as opposed to the user being required to input these surface flux boundary conditions. The actual evapotranspiration rate is generally well below the potential rate during prolonged dry periods because the suction, or negative water pressure, in the soil profile increases as the surface desiccates. In addition, VADOSE/W is a fully coupled (through the vapour pressure term) heat and mass transfer model, which is capable of predicting water vapour movement.

SEEP/W is a 2D finite element model that can be used to model the saturated and unsaturated movement of moisture and pore-water pressure distribution within porous materials such as soil and rock (Geo-Slope International, 2012b).

VADOSE/W and SEEP/W are both components of the GeoStudio suite of programs. GeoStudio 2012, Version 8.0.9.6484, was used to conduct the modelling completed for this project (Geo-Slope International, 2012c).

A3 MODEL INPUTS

Before SPA and seepage numerical modelling can be undertaken the model inputs must be clearly defined. These inputs can be placed into five categories: material properties; upper boundary conditions; lower boundary conditions; geometry; and initial conditions. Brief descriptions of these model inputs are presented in the following sections.

A3.1 Material Properties

The material properties or functions required for each material are as follows:

- moisture retention curve (MRC - suction versus volumetric water content);
- hydraulic conductivity function (k-function - suction versus hydraulic conductivity);
- thermal conductivity function (volumetric water content versus thermal conductivity); and
- volumetric specific heat function (volumetric water content versus volumetric specific heat).

A set of material properties were estimated for the overburden waste rock and tailings materials based on information provided in the Draft EIS and comparison of measured particle size distributions (PSDs) to materials in the OKC material database that have similar PSDs. A description of the material properties and the methodology used to estimate them is provided in Appendix A-1. Table A3.1 summarizes the estimated material properties for each material simulated for this modelling. Two sets of material properties were estimated for each material type to evaluate the sensitivity of a cover system design to changes in moisture retention characteristics.

Table A3.1
Summary of material inputs.

Material	Porosity	Saturated Hydraulic Conductivity (cm/s)	Air Entry Value (kPa)
Overburden Waste Rock – Base Estimate	0.35	1×10^{-3}	0.1
Overburden Waste Rock – Alternate Estimate	0.28	5×10^{-4}	0.4
Tailings – Base Estimate	0.39	5×10^{-6}	7
Tailings – Alternate Estimate	0.28	1×10^{-6}	9

The 1D SPA modelling process quickly indicated that, in such an arid environment, a significant component of the flow will be non-Darcian (i.e. flow within macropores and/or cracks within the cover systems); especially during rainfall events. However, (as stated in Section A4.4) VADOSE/W and SEEP/W do not accurately account for non-Darcian flow. To overcome this weakness in the model, the hydraulic properties of the cover layer were changed during wetting events to allow for higher hydraulic conductivity rates even at high suctions (i.e. the hydraulic conductivity during wetting events was not allowed to drop below 1×10^{-8} cm/s). The quasi-SPA modelling program evaluated the sensitivity of the simulated cover system design to changes in the cover system's material properties; specifically, its hydraulic conductivity at high suctions.

Seepage modelling did not have to account for non-Darcian flow due to the small amounts of water applied.

A3.2 Upper Boundary Conditions

The upper boundary conditions required for the models can be divided into two parts: climate and vegetation. Details regarding the model inputs developed for each are described below.

A3.2.1 Climate

The 'climate' upper boundary condition for the SPA, quasi-soil-plant-atmosphere (quasi-SPA) and seepage models are described below

A3.2.1.1 1D SPA Models

The SPA model VADOSE/W requires daily values of: maximum and minimum air temperature; maximum and minimum relative humidity (RH); average wind speed; rainfall (amount and duration), and net radiation.

A historic 100-year climate database developed for ODP was estimated from climate data obtained from the Bureau of Meteorology (BoM) for the following stations: Roxby Downs (Olympic Dam Aerodrome); Andamooka; Roxby Downs Station; Woomera (Purple Downs); Roxby Downs (Parakylia Station); and Woomera Aerodrome (BoM, 2013). Appendix A-2 contains details of how these datasets were used to develop the 100-year climate database. The monthly and yearly average climate conditions are summarised in Table A3.2.

Table A3.2
Summary of average climate parameters for the 100-year ODP climate database.

Month	**Temperature** (ºC)		**Relative Humidity** (%)		**Wind** (m/s)	**Rainfall**	
	Maximum	Minimum	Maximum	Minimum		(mm)	(# days/month)
January	36	20	37	18	5.1	15	2
February	35	20	42	21	4.8	24	2
March	32	16	45	22	4.4	10	2
April	27	12	45	27	3.7	12	2
May	22	8	58	34	3.4	14	3
June	18	5	70	41	3.3	14	4
July	18	4	68	39	3.4	10	4
August	20	5	58	32	4.1	11	3
September	24	8	46	25	4.8	12	3
October	28	12	39	21	5.0	15	3
November	31	26	39	21	5.0	12	3
December	34	18	38	19	5.1	17	2
Annual	***27***	***12***	***49***	***27***	***4.3***	***166***	***33***

A 'synthetic average' climate year was defined by averaging daily climate conditions from the 100-year climate database (e.g. averaging the maximum temperature on January 1st for all 100 years). However, rainfall was not applied just considering the daily average amount but also the average number of rainfall events per month. Hence, rainfall was applied for the average number of rainfall days per month and on days with the highest chance of rainfall. The daily rainfall amounts for days with lower chances of rainfall were added to the next high-chance event in the month so that the synthetic average climate year had the average amount of rainfall.

A3.2.1.2 2D Quasi-SPA Models

The 2D quasi-SPA models completed using SEEP/W defined the surface unit flux bounday as rainfall minus potential evaporation. The flux rate on non-rainfall days was then modified based on the relationship between the actual evaporation-to-potential evaporation (AE:PE) ratio and the suction of the cover system surface. This relationship was estimated using the SPA modelling results and is presented in Figure A3.1.

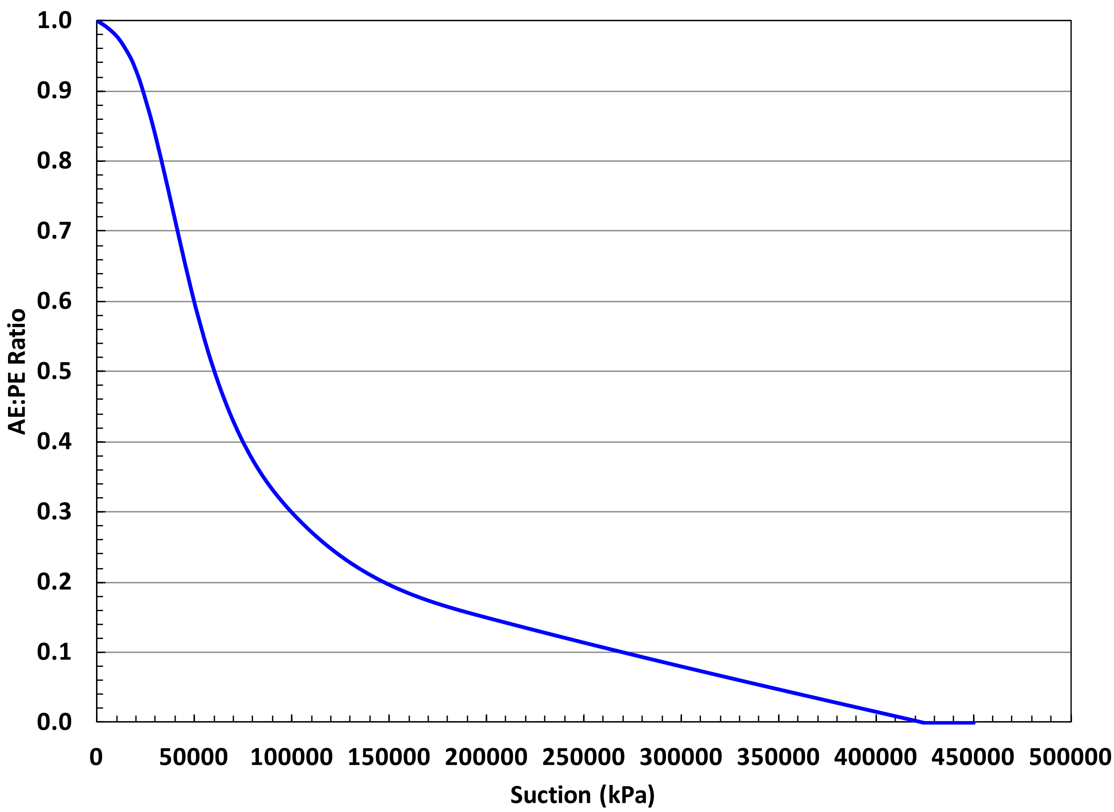


Figure A3.1 AE:PE ratio function used to modify surface flux boundary of quasi-SPA models.

The quasi-SPA models simulated a 20-year period representative of site conditions between 1989 and 2008, inclusive. This period was chosen because:

- average annual rainfall is similar to the 100-year database (i.e. 168 mm/year compared with 166 mm/year for the 100-year database);
- the wettest and second-driest years within the 100-year database are included; and
- includes the largest one-day rainfall event from the 100-year database (i.e. 132 mm).

A3.2.1.3 Seepage Models

The seepage models were completed using SEEP/W. A unit flux boundary was applied to the surface of the seepage models that represented the net percolation rates estimated by the SPA and quasi-SPA modelling.

A3.2.2 Vegetation

It is anticipated that minimal vegetation will develop on the TSF cover system. From a SPA model perspective, vegetation is generally beneficial as it allows water to be removed from deep within the cover system profile that would not be accessible just with surface evaporation. Vegetation cannot be relied upon to create this additional benefit for this project. Therefore, it was not included in any of the simulations.

A3.3 Lower Boundary Conditions

The lower boundary of all the models was simulated as a unit hydraulic gradient at the base of the waste material. This boundary condition simulates the water table to be well below the base of the cover system. A unit hydraulic gradient boundary condition assumes that at the lower boundary the soil suction (and, as a result, water content and hydraulic conductivity) are constant with depth. When this is the case, the total head equals the gravitational head causing a unit hydraulic gradient. In other words, a unit hydraulic gradient represents a location in the modelled profile where water movement is controlled mainly by gravity.

A3.4 Geometry

All models (except where stated) consisted of 1 m of overburden waste rock overlying tailings.

The 1D SPA models are of a 1 m wide by 12 m high column consisting of 139 elements, with no element being higher than 0.2 m (Figure A3.2a).

The 2D quasi-SPA models simulate an upper half of a cross-section of the ODP TSF. The models have a plan length of 1000 m, with a thickness of 12 m at the base of the slope increasing linearly to a thickness of 32 m at the crest. A 2 m level section was added at the base of the slope so that a pond forms at the base during runoff events. The quasi-SPA models consist of 9,263 elements, with no elements larger than 2 m (Figure A3.2b).

The seepage models simulate a complete cross-section of the ODP TSF. The models have a plan length of 2000 m, with a thickness of 45 m at the centre of the cross-section and increasing linearly to 65 m thick at the outer boundaries. The seepage models consist of 17,486 elements with no elements larger than 2.5 m (Figure A3.2c). Note that the rock ring walls and central decant area are also simulated (using the properties for the overburden waste rock).

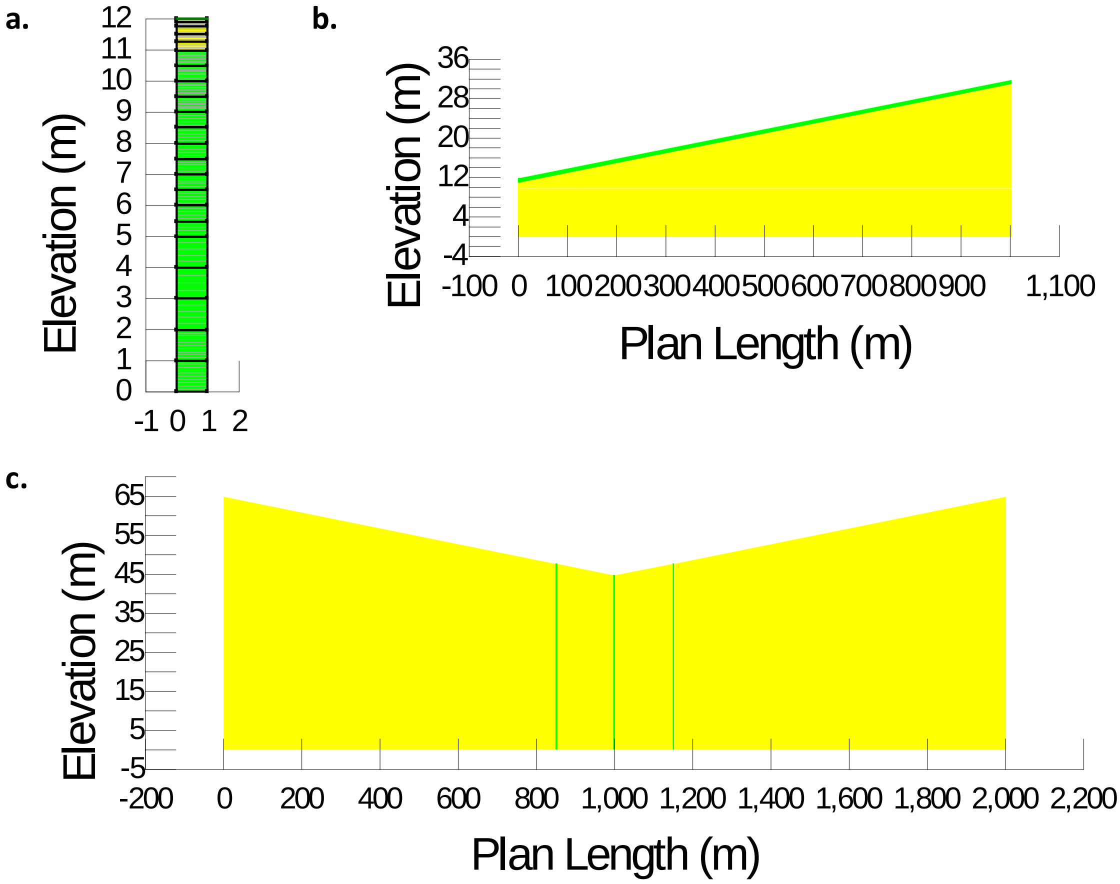


Figure A3.2 Geometry used to simulate a) SPA, b) quasi-SPA, and c) seepage models.

A3.5 Initial Conditions

Initial pressure and temperature profiles defined for the 100-year continuous (i.e. long-term) SPA simulations were developed by simulating the synthetic average climate year for consecutive years until initial and final conditions of the synthetic average model year equilibrated (i.e. the conditions at the start of the model year are the same as the conditions at the end, which means no net change in storage throughout the synthetic average model year).

The base 20-year quasi-SPA simulation was repeated five times consecutively (i.e. with the final conditions of the previous 20-year simulation used as initial conditions of the subsequent 20-year simulation) to equilibrate the model. The final conditions of this model were used as initial conditions for the sensitivity models.

Initial suction profiles of 200 kPa and 250 kPa were used to initiate the seepage models. 200 kPa and 250 kPa were chosen as they made the TSF slightly wetter and slightly drier, respectively, than the final steady-state conditions.

A4 MODEL RESULTS

The SPA and seepage modelling was completed in three parts:

1) 1D SPA modelling to determine cover system thickness and general net percolation rates, and establish the AE:PE ratio for the 2D quasi-SPA model completed using SEEP/W;
2) 2D quasi-SPA modelling to ascertain the implications of lateral water movement (i.e. runoff and interflow) on the performance of the TSF cover system and to analyse the sensitivity of the cover system design; and
3) 2D seepage modelling to show the seepage pattern through the tailings.

Each part is described in its own section below.

A4.1 1D Soil-Plant-Atmosphere Numerical Modelling

Two, 1D SPA models were simulated of cover systems consisting of 1 m and 1.5 m of overburden waste rock overlying tailings using the 100-year climate database. The average annual water balances are presented in Table A4.1. The results indicate that 0.7% of rainfall (just over 1 mm/yr) will infiltrate deep enough to result in net percolation for both cover system alternatives. This result assumes that no runoff is allowed to leave the surface of the cover system.

Additional cover thickness does not provide additional benefit. The modelling actually shows that additional thickness may be detrimental to cover system performance as the underlying tailings act as a barrier slowing percolation to depth and keeping the water stored in the cover system within reach of evaporative forces. However, increasing the cover thickness also increases the depth to which water can infiltrate within the cover system away from the surface, thereby increasing the evaporative force required to remove the infiltrated water.

Table A4.1
Predicted average annual water balance components for the modelled cover system alternatives.

Cover Alternative	Rainfall (mm/yr)	PE (mm/yr)	AE (mm/yr)	NP (mm/yr)
1.0 m Overburden Waste Rock	166	2013	165	1.2
1.5 m Overburden Waste Rock	166	2013	165	1.2

Given the measures required to get the model to allow water to infiltrate the cover system (as explained in Section 3.1) and the high intensity of rain events anticipated on the ODP, more focus was placed on the 2D quasi-SPA modelling.

A4.2 2D Quasi-Soil-Plant-Atmosphere Numerical Modelling

Ten, 20-year, 2D quasi-SPA models were completed to determine the effects of runoff and ponding on cover system performance, and to analyse the sensitivity of the performance results to variations in material properties. The list of quasi-SPA models is presented in Table A4.2 along with the resultant overall net percolation rate.

Table A4.2
Input parameters evaluated with the 2D-quasi SPA models.

Key Parameter	Values Incorporated in Numerical Model	NP (mm/yr)
Overburden Waste Rock Material	**Base case material properties**	**1.2**
	Alternate material properties	1.2
Tailings Material	**Base case material properties**	**1.2**
	Alternate material properties	1.2
Saturated Hydraulic Conductivity of Overburden Waste Rock Material	$\mathbf{k_{sat} = 1 \times 10^{-3}}$ **cm/s**	**1.2**
	$k_{sat} = 1 \times 10^{-2}$ cm/s	1.0
Saturated Hydraulic Conductivity of Tailings Material	$\mathbf{k_{sat} = 5 \times 10^{-6}}$ **cm/s**	**1.2**
	$k_{sat} = 5 \times 10^{-5}$ cm/s	1.6
Preferential Flow within Overburden Waste Rock during Rainfall Events	**With Preferential Flow**	**1.2**
	Without Preferential Flow	0.3

The results indicate that variations in the range of material properties estimated for the waste rock and tailings will cause minimal changes in to cover performance. Increasing the saturated hydraulic conductivity of the overburden waste rock results in a decrease in the amount of net percolation. A higher hydraulic conductivity allows the cover to lose water more readily to evaporation during times of drying. However, Increasing the saturated hydraulic conductivity of the tailings material allows water to permeate more quickly to depth within the tailings, thereby increasing net percolation.

Decreasing the hydraulic conductivity at high suctions of the overburden waste rock (i.e. simulating less macroporosity and/or cracking) decreases the net percolation. However, this result is misleading as lower conductivity during rainfall events means larger runoff amounts and a larger pond in the middle of the TSF. This is shown in Figure A4.1; the pond size is much larger and does not evaporate during the year when preferential flow is not simulated. Ponding will take advantage and magnify any weaknesses (i.e. macropores and/or cracks) in the cover system, substantially increasing the potential for net percolation. This issue can be solved in one of three ways:

1) Adding landforms to the TSF to attenuate the runoff water so that runoff water is distributed over a larger area, thereby reducing pressure heads on the cover and increasing evaporative efficiency;
2) Lining the anticipated pond area to block preferential flow paths into the tailings; or
3) Removing runoff for the surface of the TSF.

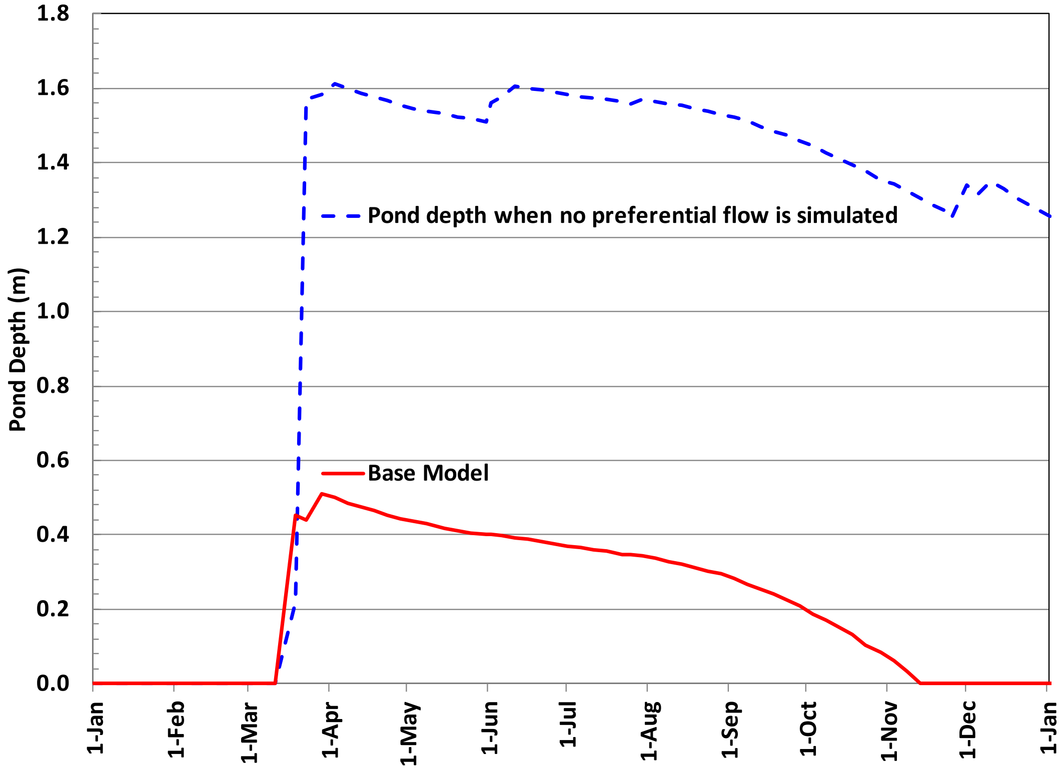


Figure A4.1 Pond depths simulated during year of largest rainfall event with and without preferential flow paths considered.

A4.3 Seepage Modelling

Four seepage models were simulated for this project. The following two scenarios were both simulated with the tailings at two initial suction conditions (to show the change in basal seepage with time when the tailings start off slightly wetter and slightly drier than the final steady-state conditions as described in Section 3.5):

- A uniform flux rate equivalent to 1.2 mm/yr across the entire surface of the tailings; and
- A flux rate equivalent to 2.2 mm/yr applied to the centre 100 m of the tailings surface and flux equivalent to 1.2 mm/yr for remaining tailings surface.

The results of these seepage models are presented in Figures A4.2 and A4.3. Figure A4.2 shows that in all four scenarios it takes approximately 200 to 300 years for the surface flux to start influencing the basal seepage and almost 2000 years for the system to reach equilibrium (i.e. flux entering the top equals flux exiting the base).

Figure A4.3 shows that, as anticipated, additional net percolation due to a central pond results in increased seepage at the base of the TSF. The three points of slightly increased basal seepage represent the locations of the rock ring walls and central decant area. However, it must be noted that the seepage model does not account for heterogeneity in the tailings, rock walls and central decant materials. Therefore, in reality, the increase in seepage at the centre of the TSF would be much less acute (but the overall basal seepage rate would still be as shown in Figure A4.2).

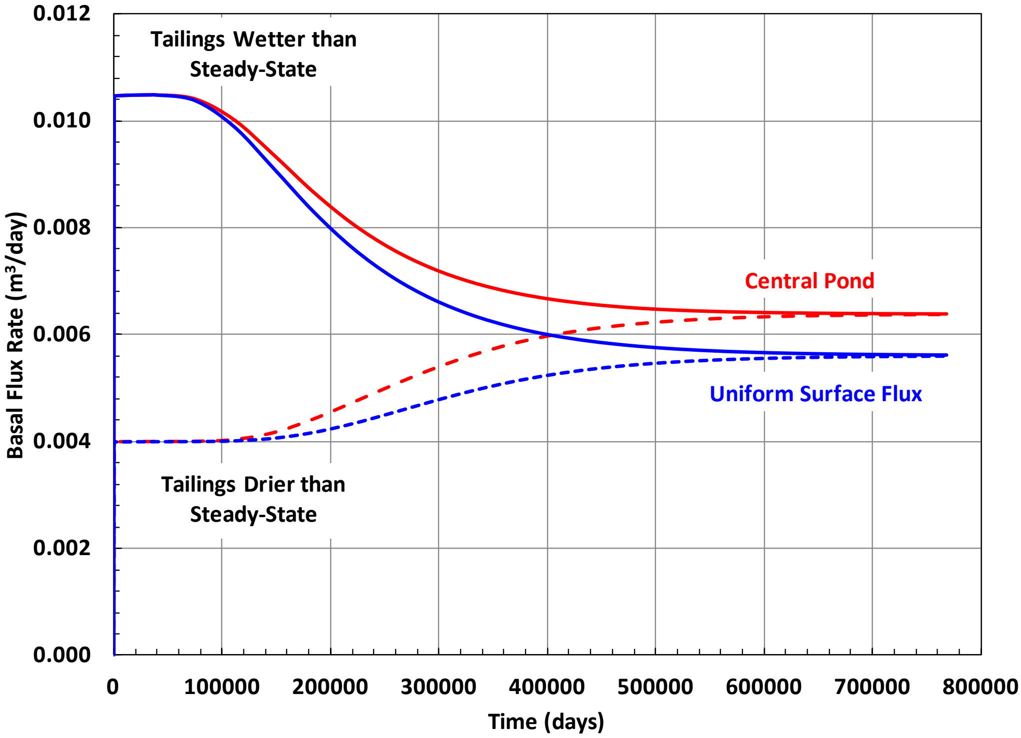


Figure A4.2 Change in basal flux rate with time for four seepage models.

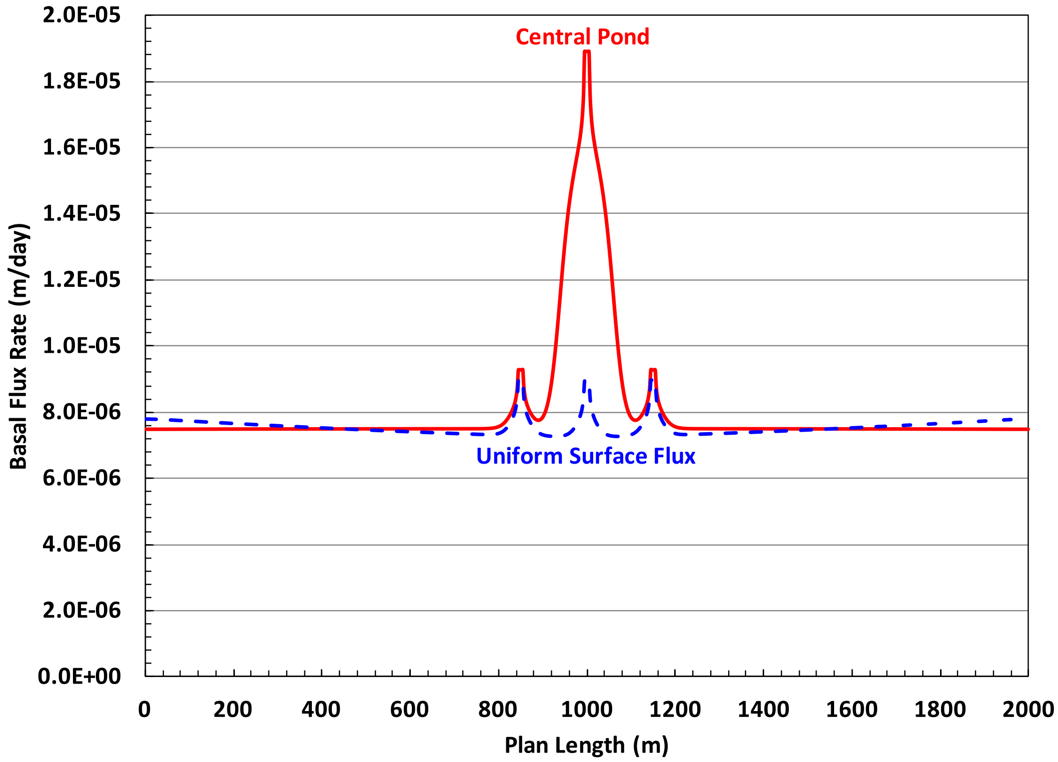


Figure A4.3 Final basal flux rates across base of TSF for two seepage scenarios.

A4.4 Model Limitations

The soil-plant-atmosphere model presented in this section is a mathematical representation of moisture and heat transport within the cover system alternatives examined for the ODP TSF. The model was constructed to develop an understanding of the performance of cover system designs in limiting net percolation to the underlying tailings material. The complex hydrogeology of the TSF had to be simplified into a conceptual model that could be represented in a mathematical model. The numerical model is thus limited by the accuracy and detail of the conceptual model.

The following limitations should be noted when interpreting the results of the model predictions for the soil-plant-atmosphere numerical modelling program.

- The conceptual model assumes that movement of water in the unsaturated zone can be represented as Darcian flow in a porous media. The model does not accurately account for any potential non-Darcian flow in macropores and/or cracks within the cover system alternatives.

- The conceptual model assumes that the cover system alternatives can be represented by various material types with homogeneous material properties. The potential influence of local heterogeneity (within a given material type) was not investigated.

- The moisture movement within the cover systems is defined by the unsaturated hydraulic conductivity versus matric suction relationship. This relationship is extremely difficult to measure *in situ* in a field condition and consequently is derived by a theoretical algorithm based on the value input for k_{sat}. The theoretical relationship defines the hydraulic conductivity function over several orders of magnitude, while a single or half order of magnitude change can greatly affect the predicted net percolation results from a simulation.

The key advantage to the numerical modelling results summarised herein is the ability to enhance judgment, rather than to lend predictive accuracy. Hence, instead of focusing on the absolute results predicted, it is recommended that the modelling results be viewed as a tool to understand key processes and characteristics that will influence performance of the potential cover designs, and develop engineering decisions based on this understanding.

A5 SUMMARY AND PRELIMINARY RECOMMENDATIONS

SPA and seepage modelling were completed to evaluate potential cover systems for the ODP TSF. These models indicate that a cover system consisting of 1 m of overburden waste rock will be sufficient to limit net percolation below 1% of rainfall. The largest risk for increased net percolation is preferential flow especially in areas where ponding will occur. This issue can be solved in three ways:

1) Adding landforms to the TSF to attenuate the runoff water so that runoff water is distributed over a larger area, thereby reducing pressure heads on the cover and increasing evaporative efficiency.
2) Lining the anticipated pond area to block preferential flow paths into the tailings.
3) Removing runoff for the surface of the TSF.

The first method is the simplest and most sustainable.

It is anticipated that it will take at least 200 years for net percolation entering the surface of the tailings to start influencing the basal flux rate, and almost 2000 years for the system to reach equilibrium (i.e. flux entering the top equals flux exiting the base).

A6 REFERENCES

BoM (Bureau of Meteorology), 2013. Climate Data. Online. www.bom.gov.au/

de Vries, D.A. 1963. Thermal properties of soils. Physics of Plant Environment, W.R. Van Wihk (ed.), North Holland Pub. Co., pp. 382.

FAO (Food and Agriculture Organization of the United Nations). 1998. Online. http://www.fao.org/docrep/X0490E/x0490e00.htm#Contents

Fredlund, D.G., Xing, A., and Huang, S. 1994. Predicting the permeability function for unsaturated soils using the soil-water characteristic curve. Canadian Geotechnical Journal, **31**: 533-546.

Geo-Slope International Ltd. 2012a. Vadose Zone Modelling with VADOSE/W 2012 – An Engineering Methodology. November 2012 Edition, GEO-SLOPE International Ltd., November.

Geo-Slope International Ltd. 2012b. Seepage Modelling with SEEP/W 2012 – An Engineering Methodology. November 2012 Edition, GEO-SLOPE International Ltd., November.

Geo-Slope International Ltd. 2012c. GeoStudio 2012, Version 8.0.10.6504. Online. www.geo-slope.com

Johansen, O. 1975. Thermal Conductivity of Soils. Ph.D. Thesis, (CRREL Draft Translation 637, 1977), Trondheim, Norway.

USDA (United States Department of Agriculture), 2004. CLIGEN Version 5.3. Online. http://www.ars.usda.gov/Research/docs.htm?docid=18094

APPENDIX A-1

Development of Material Properties

APPENDIX A-1: DEVELOPMENT OF MATERIAL PROPERTIES

This appendix supplements the information in Section A3.1 by providing a summary and more complete definition of the pertinent material properties required to simulate the cover and waste material layers. Details are provided for the methodology used to develop the final functions for the model.

A-1.1 Particle Size Distribution

A particle size distribution (PSD) curve for a given soil or rock material indicates the relative proportions of the different particle sizes that make up the material on a mass basis. This test determines whether the material is well-graded, poorly graded (i.e. uniform), or gap-graded. A PSD curve also gives an indication of the relative permeability and moisture retention capability for a given soil or rock material.

Multiple PSD curves were provided to OKC for the ODP overburden waste rock and tailings materials. The PSDs were then compared to similar materials in the OKC material database to estimate moisture retention curves (MRCs) and saturated hydraulic conductivity (k_{sat}) values. The range and average PSD curves are presented in Figure A-1.1 along with the range of comparable samples in the OKC material database.

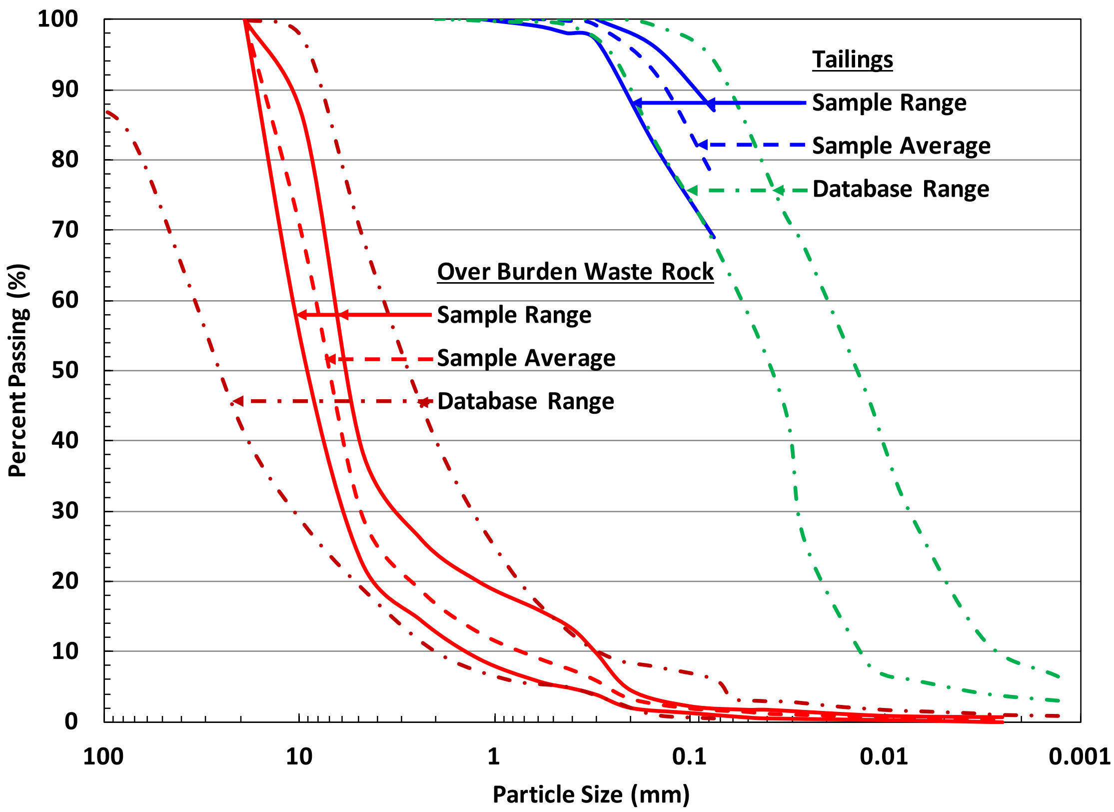


Figure A-1.1 Range and average PSD curves for overbuden waste rock and tailings materials.

A-1.2 Moisture Retention Curve

The moisture retention curve (MRC), or soil-water characteristic curve, is a continuous function relating energy and the state of water, and hence describes the water content of a material as a function of soil suction, or negative pore-water pressure. The MRC is central to the design of an unsaturated soil system, and the most fundamental characterisation required for design.

Moisture retention curves for all the materials were first estimated by comparing the PSDs to similar materials in the OKC material database. The resultant MRCs are presented in Figure A-1.2. Two MRCs were estimated for each material to evaluate the sensitivity of the simulated cover system designs to changes in moisture retention characteristics.

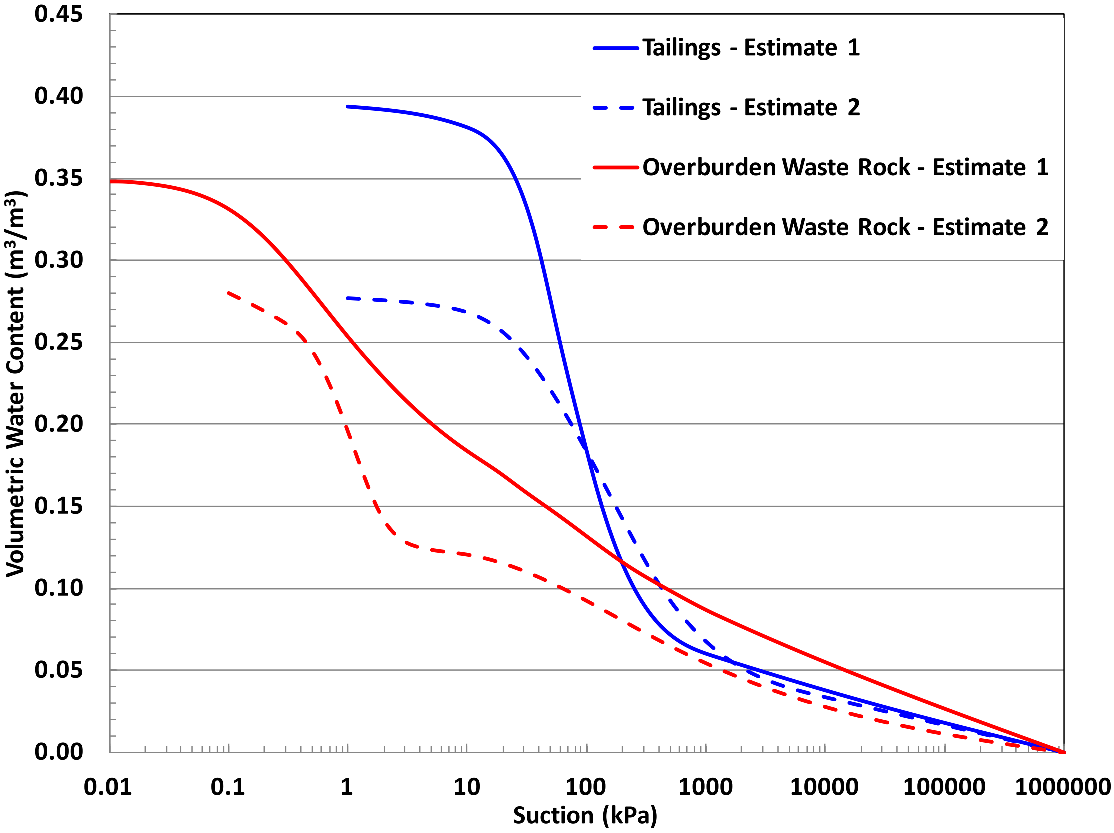


Figure A-1.2 MRCs estimated for overburden waste rock and tailings materials.

A-1.3 Hydraulic Conductivity Function

The hydraulic conductivity is a measure of the ability of a soil or rock material to transmit water, and is a maximum for saturated soil or rock materials. The saturated hydraulic conductivity (k_{sat}) is a key input parameter to a soil-atmosphere numerical model.

K_{sat} estimates for the materials were estimated from comparable materials in the OKC database and information provided in Appendix F1 of the 2009 Draft EIS. The k-functions were estimated from the MRCs using the Fredlund *et al.* (1994) method. Figures A-1.3 shows the k-functions estimated for all materials. The hydraulic conductivity of the overburden material was increased during rainfall events so that water would infiltrate the cover system during these events.

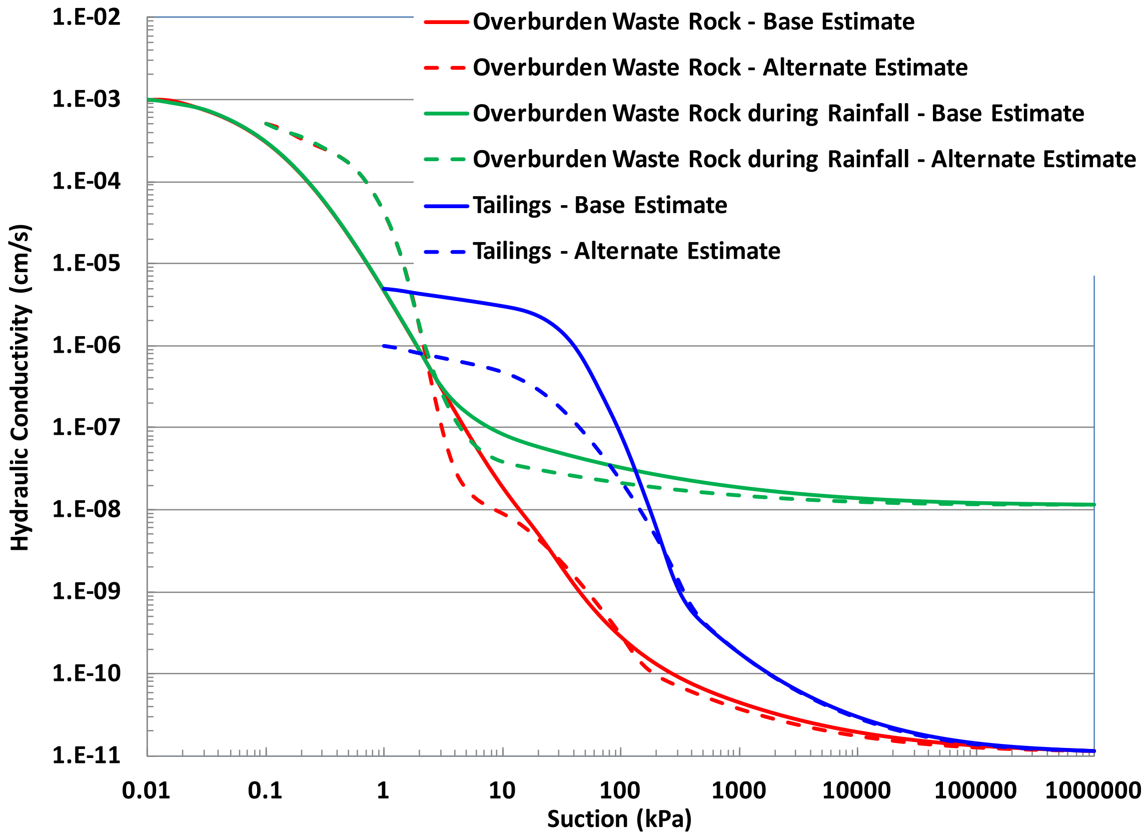


Figure A-1.3 K-functions estimated for overburden waste rock and tailings materials.

A-1.4 Thermal Conductivity Function

Thermal conductivity characterises the ability of a soil medium to transmit heat by conduction. It is defined as the quantity of heat that will flow through a unit area of a soil medium of unit thickness in unit time under a unit temperature gradient.

The thermal conductivity functions for all the materials were estimated using the Johansen (1989) method.

A-1.5 Volumetric Specific Heat Function

The heat capacity of a material is defined as the quantity of heat required to raise the temperature of the material by a unit degree. A volumetric specific heat function describes the relationship between volumetric water content and volumetric specific heat.

The volumetric specific heat functions for all the materials were estimated using the de Vries (1963) method.

APPENDIX A-2

Development of a Climate Database

APPENDIX A-2: DEVELOPMENT OF A CLIMATE DATABASE

This appendix supplements the information in Section A3.2.1 providing further explanation of the development of the 100-year climate database.

VADOSE/W requires daily climate inputs of maximum and minimum air temperature, rainfall (amount and duration), maximum and minimum relative humidity, average wind speed, and net radiation. The following sections describe how each of the daily inputs is defined for the historic 100-year climate database and then how the historic database was adjusted to represent potential climate change scenarios.

A-2.1 Maximum and Minimum Temperature

The Bureau of Meteorology (BoM) website (BoM, 2013) only lists three stations, open or closed, within 100 km of the ODP TSF with daily temperature data:

- Roxby Downs (Olympic Dam Aerodrome) – 15 years of data between 1997 and 2013, and located 7 km southeast of the TSF (136.88°E, 30.48°S)
- Andamooka - 43 years of data between 1969 and 2013, and located 32 km east of the TSF (137.17°E, 30.45°S)
- Woomera Aerodrome – 63 years of data between 1949 and 2013, and located 80 km south of the TSF (136.81°E, 31.16°S)

The data from Roxby Downs (Olympic Dam Aerodrome) station was assumed to be representative of conditions at the TSF. The data from Andamooka and Woomera Aerodrome was compared for the overlapping time periods of the datasets (i.e. between 1997 and 2011), to determine adjustments for the Andamooka and Woomera Aerodrome datasets. The three datasets were then combined (in order of precedence above) to form a 62-year estimated maximum and minimum temperature record for the TSF representing the years 1950 to 2011, inclusive.

The USDA's water erosion prediction project (WEPP) climate input generator (CLIGEN – USDA, 2004) was used to create a 100-year climate database for the TSF, based on the monthly statistics of the 62-year historic database. 38 years of maximum and minimum temperature data (selected based on comparison of rainfall days and amounts to those measured between 1912 and 1949, inclusive) were taken from the CLIGEN database and added to the 62 years of historic temperature data. However, the CLIGEN data needed to be adjusted prior to adding it to the final ODP TSF climate database, as CLIGEN does not create a 'natural' temperature pattern (Figure A-2.1). Therefore, the 100-year CLIGEN temperature database was adjusted to conform with the average daily maximum and minimum temperature trendlines (equations A-2-1 and A-2-2) developed from the 62-year historic database. The average daily maximum and minimum temperatures from the 100-year climate database estimated for the ODP TSF are shown in Figure A-2.1.

$$T_{max} = 6.29034932112222\text{x}10^{-13}t^6 - 6.64771042081076\text{x}10^{-10}t^5 + 2.40495700712341\text{x}10^{-7}t^4 - 3.08476517288658\text{x}10^{-5}t^3 + 3.43705407233941\text{x}10^{-5}t^2 + 0.0129064876779807t + 35.8 \quad \text{[A-2-1]}$$

$$T_{min} = 3.00384421220948\text{x}10^{-13}t^6 - 3.19744466136065\text{x}10^{-10}t^5 + 1.08334773397554\text{x}10^{-7}t^4 - 8.57905967521777\text{x}10^{-6}t^3 - 1.27794046106722\text{x}10^{-3}t^2 + 0.0697927089087784t + 19.5 \quad \text{[A-2-2]}$$

where:

T_{max} = average daily maximum temperature on dry days (ºC),

T_{min} = average daily minimum daily temperature on dry days (ºC), and

t = day of the year, where 1 equals January 1st (day).

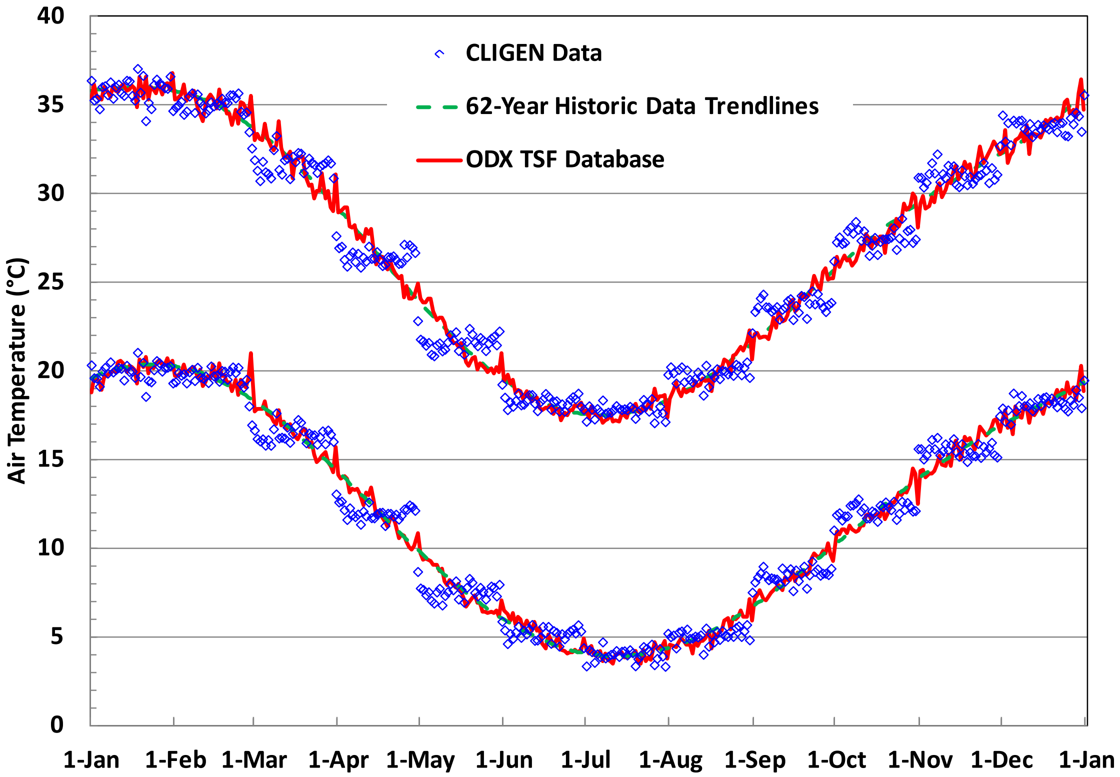


Figure A-2.1 Average maximum and minimum daily temperatures.

A-2.2 Rainfall

A-2.2.1 Amount

100 years of rainfall data was estimated for the ODP TSF using the following BoM stations (BoM 2013), listed in order of precedence and all within 45 km of the TSF:

- Roxby Downs (Olympic Dam Aerodrome) – 15 years of data between 1997 and 2013, and located 7 km southeast of the TSF (136.88°E, 30.48°S)

- Andamooka - 47 years of data between 1965 and 2013, and located 32 km east of the TSF (137.17°E, 30.45°S)
- Roxby Downs Station – 82 years of data between 1931 and 2013, and located 32 km south of TSF (136.75°E, 30.70°S)
- Woomera (Purple Downs) – 105 years of data between 1903 and 2008, and located 39 km south of the TSF (136.90°E, 30.79°S)
- Roxby Downs (Parakylia Station) - 77 years of data between 1936 and 2013, and located 44 km west of the TSF (136.39°E, 30.40°S)

All the rainfall datasets were compared to each other to determine appropriate adjustments to make them all representative of anticipated conditions at the ODP TSF. The datasets were then combined (using the above order of precedence) to form a 100-year rainfall database for the ODP TSF. The final distribution of annual rainfall amounts is shown in Figure A-2.2.

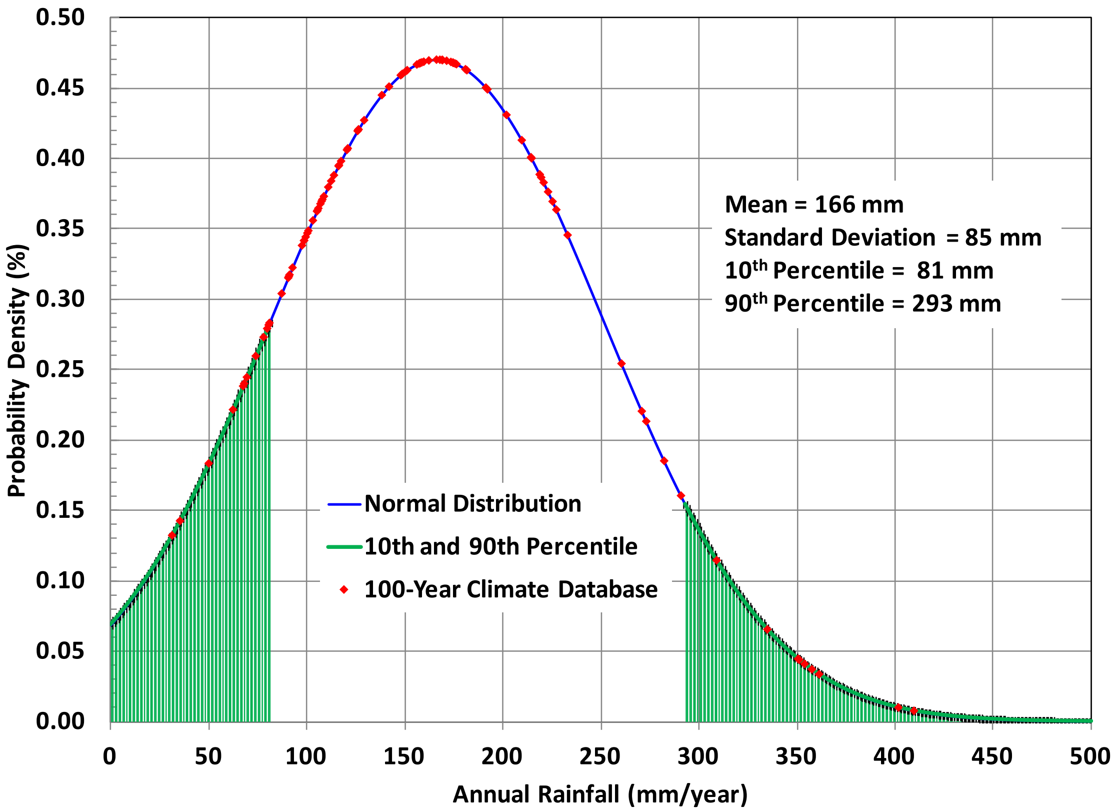


Figure A-2.2 Distribution of annual rainfall amounts for the 100-year climate database.

A-2.2.2 Duration

The USDA's water erosion prediction project (WEPP) climate input generator (CLIGEN) was used to estimate storm durations for the climate database (USDA, 2004). This was done by developing a database using CLIGEN with similar precipitation results as the database described above. The storm durations predicted by CLIGEN were then applied to the ODP TSF climate database.

A-2.3 Maximum and Minimum Relative Humidity

CLIGEN was used to generate 100 years of daily average dewpoint temperatures based on dewpoint temperatures measured at Roxby Downs (Olympic Dam Aerodrome) station between 1997 and 2012. The daily average dewpoint temperatures developed using CLIGEN were then offset to obtain estimates of daily maximum and minimum dewpoint temperatures. The offsets were determined by comparing the monthly average dewpoint temperatures developed using CLIGEN to the monthly average maximum and minimum dewpoint temperatures reported by BoM. The dewpoint temperatures were then converted to relative humidity using the following equation:

$$RH = 100\frac{\exp(\frac{aT_d}{b+T_d})}{\exp(\frac{aT}{b+T})} \qquad \text{[A-2-3]}$$

where:

RH = relative humidity (%),

T_d = dewpoint temperature (°C),

T = Air temperature (°C),

a = 17.271, and

b = 237.7.

The calculated average monthly maximum and minimum relative humidity values were compared to the values reported by BoM and found to be accurate.

A-2.4 Wind Speed

CLIGEN was used to generate 100 years of daily average wind speed data based on measurements taken at Roxby Downs (Olympic Dam Aerodrome) station between 1997 and 2012.

A-2.5 Net Radiation

Net radiation was estimated based on the latitude of the site, air temperature, relative humidity and the albedo of the surface. The following section explains in detail the methodology used to estimate net radiation. More information regarding net radiation is available on the Food and Agriculture Organization of the United Nations (FAO) website (FAO, 1998).

A-2.5.1 Atmospheric Radiation

Atmospheric radiation (R_a) is the solar radiation received at the top of the earth's atmosphere on a horizontal surface. If the sun is directly overhead, the angle of incidence is zero and the R_a is 0.0820 MJ/m^2-min, known as the solar constant (G_{sc}). As seasons change, the position of the sun, the length of the day and, hence, R_a change as well. Therefore, R_a is a function of latitude, date and time of day. The R_a for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year using the following formula:

$$R_a = \frac{24(60)}{\pi} G_{sc} \cdot D_r \left[w_s \cdot \sin(Lat) \cdot \sin(d) + \cos(Lat) \cdot \cos(d) \cdot \sin(w_s) \right] \quad \text{[A-2-4]}$$

where:

R_a = atmospheric radiation (MJ/m^2-day),

G_{sc} = solar constant (0.0820 MJ/m^2-min),

D_r = inverse relative distance Earth to Sun

= 1+0.0333·cos(2·π·t/365),

t = day of the year, where 1 equals January 1st (day),

w_s = sunset hour angle (radians)

= arcos[-tan(Lat)·tan(d)],

Lat = latitude (radians), and

d = solar decimation (radians)

= 0.408·sin[(2·π·t/365)-1.39].

A-2.5.2 Solar and Shortwave Radiation

As radiation penetrates the atmosphere, some of the radiation is scattered, reflected or absorbed by atmospheric gases, clouds and dust. The amount of radiation reaching a horizontal plane is known as the solar radiation, R_s. Because the sun emits energy by means of electromagnetic waves characterised by short wavelengths, solar radiation is also referred to as shortwave radiation.

The difference between the maximum and minimum air temperature is related to the degree of cloud cover in a location. Clear-sky conditions result in high temperatures during the day (T_{max}), because the atmosphere is transparent to the incoming solar radiation, and in low temperatures during the night (T_{min}) because less outgoing longwave radiation is absorbed by the atmosphere. In contrast, in overcast conditions, T_{max} is relatively smaller because a significant part of the incoming solar radiation never reaches the earth's surface and is absorbed and reflected by clouds. Similarly, T_{min} will be relatively higher as the cloud cover acts as a blanket and decreases the net outgoing longwave radiation. Therefore, the difference between the maximum and minimum air temperature (T_{max} - T_{min}) can be used as an indicator of the fraction of atmospheric radiation (R_a) that reaches the earth's surface. The Hargreaves' radiation formula (Equation A-2-5) uses this principle to estimate the daily amount of shortwave radiation (R_s).

$$R_s = K_{Rs} \cdot R_a \cdot \sqrt{T_{\max} - T_{\min}} \quad \text{[A-2-5]}$$

where:

R_s = shortwave radiation (MJ/m^2-day),

K_{Rs} = Hargreaves' adjustment factor [0.16 (interior) ~ 0.19 (coastal) ºC$^{-0.5}$],

T_{max}= maximum air temperature (ºC), and

T_{min} = minimum air temperature (ºC).

A-2.5.3 Relative Shortwave Radiation

The relative shortwave radiation is the ratio of shortwave radiation (R_s) to the clear-sky shortwave radiation (R_{so}). In other words, R_s is the solar radiation that actually reaches the earth's surface in a given period, while R_{so} is the shortwave radiation that would reach the same surface during the same period but under cloudless conditions.

Clear-sky shortwave radiation is estimated using the following:

$$R_{so} = (0.75+4x10^{-5}) \cdot R_a \qquad [A-2-6]$$

where:

R_{so} = clear-sky shortwave radiation (MJ/m^2-day).

B.5.4 Net Shortwave Radiation and Albedo

A considerable amount of shortwave radiation reaching the earth's surface is reflected. The fraction of the shortwave radiation reflected by the surface is known as the albedo (α). The albedo is highly variable for different surfaces and for the angle of incidence or slope of the ground surface. It may be as large as 0.95 for freshly fallen snow and as small as 0.05 for a wet bare soil. An albedo of 0.4 was estimated for the site.

Net shortwave radiation is the fraction of the shortwave radiation that is not reflected from the surface. Hence:

$$R_{ns} = (1-\alpha) \cdot R_s \qquad [A-2-7]$$

where:

R_{ns} = net shortwave radiation (MJ/m^2-day)

α = albedo (0.4 estimated for the site)

A-2.5.5 Net Longwave Radiation

The shortwave radiation absorbed by the earth is converted to heat energy by several processes, including emission of radiation, the earth loses this energy. The earth, which is at a much lower temperature than the sun, emits radiative energy with wavelengths longer than those from the sun. Therefore, the terrestrial radiation is referred to as longwave radiation. The emitted longwave radiation is absorbed by the atmosphere or lost into space. The longwave radiation received by the atmosphere increases its temperature and, as a consequence, the atmosphere radiates energy of its own. Hence, part of the radiation finds its way back to the earth's surface. Consequently, the earth's surface emits and receives longwave radiation. The difference between outgoing and incoming longwave radiation is called the net longwave radiation (R_{nl}). As the outgoing longwave radiation is almost always greater than the incoming longwave radiation, R_{nl} represents an energy loss.

The rate of longwave energy emission is proportional to the absolute temperature of the surface raised to the fourth power. This relation is expressed quantitatively by the Stefan-Boltzmann law. However, the net energy flux leaving the earth's surface is less than that emitted and given by the Stefan-Boltzmann law due to the absorption and downward radiation from the sky. As humidity and cloudiness play an important role, the Stefan-Boltzmann law is corrected by these two factors when estimating the net outgoing flux of longwave radiation (Equation A-2-8).

$$R_{nl} = \sigma \left[\frac{T_{max,K}^4 + T_{min,K}^4}{2} \right] \cdot (0.34 - 0.14\sqrt{e_a}) \cdot \left(1.35\frac{R_s}{R_{so}} - 0.35\right)$$

[A-2-8]

where:

R_{nl} = net longwave radiation (MJ/m^2-day),

σ = Stefan-Boltzman constant (4.903 x 10^{-9} MJ/K^4-m^2-day),

$T_{max,K}$ = maximum absolute temperature during the 24-hour period (K = ºC+273.16),

$T_{min,K}$ = minimum absolute temperature during the 24-hour period (K = ºC+273.16),

e_a = actual vapour pressure (kPa), and

R_s/R_{so} = relative shortwave radiation (limited to ≤ 1).

The actual vapour pressure (e_a) is calculated using relative humidity and air temperature using the following equations:

if Tavg > 0 then:

$$e_a = RH_{avg} \cdot 0.611 \cdot e^{\left(\frac{17.27 \cdot T_{avg}}{T_{avg,K}}\right)}$$ [A-2-9]

if Tavg < 0 then:

$$e_a = RH_{avg} \cdot e^{\frac{\left(\frac{-6140.4}{T_{avg,K}} + 28.916\right)}{1000}}$$ [A-2-10]

else:

$$e_a = RH_{avg} \cdot 0.611 \qquad \text{[A-2-11]}$$

where:

e_a = actual vapour pressure (kPa)

RH_{avg} = average relative humidity (decimal)

= $(RH_{max} - RH_{min})/2$

RH_{max} = maximum relative humidity (decimal)

RH_{min} = minimum relative humidity (decimal)

T_{avg} = average air temperature (ºC)

= $(T_{max} – T_{min})/2$

$T_{avg,K}$ = absolute average air temperature (K)

= T_{avg} + 273.16

APPENDIX B

Tailings Consolidation Analysis

BHP Billiton Olympic Dam

Tailings Storage Facility Cover System and Landform Design 2013

Appendix B:

Tailings Consolidation Analysis

Report No. 809/5-01

Prepared for:

bhpbilliton
resourcing the future

Prepared by:

O'Kane Consultants Pty Ltd
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

May 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

B1 INTRODUCTION

O'Kane Consultants Pty Ltd. (OKC) completed a one-dimensional (1D) consolidation analysis in support of closure design for the Olympic Dam Expansion Project (ODP). This 1D consolidation analysis was carried out using Terzaghi's theory of consolidation (Terzaghi, 1921).

Rather than focusing on the absolute results predicted, numerical results will provide a better understanding of key processes and characteristics which will influence the performance of potential cover designs and develop engineering decisions based on this understanding.

B1.1 Objective and Approach

One-dimensional consolidation analysis was conducted to assess the potential for overall tailings settlement and differential tailings settlement due to changes in phreatic surface and additional loading from cover placement. The specific objective of 1D consolidation analysis was to estimate the long-term settlement of the tailings mass following cessation of tailings into the TSF.

Analytical modelling was used for evaluation of tailings consolidation for this specific case based on the available tailings' parameters. Material properties (e.g., unit weight) of the tailings and overburden waste rock cover material available in the Olympic Dam Expansion Draft and Supplementary EISs were used to calculate initial and final vertical effective stresses in the tailings. The tailings ultimate settlement due to consolidation was then determined based on the calculated vertical effective stresses. The tailings consolidation in this appendix is referred to as tailings volume change (settlement) after the end of tailings deposition (i.e., TSF achieves a 65 m tailings height at the end of deposition at Year 40). Drawdown of phreatic surface in the tailings due to seepage and external load from cover placement are major factors leading to tailings settlement following tailings deposition. The tailings consolidation during the deposition processes was not analysed in this appendix due to sparse data.

B1.2 Organisation of Appendix

Section 2 of this appendix provides a description of the calculation scenarios, an overview of methodology, and material properties required to calculate settlement and rate of consolidation. Results of the analysis are presented in Section 3. Section 4 presents implications of the calculated tailings settlement on cover design. A list of references is provided in Section 5.

B2 DETERMINATION OF TAILINGS SETTLEMENT AND RATE OF CONSOLIDATION

B2.1 Consolidation Analysis Scenarios

Five base scenarios were selected for calculation of bulk tailings (here bulk tailings is referred to the tailings has average dry density) settlement and rate of consolidation following cessation of tailings material into the TSF. Currently the preferred cover design for the TSF has a minimum thickness of 1 m. The cover layer may increase to approximately 2 m to satisfy the need of landform design and surface water management.

Figure B2.1 illustrates water table and cover loading conditions for each of the five base scenarios for bulk tailings. The first scenario applies no cover. This scenario simulates tailings consolidation when the phreatic surface decreases due to surface evaporation and bottom under-drainage. The second and third scenario includes a 2 m overburden waste rock cover on top of the tailings. The second scenario has a water drawdown to the tailings base, while the third scenario has no water drawdown (i.e., the water table maintains at the surface of the tailings material). These two cases simulate effect of both cover load and water drawdown on tailings settlement. The fourth and fifth scenario is the same as the second and third except for having a 1 m overburden water rock cover on top of the tailings.

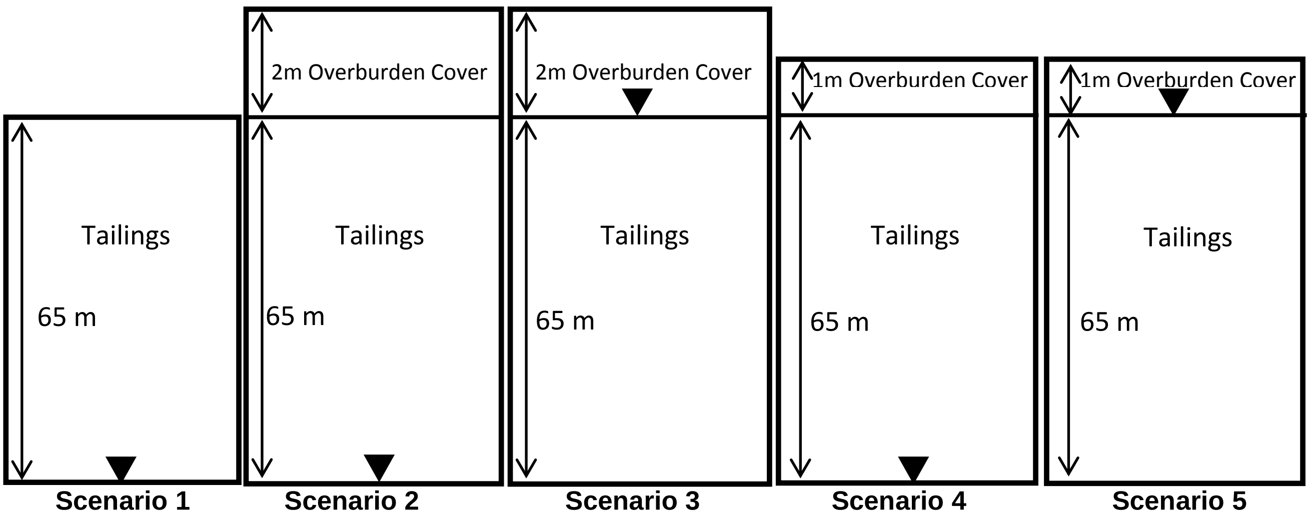


Figure B2.1 Tailings consolidation analysis base scenerios for the ODP TSF.

In addition to base scenarios, sensitivity analyses were also conducted to consider tailings spatial variation along the tailings flow pathway during deposition. The tailings in upper beaches (upper beach tailings) have higher dry density than the bulk tailings, while the tailings in pool area (pool area tailings) have lower dry density than the bulk tailings. Moreover, the upper beach tailings may be over-consolidated due to sun-drying. The sensitivity analyses have the same phreatic surface change and soil cover loading conditions as the base scenarios. Table B2.1 list all scenarios analysed.

Table B2.1
Scenarios analysed for tailings consolidation settlement for ODP tailings facilities

Scenario	Tailings material	Scenario description	Notes
#1	Bulk tailings	No cover – unsaturated tailings	Base Cases Normally consolidated
#2	Bulk tailings	2 m cover – unsaturated tailings	
#3	Bulk tailings	2 m cover – saturated tailings	
#4	Bulk tailings	1 m cover – unsaturated tailings	
#5	Bulk tailings	1 m cover – saturated tailings	
#6	Upper beach tailings	No cover – unsaturated tailings	Sensitivity analysis Pre-consolidated
#7	Upper beach tailings	2 m cover – unsaturated tailings	
#8	Upper beach tailings	2 m cover – saturated tailings	
#9	Upper beach tailings	1 m cover – unsaturated tailings	
#10	Upper beach tailings	1 m cover – saturated tailings	
#11	Pool area tailings	No cover – unsaturated tailings	Sensitivity analysis Normally consolidated
#12	Pool area tailings	2 m cover – unsaturated tailings	
#13	Pool area tailings	2 m cover – saturated tailings	
#14	Pool area tailings	1 m cover – unsaturated tailings	
#15	Pool area tailings	1 m cover – saturated tailings	

B2.2 Method for Calculating Settlement

Settlement analyses are based on changes of effective stress in the tailings. Equation B-1 was used to calculate the ultimate settlement of the normally consolidated tailings materials (i.e. bulk tailings and pool area tailings).

$$(\delta_c)_{ult} = \sum \frac{c_c}{1+e_o} Hlog\left(\frac{\sigma'_{zf}}{\sigma'_{zo}}\right) \quad \text{[B-1]}$$

where:

$(\delta_c)_{ult}$ = ultimate consolidation settlement (m),

c_c = compression index,

e_o = initial void ratio,

H = thickness of tailings material (m),

σ_{zf}' = final vertical effective stress (kPa), and

σ_{zo}' = initial vertical effective stress (kPa).

Equation B-2 was used to calculate the ultimate settlement of the pre-consolidated tailings (i.e. upper beach tailings).

$$(\delta_c)_{ult} = \sum \left[\frac{c_r}{1+e_0} Hlog\left(\frac{\sigma'_c}{\sigma'_{z0}}\right) + \frac{c_c}{1+e_0} Hlog\left(\frac{\sigma'_{zf}}{\sigma'_c}\right)\right] \quad \text{[B-2]}$$

where:

c_r = recompression index,and

σ_c' = pre-consolidation stress (kPa).

During the settlement calculation, the total tailings thickness (65 m) was divided into 40 sub-layers, based on the design life of the tailings facility, with each sub-layer having a 1.625 m thickness. Initial and final effective stresses were calculated based on the tailings initial and final state for each scenario. It is important to note that depending on the final position of the water table, a different unit weight of tailings may be used for the tailings final state.

B2.3 Method for Calculating Rate of Consolidation

Terzaghi's theory of consolidation (Terzaghi, 1921) was used to calculate rate of consolidation when the tailings maintains its saturated condition during consolidation (e.g. Scenarios #3, #5, #8, #10, #13, #15). Equation B-3 was used to calculate the time factor (T_v).

$$T_v = \frac{c_v\, t}{H_{dr}^2} \qquad \text{[B-3]}$$

where:

T_v = time factor,

c_v = coefficient of consolidation (m^2/yr),

t = time since application of cover, and

H_{dr} = length of longest drainage path (m) (for single drainage, H_{dr} = thickness of tailings; for double drainage, H_{dr} = half the thickness of tailings).

The longest drainage path was single drainage, where H_{dr} equals the height of the tailings deposit (i.e. 65 m).

Equations B-4 and B-5 were used to calculate degree of consolidation.

$$If\ T_v \le 0.217\ then\ U = \sqrt{\frac{4T_v}{\pi}} \times 100\% \qquad \text{[B-4]}$$

where:

U = degree of consolidation (%).

$$If\ T_v \ge 0.217\ then\ U = \left[1 - 10^{-\left(\frac{0.085+T_v}{0.933}\right)}\right] \times 100\% \qquad \text{[B-5]}$$

The tailings consolidation rate is dependent on water seepage rate through the tailings base when a water drawdown of the phreatic surface in the tailings occurs. It was assumed that Darcy's law describes water flow in the tailings under unit hydraulic gradient conditions. When the phreatic surface in the tailings decreases, the tailings effective stress increases, which results in tailings consolidation. This results in a decrease in tailings void ratio. The tailings hydraulic conductivity was calculated from the tailings void ratio versus hydraulic conductivity relationship. Basal seepage rates decrease as further tailings consolidation occurs. Tailings consolidation continues until the phreatic surface in the tailings mass reaches the base of the tailings facilities. The degree of tailings consolidation is defined by Equation B-6 when a water drawdown of the phreatic surface occurs.

$$U = \frac{\delta_c}{(\delta_c)_{ult}} \times 100 \quad \text{[B-6]}$$

where:

δ_c = consolidation settlement (m) in certain timeframe.

B2.4 Parameters Used for Consolidation Analyses

Table B2.1 presents tailings properties used for consolidation analyses. The tailings initial void ratio was calculated based on a tailings specific gravity and its dry density. The tailings specific gravity is 3.4 according to the ODP Supplementary EIS (ODP, 2011).

Table B2.2
Tailings parameters used for consolidation analyses

Tailings material	**Dry density (t/m^3)**	**Moist unit weight (kN/m^3)**	**Saturated unit weight (kN/m^3)**	**c_c**	**c_r**	**c_v (m^2/year)**
Bulk tailings*	1.70	18.0	21.0	0.08	n/a	30
Upper beach tailings**	1.95	20.3	23.3	0.08	0.016	50
Pool area tailings**	1.45	15.8	19.8	0.16	n/a	20

*Data available in ODP's Supplementary EIS (ODP, 2011).
** Data are assumed.

To calculate the consolidation rate due to a water drawdown of the phreatic surface in the tailings, a similar tailings void ratio and hydraulic conductivity relationship was assumed (Equation B-7).

$$k = a \times e^{2.1} \quad \text{[B-7]}$$

where:

k = tailings hydraulic conductivity (m/yr),

e = void ratio, and

a = coefficient (m/yr).

a is 0.79 m/yr (or 2.5 x 10^{-8} m/s) for the bulk tailings, 3.16 m/yr (or 1.0 x 10^{-7} m/s) for the upper beach tailing, and 0.32 m/yr (or 1.0 x 10^{-8} m/s) for the pool area tailings. The calculated initial saturated hydraulic conductivity of the tailings deposit is the range of the tailings permeability (1 x 10^{-8} m/s – 5 x10^{-8} m/s) listed in the ODP Supplementary EIS (ODP, 2011).

In addition, it was also assumed that the upper beach tailings have a pre-consolidation stress of 650 kPa and the cover material has a unit weight of 21 KN/m^3 in the tailings consolidation analyses.

B3 RESULTS OF CONSOLIDATION ANALYSES

Tailings will undergo settlement due to consolidation following cessation of tailings deposition in the TSF at Year 40. Long-term drain down of the TSF and the resultant phreatic surface is an important component of closure design. Recession of the phreatic surface will dictate the timing of reclamation cover placement, as well as any subsequent loading to downstream receptors. Table B3.1 displays the results calculated for tailings consolidation scenarios. Included in Table B3.1 are ultimate settlement, as well as the time it will take to reach 50%, 90%, and 95% consolidation following the final deposition of tailings material at Year 40.

Table B3.1
Settlement and rates of consolidation for various tailings consolidation scenarios

Scenario	$(\delta_c)_{ult}$ (m)	T_{50}^{*} (years)	T_{90} (years)	T_{95} (years)
#1	0.54	8	25	30
#2	0.71	8	25	30
#3	0.24	28	120	160
#4	0.64	8	25	30
#5	0.14	28	120	160
#6	0.27	6	11	12
#7	0.33	6	11	12
#8	0.06	17	72	95
#9	0.30	6	11	12
#10	0.04	17	72	95
#11	0.83	13	38	45
#12	1.20	13	38	45
#13	0.45	42	180	240
#14	1.06	13	38	45
#15	0.26	42	180	240

*T_{50} represents the timeframe required to achieve a 50% consolidation degree.

Table B3.1 indicates that the tailings settlement induced by the placement of cover materials on the upper beach tailings is negligible. However, the tailings settlement could be half a meter when two meters of cover material is placed on top of the pool area tailings. This is attributed to the tailings segregation along its flow pathway. The coarser textured tailings settle in the upper beaches, while the finer textured tailings flow to the pool areas in suspension. It is important to not focus on the exact ultimate settlements and time scales with the analysis, given that there are number of simplifying assumptions required. The key message is that the tailings properties will cause variations of the ultimate consolidation settlements and consolidation rates.

Figure B3.1 illustrates the tailings height due to settlement with respect to time for Scenarios #3 #8, and #13 for three types of tailings. In all three scenarios the tailings were assumed to be saturated and the consolidation settlement of the tailings is produced due to the soil cover placement. The upper beach tailings will settle much quicker than the bulk tailings and the pool area tailings and also have the least settlement (0.06 m) compared to the bulk tailings and pool area tailings. The pool area tailing is anticipated to have the largest settlement (0.45 m) in the TSFs.

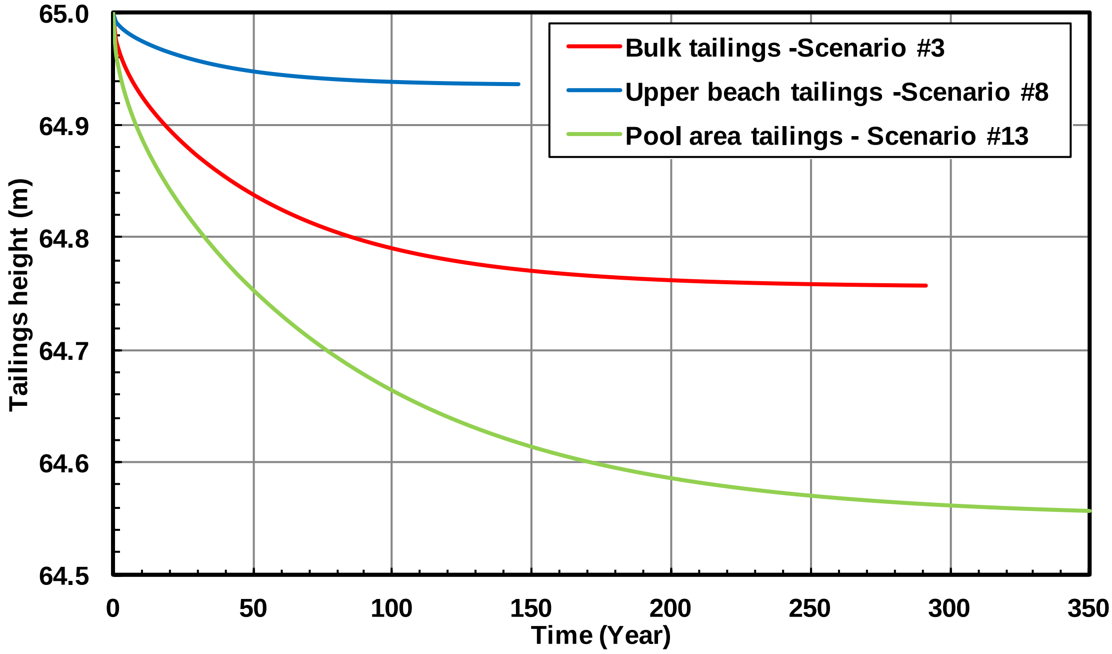


Figure B3.1 Tailings settlement for Scenarios #3, #8 and #13 for various tailings following 40 years of tailings deposition.

B4 IMPLICATIONS OF TAILINGS SETTLEMENT ON COVER DESIGN

B4.1 Proposed Cover Design Field Trial

The proposed cover design field trial is to be constructed with ROM overburden with a thickness of 1 m to 2 m. The maximum differential settlement was calculated to be 0.57 m using Scenarios #2 and #5 with the assumption that the cover field trial will be build on top of the bulk tailings. The resulting slope caused by tailings differential settlement was 0.6% over a length of 97.5 m (the length between cover material deposited at 1 m and 2 m) from drawing 809-5-101 in Appendix F. This resulting slope could be achieved over decades based on the tailings rate of consolidation presented in Table B3.1. Considering a relatively short duration of the cover design field trial, the final tailings settlement may not complete and thus the resulting slope during the cover design field trial would be much smaller than 0.6%. As a result, tailings differential settlement will not substantially influence the integrity of the proposed cover design field trial. Moreover, it is anticipated that the tailings differential settlement due to the soil cover placement will be smaller when the cover field trial is built on top of the upper beach tailings.

B4.2 Tailings Storage Facility Cells

It is proposed in the Olympic Dam Expansion Draft and Supplementary EISs that each cell is to have an area of approximately 400 ha (2,000 m x 2,000 m) with tailings deposited at a slope of approximately 1%. Over a length of 1,000 m from the rockfill embankment to the central water pooling area, the tailings slope may increase from 1% to 1.2% when a total tailings settlement of 1.20 m (Scenario #12) is considered at the centre (water pool area) of TSF. This margin of increase in slope will not generate substantial impacts on the integrity of the cover system (compacted cover layers and/or geomembrane liners).

B4.3 Limitations of Tailings Consolidation Analysis and Recommendations

The consolidation analyses completed for this study are a simplification of tailings consolidation (settlement and rate). A number of factors could affect the properties of the tailings mass and complicate the actual tailings consolidation processes. These factors may include crust development at top of the tailings due to evaporation, tailings segregation along flow pathway, local water pooling to change tailings segregation, low permeability material seating at the TSF base to reduce water drawdown in the tailings, and others. The tailings mass in the TSF is hardly homogeneous and it is almost impossible to obtain geotechnical properties of all tailings. Therefore the consolidation analysis is thus limited by the accuracy and detail of the conceptual model.

The following limitations should be noted when interpreting the results of the consolidation analyses included in this report.

- Most parameters used in the consolidation analyses were assumed. The accuracy of these parameters is limited.
- Surface crust is not considered in the analysis.

- A unit hydraulic gradient was employed to calculate the rate of water drawdown in the tailings and to estimate the tailings consolidation rate. However, the water drawdown in the tailings is a complex process and could not occur in exact a unit hydraulic gradient.
- The consolidation analyses assumed that the phreatic surface in the tailings mass after cessation of tailings deposition is located at the tailings surface for all tailings. The actual phreatic surface in the TSF after deposition could vary depending on discharging points.
- The potential influence of local heterogeneity within a certain area was not investigated.

In order to accurately determine tailings settlement and consolidation rate for cover system and landform design for closure, it is recommended that the tailings deposition process needs to be monitored and tailings consolidation properties should be tested (also considering tailings variations). The tailings consolidation analyses should be re-visited once above information is updated.

B5 REFERENCES

BHP Billiton 2011. Olympic Dam Expansion Supplementary Environmental Impact Statement 2011, Section 5.3 Tailings Storage Facility, pp 129-139.

Terzaghi, K. 1921. Die physikalischen Grundlagen der technischgeologischen Gutachtens. Österreichischer Ingenieur und Architekten-Verein Zeitschrift, **73**: pp 237-241 (in German).

APPENDIX C

Landform Erosion Assessment

C1: Initial WEPP Simulations

C2: WEPP Simulations for Extreme Events

BHP Billiton Olympic Dam - Initial WEPP simulations

Progress report 21 January 2013

Report prepared for O'Kane Consultants Ltd

To reference this report:
Landloch Pty Ltd (2013). *BHP Billiton Olympic Dam - Initial WEPP simulations. Progress report 21 January 2013.* Report prepared for O'Kane Consultants Ltd.

Author	Review	Client contact
Dr R. Loch, CPSS3	Evan Howard	Andre Kemp

Landloch Pty Ltd
A.C.N. 011 032 803
A.B.N. 29011032803

TOOWOOMBA OFFICE
PO Box 57
HARLAXTON QLD 4350
Phone (07) 4613 1825
Fax (07) 4613 1826

PERTH OFFICE
PO Box 5175
SOUTH LAKE WA 6164
Phone (08) 9494 2835
Fax (08) 9494 2837

NEWCASTLE OFFICE
PO Box 1102
WARNERS BAY NSW 2282
Phone (02) 4965 7717
Fax (07) 4613 1826

Web site: www.landloch.com.au
Email: admin@landloch.com.au

TABLE OF CONTENTS

1. Background

BHP Billiton Olympic Dam (BHPB-OD) is a world-class mining and mineral-processing operation, located 564km north of Adelaide in South Australia. BHP Billiton has considered a proposal to significantly expand its existing mining and processing operations at Olympic Dam. The Olympic Dam Expansion (ODX) would establish a new open pit mine that would operate simultaneously with the existing underground mine.

A site closure plan for the proposed ODX is required to be submitted for regulatory approval, and is required to encompass the commitments made in the ODX Draft and Supplementary Environmental Impact Statements (EISs), and conditions stipulated in regulatory approvals for the EIS (10 October 2011). Within the site closure plan, the Tailings Storage Facility (TSF) cover system would require minimal ongoing monitoring or care and maintenance, and would ensure that all key risks would be well controlled in the very long term. These risks include:

- Landform instability,
- Cover integrity,
- Release of radioactive tailings into the environment,
- Erosion,
- Flora and fauna impacts,
- Dust generation,
- Groundwater contamination, and
- Radiation doses to members of the public.

A proposed work scope for the TSF cover system was developed by O'Kane Consultants, based on BHPB-OD's Request for Proposal (RFP) dated 13 July 2012. It consists of the following major tasks:

1) Project orientation through consultation with BHPB-OD staff and review of historical studies pertinent to the work scope;
2) Define TSF closure cover criteria and design parameters;
3) Develop cover system and final landform design alternatives based on required performance criteria and economically available cover materials at BHPB-OD;
4) Conduct numerical analyses of the various design alternatives, including soil-plant-atmosphere, consolidation, seepage, landform erosion/evolution, and slope stability analyses;
5) Finalise design of the TSF closure cover system and landform based on the results of Task 4 numerical analyses as well as a Failure Modes and Effects Analysis (FMEA);
6) Design a cover system field trial program including recommendations for trial footprint, location, construction methods, and monitoring program; and
7) Prepare draft and final versions of a project report detailing the results of numerical analyses, key findings, and recommendations.

Landloch's contribution to this work is to provide landform erosion and evolution simulations as part of development and testing of various design alternatives.

1.1 Project scope and modelling approach

In the initial proposal, the Project Team recommended use of the Water Erosion Prediction Project (WEPP) runoff/erosion model (Flanagan and Livingston 1995) to develop initial landform options, with the SIBERIA landform evolution model then providing the option of assessing the long-term evolution of those TSF landform design alternatives.

In terms of parameterisation, WEPP is particularly well-suited to development of parameters using either (a) available data on site materials or (b) data from similar materials at other sites. In contrast, parameters required for input to SIBERIA require either long-term runoff and erosion measurements from monitored catchments, or from runoff/erosion data from long-term WEPP simulations. For application of WEPP, Landloch has developed relatively simple approaches that can be applied to estimate the required erodibility parameters even when direct measurements are not possible. A detailed description of the WEPP model is given in Appendix 1.

1.2 Data availability

Generally, application of the WEPP model relies on having directly-measured erodibility parameters available. In this case, samples were not able to be sourced, and direct measurements of erodibility were not possible. Therefore, alternative methods for inferring parameters were applied. Although estimation of parameters used the best information available, it should be noted that this latter approach is less accurate than the use of direct measurement of model parameters, and is, therefore, not Landloch's preferred approach to landform design.

1.3 Modelling approach

Simulations using the WEPP model have been carried out for the Olympic Dam (OD) TSF batter slopes. For the existing TSF, there is little potential for modification of batter heights and gradients. It is understood that the same batter gradients and heights are planned for any new TSF construction.

Therefore, for a number of reasons, Landloch's initial simulations did not consider any potential for alteration of the TSF batters, but, instead, focussed on ways in which the batter surface may be established or managed to restrict erosion to acceptable levels. Reasons for that approach included:

- The need to consider existing batters for the current TSF;
- Changes in TSF batter height or gradient to control erosion would need to be relatively significant to achieve significant change in erosion rates, whereas surface management (rock armouring) could achieve similar levels of erosion control without changes to batter design; and

- It was understood that rock armouring of TSF batter slopes was possible and a well-recognised option for the site.

In carrying out simulations to identify landform options for which erosion rates are "acceptable", it should be noted that there is currently no information or guidelines for establishment of "acceptable" erosion rates for minesite landforms. However, as the long-term integrity of the slopes and containment of tailings is essential, erosion rates achieved should be clearly sufficiently low that gullies do not develop on the batters over periods of up to 1000 years. In general, Landloch has defined "non-gullying" erosion rates as being equivalent to:

a) average erosion on the slope being <5t/ha/y; and
b) peak erosion at any point on the slope being <10t/ha/y.

Experience with minesites has confirmed that those erosion rates appear to restrict gully development. For structures such as the OD TSF, for which the period of stability is likely to be particularly long, those target erosion rates should be considered as the absolute maximum that could be accepted.

2. Inputs to simulations

2.1 Site overview

Basic assumptions for the OD TSF batter slopes are:

- 65m high slope with linear profile shape.
- 50% gradient.

Simulations used the 100-year OD climate file provided by O'Kane Consultants, which gave an average annual rainfall total of 166mm/y.

WEPP simulations considered rill spacings across the slope of 1 and 5 m. Normally, where slopes are rock-armoured, a rill spacing of 1 m would be used to reflect relatively even spreading of flow due to high surface hydraulic roughness, but in this case, the potential for the batter to be spatially uneven is considered to be of concern, making occasional concentration of overland flow relatively likely, and the 5 m rill spacing a more appropriate simulation of overland flow paths on the batter slopes.

2.2 Material parameters

Four key material parameters are required by the WEPP model:

1) Effective hydraulic conductivity, (K_e);
2) Critical shear for rill initiation (τ_c);
3) Rill erodibility (K_R), and
4) Interrill erodibility (K_i).

It was assumed that the TSF batters will be stabilised by spreading rock over the existing batters, consistent with the treatment applied to some existing batter slopes. As the underlying TSF wall will have been compacted during construction, rates of infiltration into the compacted material will be low. Consequently, Effective Hydraulic Conductivity (K_e) was set to 0.3mm/h, giving a steady infiltration rate of approximately 3mm/h.

The rill detachment parameter (K_R) was set to 0.003, consistent with a compacted cohesive, sandy material. Effectively, this parameter describes the potential rill detachment rate of the underlying batter material if the overlying rock layer is removed by surface flows. Based on material visible in photographs of existing batter slopes, the material particle size distribution input to the model was selected to be consistent with a sandy soil of relatively low clay content.

This approach ensured that the inputs for climate and for infiltration capacity can be considered to be accurate, and the rill erodibility parameter is reasonably consistent with values measured for other materials of similar particle size. Therefore, the WEPP simulations can be considered to be reasonably soundly based, though with rates of rill detachment and of peak sediment transport capacity being regarded with less confidence.

A range of Critical Shear values was calculated for limestone[1] rock (assuming a specific gravity of 2.45g/cc). Calculations used the Shields equation (Shields 1936), and considered a range of D_{50} values consistent with rock present on the site (as indicated by site photos - see Figures 2-4). The variation in Critical Shear with D_{50} is shown in Figure 1.

[1] Limestone rock is known to be available, and it has been assumed that the rock used in armouring surfaces will either be limestone, or a waste rock of similar properties.

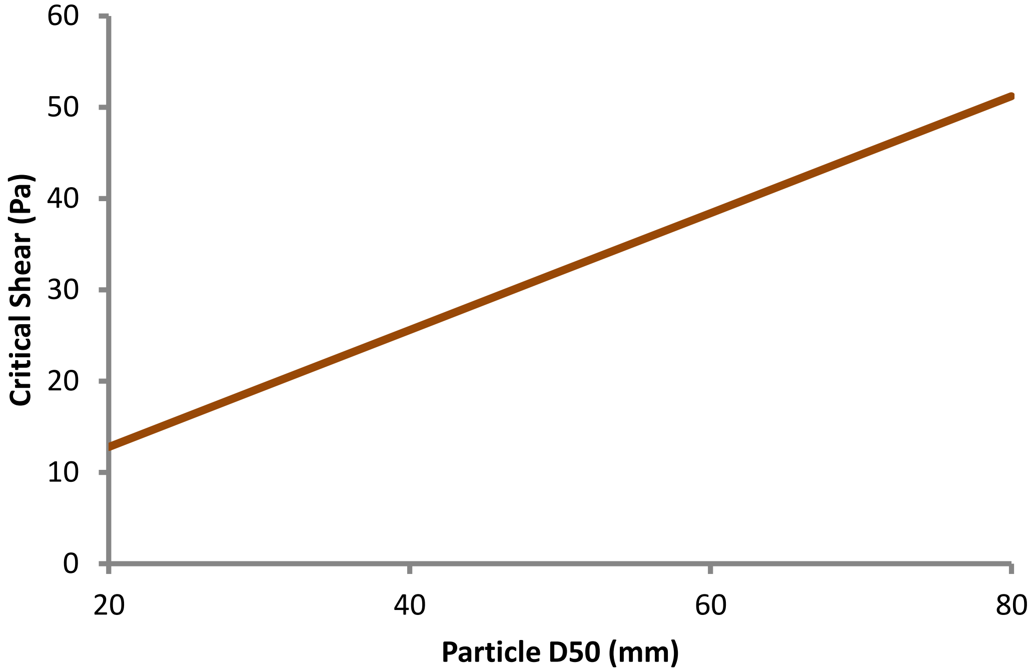


Figure 1: *Critical Shear values calculated for limestone rock of varying particle size.*

Photographs of a range of batter surfaces and rock materials were analysed to derive particle size distributions of the rock layers currently placed. The median particle sizes (D_{50}) of these distributions are shown in Table 1. D_{50} values of 13.7, 30.8, and 43.3mm are shown for the relevant areas in Figures 2 - 4. For all images the tape measures show a distance of 1m.

Table 1: *Rock D_{50} values derived from photos of the TSF*

TSF Cell	Batter Location	D_{50} (mm)
1	Upper batter slope	30.8
1	Lower batter slope	13.7
2	Upper batter slope	43.3
2	Lower batter slope	1.4
3	Upper batter slope	14.3
3	Lower batter slope	7.4
4	Upper batter slope	32.9
4	Lower batter slope	49.5
Quarry	2	33.3
Quarry	7	81.8

Figure 2: *Cell 1 lower slope batter section with D_{50} of 13.7mm.*

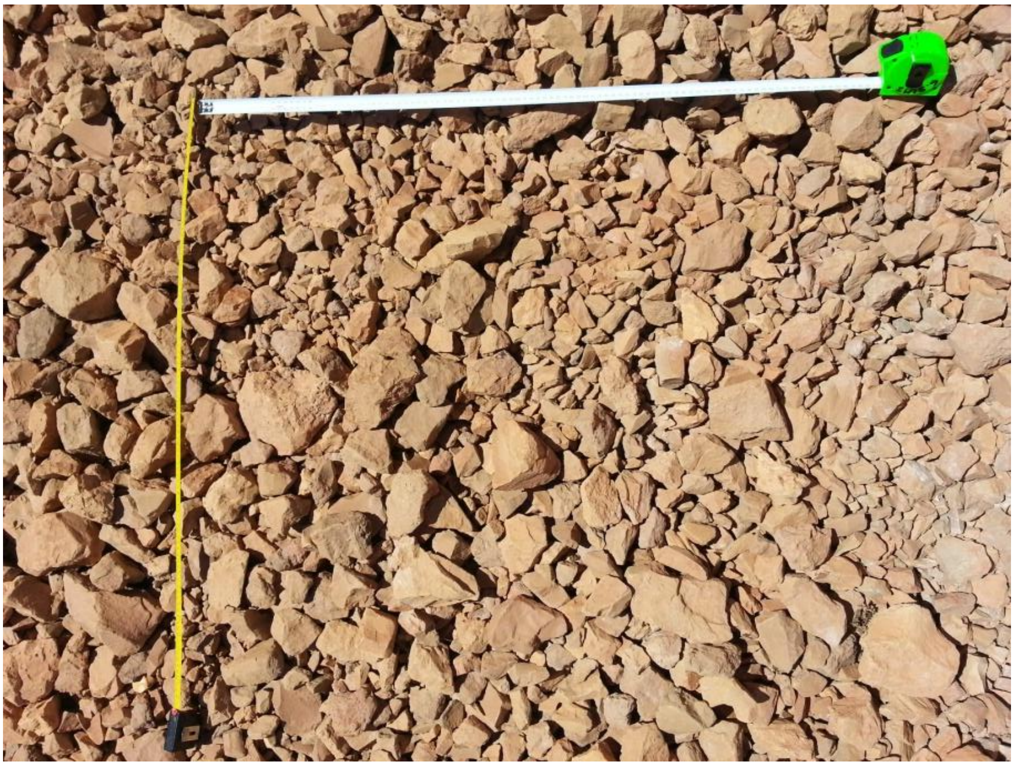


Figure 3: *Cell 1 upper slope batter section with D_{50} of 30.8mm.*

Figure 4: *Cell 2 upper slope batter section with D_{50} of 43.3mm.*

3. Model output

Average annual runoff for the batter slope tested is predicted to be 18.6mm/y. Predicted average and peak erosion rates for 1 and 5m rill spacings and a range of mean rock sizes are shown in Figures 5 and 6.

For the 5 m rill spacing, the predicted rates of average erosion are slightly <5 t/ha/y for a D_{50} of 40mm, and reduce to a very low level for D_{50} of 50 mm. In slight contrast, peak erosion rates reduce to below the "acceptable" level of 10 t/ha/y for D_{50} of 50mm, and reach a very low level for $D_{50} \geq 60$mm.

For 1 m rill spacing, 30 mm appears to be a sufficiently large D_{50} for both average and peak erosion rates to be acceptable. However, given likely inaccuracies in batter slope construction and shaping, it is <u>strongly recommended</u> that the data for a 5 m rill spacing be used to guide final slope stabilisation.

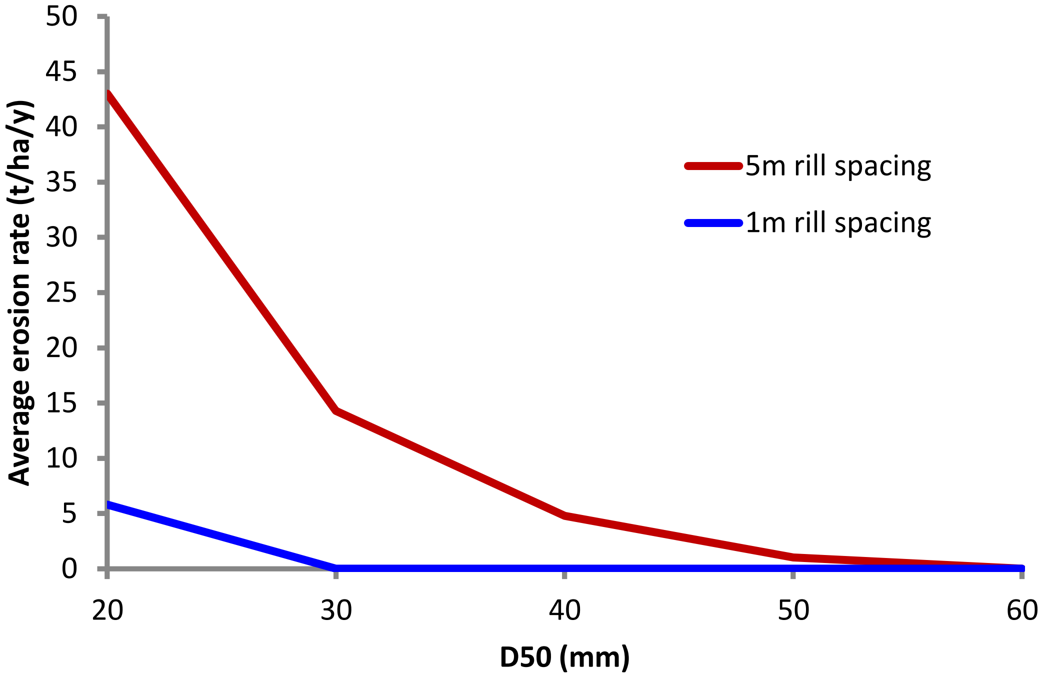


Figure 5: *Predicted impacts of rock D_{50} on average rates of erosion from batters 65m high, 50% gradient.*

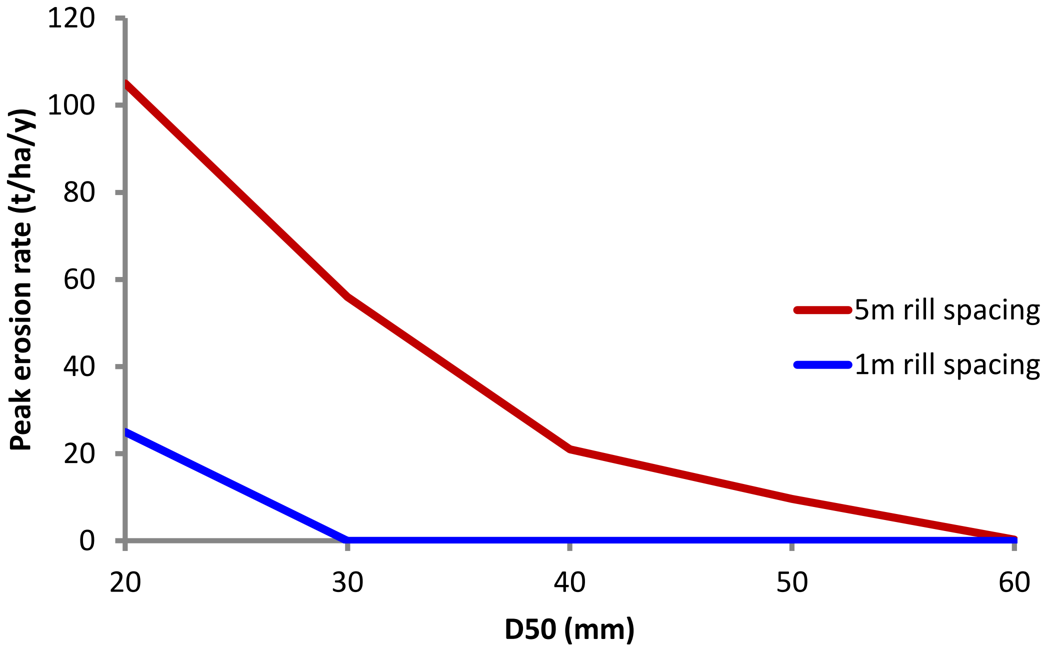


Figure 6: *Predicted impacts of rock D_{50} on peak rates of erosion on batters 65m high, 50% gradient.*

4. Erosion process and landform considerations

4.1 Flow Concentration

In general, significant erosion of rock armoured slopes will only occur if either:

a) overland flows are sufficiently large to cause movement of surface rock layers; or
b) scour of the underlying finer-textured material occurs due to turbulent flow moving under or through the rock layer.

Concentration of large volumes of flow would be needed to cause movement of surface rock. For that reason, the TSF outer batter will need to be carefully shaped so that there is no bench or discontinuity left between upper and lower batter segments to concentrate flow. Use of equipment with guidance systems to increase precision in slope construction is strongly recommended.

4.2 Rock sizes and placement

To achieve reasonable certainty of erosion control, the simulations indicate that placement of rock with a D_{50} ≥60 mm is required. Obviously, the size distributions of waste rock will vary, and – in general – provided the rock D_{50} is ≥60 mm, and the rock is poorly-sorted (containing a wide range of particle sizes), the rock should provide suitable protection against erosion. Ideally, the rock would have a D_{30} of approximately 20mm, and few, if any, particles >200mm.

To some degree, the finer fraction of particles in rock placed for erosion control will tend to gravitate to the bottom of the rock layer during placement, with that layer of finer rock tending to prevent potential scour by flow under the layer of coarser rock. The finer rock particles function to absorb flow energy, and the large particles act to prevent the rock layer from being entrained by flow.

However, greater certainty of rock effectiveness could be achieved by placing rock in 2 layers, with the first layer being composed of finer material (D_{50} of 30mm), and then a coarser layer (D_{50} ≥60mm) being placed over that. The depth of layer to be placed has not been considered, but - given the likely long time frame for which stability is required - a layer of a minimum of 1 metre thickness in total is advisable. If placed in two layers, the depth of fine material should be approximately 300mm, with 700mm of coarser rock overlying that. This specific recommendation may need to be considered further.

In terms of assessment of rock sizes for placement, it is likely that the best approach would be to develop photo standards that could be used by field (construction) staff to determine whether rock complied with the required particle sizes. (Generally, photo standards provide reasonable accuracy and are extremely convenient.)

4.3 Landform drainage

Structures for drainage of flow from the top of the TSF will have no impact on conclusions from the current simulations, nor on batter stabilisation recommendations.

5. TSF top

At this stage, erosion simulations have not considered the TSF top. As the capping layer is likely to be placed at quite low gradient relative to the outer batter slopes, rock armouring of the TSF top is likely to reduce erosion to extremely low levels.

However, if the rock to be placed on the TSF capping layer is expected to be of significantly finer particle size, there would be value in carrying out WEPP simulations for that area once the likely topography is established.

6. Further simulations

As landform and capping designs progress further, further WEPP simulations and some long-term landform evolution simulations with the SIBERIA model will be discussed.

7. References

Flanagan, D. C., and Livingston, S. J. (1995). WEPP user summary. NSERL Report No 11, USDA-ARS-MWA.

Shields, A. (1936). Anwendung der Aenlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung, Mitteilungen der Preussischen Versuchsanstalt fur Wasserbau und Schiffbau, Berlin, Germany, translated to English by W.P.Ott and J.C. van Uchelen,California Institute of Technology, Pasadena, Calif.

APPENDIX 1: The WEPP model

The Water Erosion Prediction Project (WEPP) (Flanagan and Livingston 1995) was developed by the United States Department of Agriculture (USDA) to predict runoff, erosion, and deposition for hillslopes and watersheds. It is the product of continued USDA research and development of soil erosion models since the 1940's. As such, it is based on an enormous body of research data and modelling experience, and is widely regarded as the state of the art in erosion modelling at this time.

WEPP is a simulation model with a daily input time step, but internal calculations can use shorter time steps. For example, the climate file (for each day) includes information on:

- Amount of rain
- Duration of the rain
- Time to peak intensity
- Ratio between peak intensity and average intensity.

This information is used in infiltration calculations, so that the model takes intensity and duration of rainfall into account. For every day, plant and soil characteristics important to erosion processes are updated. When rainfall occurs, those plant and soil characteristics are considered in determining whether runoff occurs. If runoff is predicted to occur, the model computes sediment detachment, transport, and deposition at points along the slope profile, and, depending on the version used, in channels and reservoirs.

Conceptually, the WEPP model can be divided into six components: climate generation, hydrology, plant growth, soils, management, and erosion.

Hydrology

The hydrology component of WEPP computes infiltration, runoff, soil evaporation, plant transpiration, soil water percolation, plant and residue interception of rainfall, surface depression storage, and soil profile drainage by subsurface tiles. Infiltration is calculated using a modified Green and Ampt infiltration equation. Runoff is computed using the kinematic wave equations or an approximation to the kinematic wave solutions obtained for a range of rainfall intensity distributions, hydraulic roughness, and infiltration parameter values.

Two methods are used to compute the peak discharge rate depending if the model is run in a continuous or single storm mode and if there are multiple overland flow elements (OFE). A semi-analytical solution of the kinematic wave model is used to compute the runoff hydrograph when the model is run in the single storm mode for a single OFE or when multiple OFEs can be treated as a single OFE. A peak discharge approximation based on the kinematic wave model is used for most events when the model is run in the continuous simulation mode. Infiltration and rainfall excess on multiple OFEs are approximated by either averaging the infiltration parameters and treating the multiple OFEs as a single OFE or by computing a simple water balance to determine if runoff occurs. For multiple OFEs, an equivalent depth-discharge coefficient for the kinematic wave model is computed based on the equilibrium storage of water on a cascade of OFEs.

Erosion

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

Validation of the WEPP model

The WEPP model has been widely tested against measured data (Nearing and Nicks 1998, Ghidey and Alberts 1996, Liu *et al.* 1997, Zhang *et al*. 1996, Tiwari *et al*. 2000, Yu and Rosewell 2001). In general, the tests indicate that the model performs well – given that no erosion model is expected to be extremely precise, and that experimental erosion data are somewhat variable (Nearing *et al*. 1999). Interestingly, the model is more accurate in its prediction of long-term averages than of erosion associated with individual years (Figure 1-1) – again, a consequence of the extreme variability of erosion from individual events.

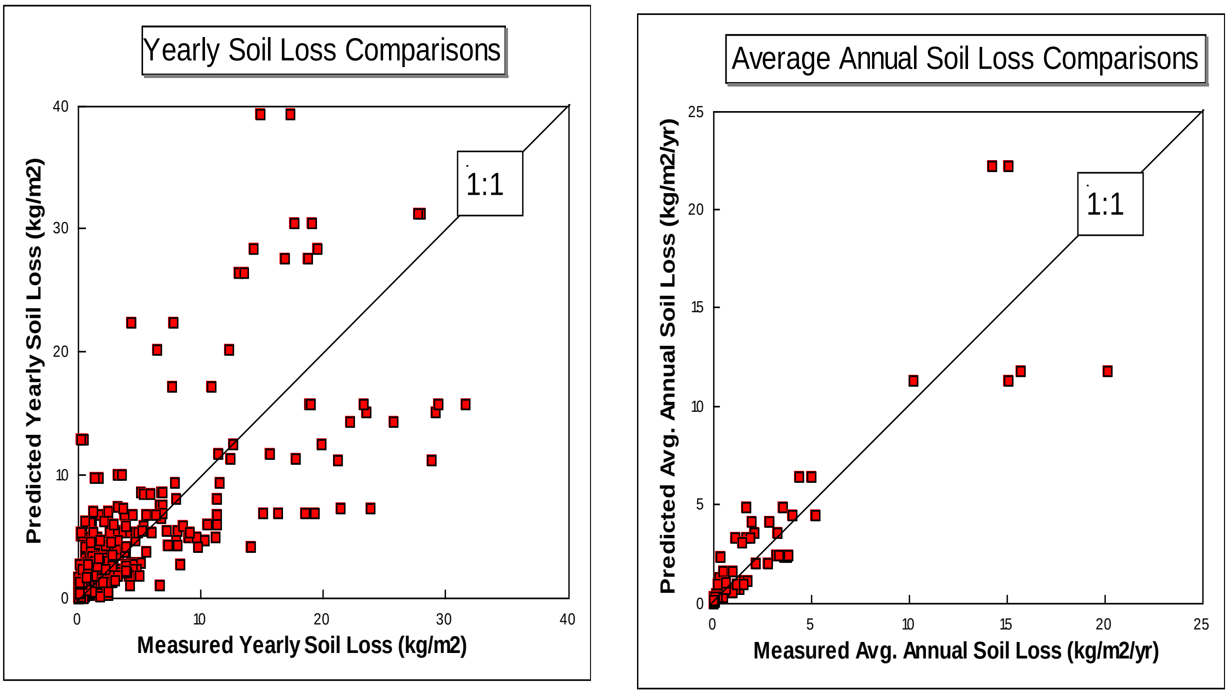


Figure 1-1: *Figures from Nearing and Nicks (1998) showing WEPP model performance against measured data.*

Experience with, and assessment of, the WEPP model for Australian minesite landforms has found that the accuracy of its predictions is high when directly-measured erodibility and infiltration data are available (Figure 1-2 from Howard and Roddy, 2012).

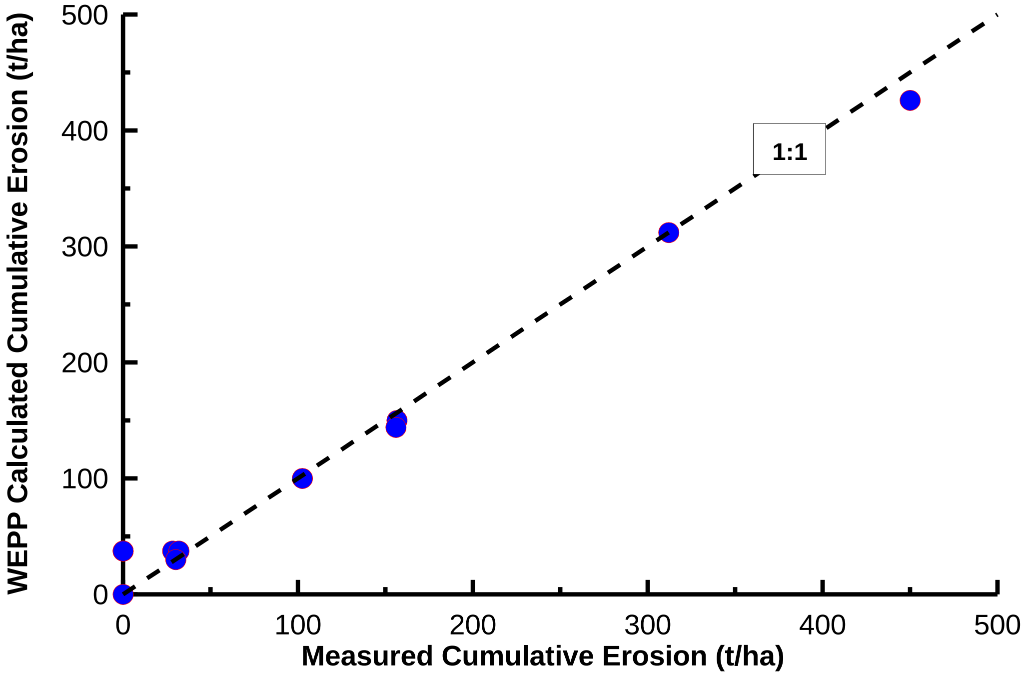


Figure 1-2: *Predicted and observed cumulative erosion rates for 11 batter slope locations in Western Australian mine sites (Howard and Roddy 2012).*

References

Flanagan, D. C., and Livingston, S. J. (1995). WEPP user summary. NSERL Report No 11, USDA-ARS-MWA.

Ghidey, F., and Alberts, E.E. (1996). Comparison of measured and WEPP predicted runoff and soil loss for Midwest claypan soil. *Trans. Am. Soc. of Agric. Engrs.,* 39: 1395-1402.

Howard, E.V. and Roddy, B.M. (2012). Evaluation of the Water Erosion Prediction Project (WEPP) model: validation data from sites in Western Australia**. In** Mine Closure 2012 — A.B. Fourie and M. Tibbett (eds) © 2012 Australian Centre for Geomechanics, Perth, ISBN 978-0-9870937-0-7.

Liu, B.Y., Nearing, M.A., Baffaut, C., and Ascough II, J.C., (1997). The WEPP watershed model: III. Comparisons to measured data from small watersheds: *Trans. Am. Soc. of Agric. Engrs.,* 40(4): 945-951.

Nearing, MA and Nicks, AD. (1998). Evaluation of the Water Erosion Prediction Project (WEPP) model for hillslopes: in *Modelling Soil Erosion by Water* (J Boardman and DT Favis-Mortlock, eds.), Springer-Verlag NATO-ASI Series I-55, Berlin: 45-56.

Tiwari, A.K., Risse, L.M., and Nearing, M.A. (2000) Evaluation of WEPP and its comparison with USLE and RUSLE. *Trans. Am. Soc. of Agric. Engrs. 43: 1129-1135.*

Yu, B., and Rosewell, C.R. (2001) Evaluation of WEPP for runoff and soil loss prediction at Gunnedah, NSW, Australia. *Australian Journal of Soil Research* 39: 1131-1145.

Zhang, X.C., M.A. Nearing, L.M. Risse, and K.C. McGregor. (1996). Evaluation of runoff and soil loss predictions using natural runoff plot data. *Trans. Am. Soc. Agric. Eng.*, 39(3): 855-863.




BHP Billiton Olympic Dam - WEPP simulations for extreme events

21 February 2013

Report prepared for O'Kane Consultants Ltd

Landloch Pty Ltd
Contact: Rob Loch
admin@landloch.com.au

To reference this report:
Landloch Pty Ltd (2013). *BHP Billiton Olympic Dam - WEPP simulations for extreme events. Progress report 21 February 2013.* Report prepared for O'Kane Consultants Ltd.

Author	Date	Review	Client contact
Dr R. Loch, CPSS3	21/02/2013	Dr A.Cclark	Andre Kemp

Landloch Pty Ltd
A.C.N. 011 032 803
A.B.N. 29011032803

TOOWOOMBA OFFICE
PO Box 57
HARLAXTON QLD 4350
Phone (07) 4613 1825
Fax (07) 4613 1826

PERTH OFFICE
PO Box 5175
SOUTH LAKE WA 6164
Phone (08) 9494 2835
Fax (08) 9494 2837

NEWCASTLE OFFICE
PO Box 1102
WARNERS BAY NSW 2282
Phone (02) 4965 7717
Fax (07) 4613 1826

Web site: www.landloch.com.au
Email: admin@landloch.com.au

TABLE OF CONTENTS

1. Background

BHP Billiton Olympic Dam Corporation Pty Ltd (ODC) is a world-class mining and mineral-processing operation, located 564km north of Adelaide in South Australia. BHP Billiton has considered a proposal to significantly expand its existing mining and processing operations at Olympic Dam. The Olympic Dam Expansion Project (ODP) would establish a new open pit mine that would operate simultaneously with the existing underground mine.

A site closure plan for the proposed ODP is required to be submitted for regulatory approval, and is required to encompass the commitments made in the ODX Draft and Supplementary Environmental Impact Statements (EISs), and conditions stipulated in regulatory approvals for the EIS (10 October 2011). Within the site closure plan, the Tailings Storage Facility (TSF) cover system would require minimal ongoing monitoring or care and maintenance, and would ensure that all key risks would be well controlled in the very long term. These risks include:

- Landform instability,
- Cover integrity,
- Release of radioactive tailings into the environment,
- Erosion,
- Flora and fauna impacts,
- Dust generation,
- Groundwater contamination, and
- Radiation doses to members of the public.

A proposed work scope for the TSF cover system was developed by O'Kane Consultants, based on ODC's Request for Proposal (RFP) dated 13 July 2012. It consists of the following major tasks:

1) Project orientation through consultation with ODC staff and review of historical studies pertinent to the work scope;
2) Define TSF closure cover criteria and design parameters;
3) Develop cover system and final landform design alternatives based on required performance criteria and economically available cover materials at ODC;
4) Conduct numerical analyses of the various design alternatives, including soil-plant-atmosphere, consolidation, seepage, landform erosion/evolution, and slope stability analyses;
5) Finalise design of the TSF closure cover system and landform based on the results of Task 4 numerical analyses as well as a Failure Modes and Effects Analysis (FMEA);
6) Design a cover system field trial program including recommendations for trial footprint, location, construction methods, and monitoring program; and
7) Prepare draft and final versions of a project report detailing the results of numerical analyses, key findings, and recommendations.

Landloch's contribution to this work is to provide landform erosion and evolution simulations as part of development and testing of various design alternatives. This short report contributes to task 4.

1.1 Project scope and modelling approach

In the initial proposal, the Project Team recommended use of the Water Erosion Prediction Project (WEPP) runoff/erosion model (Flanagan and Livingston 1995) to develop initial landform options.

WEPP is a useful approach because it can be parameterised relatively easily, either (a) directly from available data on site materials or (b) indirectly from data from similar materials at other sites. For application of WEPP, Landloch has developed relatively simple approaches that can be applied to estimate the required erodibility parameters even when direct measurements are not possible.

1.2 Data availability

Measured erodibility data were not available, so an indirect method was used to estimate WEPP parameters on this site. Although this uses the best information available, it should be noted that this latter approach is less accurate than the use of direct measurement. This could lead to error or inaccuracies in the final design specification, so, is, therefore, not Landloch's preferred approach to landform design.

1.3 Initial modelling approach

1.3.1 Landform considered

Initial simulations using the WEPP model considered the Olympic Dam (OD) TSF batter slopes. For the existing TSF, there is little potential for modification of batter heights and gradients. It is understood that the same batter gradients and heights are planned for any new TSF construction.

Therefore, for a number of reasons, Landloch's initial simulations did not consider any potential for alteration of the TSF batters, but, instead, focussed on ways in which the batter surface may be established or managed to restrict erosion to acceptable levels.

Basic assumptions for the OD TSF batter slopes were:

- 65m high slope with linear profile shape.
- 50% gradient.

WEPP simulations considered rill spacings across the slope of 1 and 5 m. Normally, where slopes are rock-armoured, a rill spacing of 1 m would be used to reflect relatively even spreading of flow due to high surface hydraulic roughness, but in this case, the potential for the batter to be spatially uneven is considered to be of concern, making occasional concentration of overland flow relatively likely, and the 5 m rill spacing was concluded to be a more appropriate simulation of overland flow paths on the batter slopes.

1.3.2 Climate considered

Simulations used the 100-year OD WEPP climate file provided by O'Kane Consultants, which gave an average annual rainfall total of 166mm/y.

1.3.3 Surface modelled

Simulations considered a rock-armoured surface.

It was assumed that the TSF batters will be stabilised by spreading rock over the existing batters, consistent with the treatment applied to some existing batter slopes. As the underlying TSF wall will have been compacted during construction, rates of infiltration into the compacted material will be low. Consequently, Effective Hydraulic Conductivity (K_e) was set to 0.3mm/h, giving a steady infiltration rate of approximately 3mm/h.

The rill detachment parameter (K_R) was set to 0.003, consistent with a compacted cohesive, sandy material. Effectively, this parameter describes the potential rill detachment rate of the underlying batter material if the overlying rock layer is removed by surface flows. Based on material visible in photographs of existing batter slopes, the material particle size distribution input to the model was selected to be consistent with a sandy soil of relatively low clay content.

A range of Critical Shear values was calculated for limestone[1] rock (assuming a specific gravity of 2.45g/cc). Calculations used the Shields equation (Shields 1936), and considered a range of D_{50} values consistent with rock present on the site (as indicated by site photos).

1.3.4 Results of initial simulations

Average annual runoff for the batter slope tested is predicted to be 18.6mm/y. Predicted average and peak erosion rates for 1 and 5m rill spacings and a range of mean rock sizes are shown in Figures 1 and 2.

For the 5 m rill spacing, the predicted rates of average erosion are slightly <5 t/ha/y for a D_{50} of 40mm, and reduce to a very low level for D_{50} of 50 mm. In slight contrast, peak erosion rates reduce to below the "acceptable" level of 10 t/ha/y for D_{50} of 50mm, and reach a very low level for $D_{50} \geq$ 60mm.

---

[1] Limestone rock is known to be available, and it has been assumed that the rock used in armouring surfaces will either be limestone, or a waste rock of similar properties.

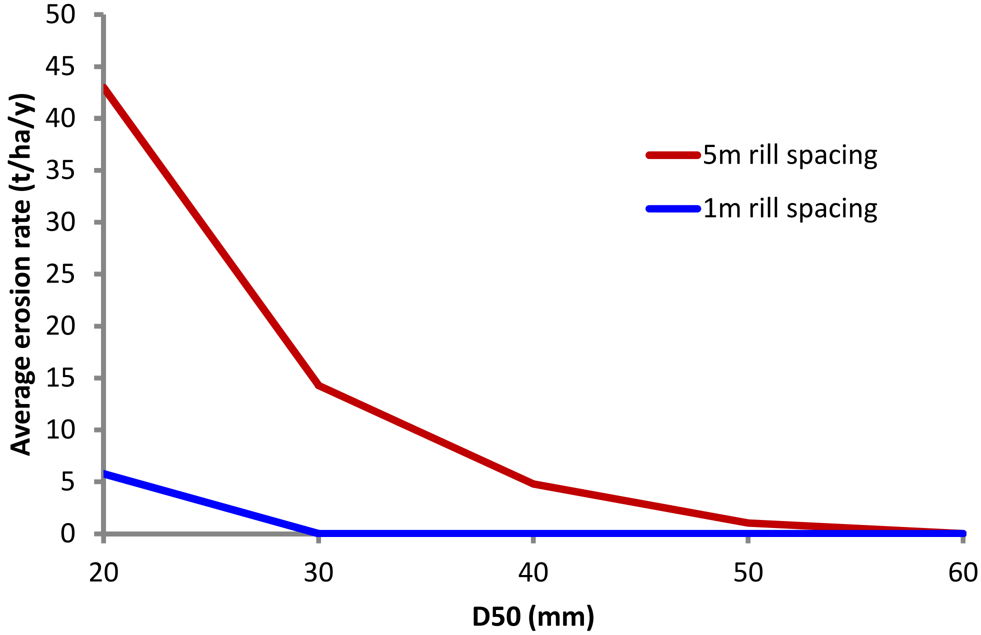


Figure 1: *Predicted impacts of rock D_{50} on* ***average*** *rates of erosion from batters 65m high, 50% gradient.*

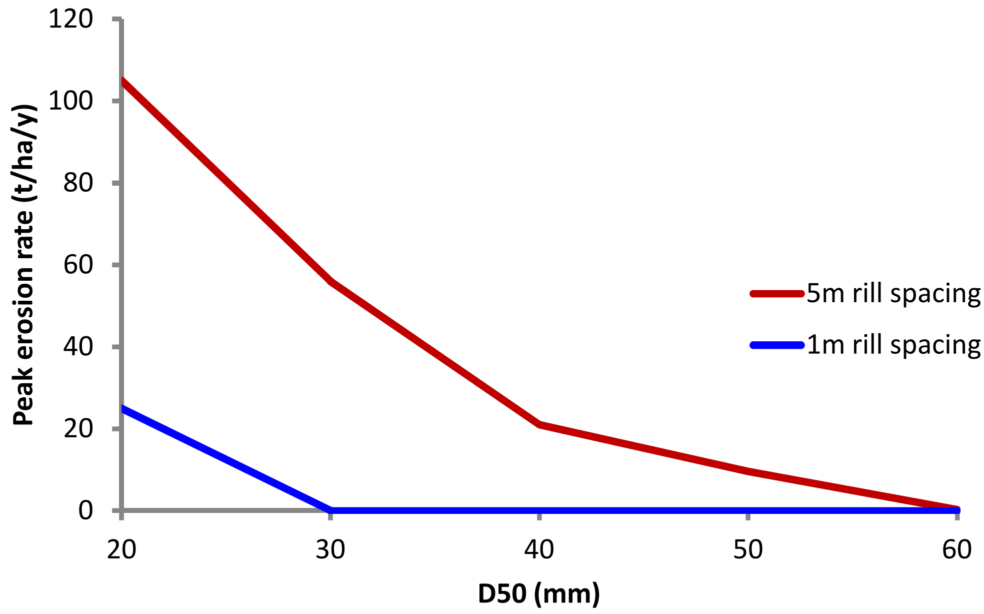


Figure 2: *Predicted impacts of rock D_{50} on* ***peak*** *rates of erosion on batters 65m high, 50% gradient.*

1.4 Consideration of extreme events

1.4.1 Concepts

As the rehabilitated TSF structures are required to remain stable for up to 10,000 years, some consideration was given to ways of developing and ensuring that the design parameters developed are adequate to achieve that stability[2].

For such situations, it is common carry out long-term simulations using a landform evolution model to consider cumulative impacts of long-term changes due to erosion and deposition.

However, in this case, those simulations are likely to be of limited value. Landform evolution models typically runs on an annual time step, with rates of erosion constant from year to year. Therefore, the simulation considers cumulative impacts of surface processes. It does not - importantly - consider the impact of large erosive events of extremely long return periods.

For the TSF landform, the critical issue is the long-term integrity of the surface armour layer of rock. If a large event can breach the armour layer, then the major surface protection mechanism would - effectively - be permanently lost, and the surface would become relatively unstable. This process would happen via lines of concentrated flow, and would expose the underlying fine-textured material in those flow lines, thereby establishing a potential rill and gully network.

Therefore, the more critical question for simulations to consider is:

"what surface conditions are required to achieve stability to large events over 10,000 years?"

To address this question, WEPP simulations were carried out to consider potential erosion by a 1:10,000 storm event.

1.4.2 Rainfall event considered

Simulations used data provided by O'Kane Consultants, who ran the CLIGEN weather generator to produce a 10,000 year climate file, and the largest event in that file was selected for use in the simulations.

1.4.3 Surface erodibility characteristics considered

The surface considered was:

- a rock armour layer of 300-500 mm thickness;
- critical shear based on D_{50} of the rock;

---

[2] It should be noted, however, that neither simulations nor designs can realistically consider, or cater for, the full range of possible events or changes that may occur on a site over such a long period. Rather, the process generates designs that have a high probability of remaining stable for that period when subject to known environmental stresses and process.

- rill detachment parameter set to either a low value consistent with the rock layer (more realistic option); or
- rill detachment parameter set consistent with the underlying fine-textured material; and
- hydraulic conductivity set low, consistent with the underlying compacted fine-textured material.

Rill spacing of 1 m and 5 m were considered.

1.4.4 Interpretation of erosion predictions

What constitutes stability? In this case, it would be essential that flow in some relatively narrow flow line did not incise completely through the armour layer. If it is expected that rill lines (on 5 m spacing) may be up to 0.33 m wide, then rills could occupy approximately 7% of the total surface. If a depth of incision of 100 mm was considered the maximum acceptable depth of incision in a flow line, then that is equivalent to erosion of 91 t/ha averaged over the complete surface.

For a margin of safety, an acceptable erosion rate for the single extreme event has been set at 50 t/ha.

2. Predicted erosion for 1:10,000 year storm

2.1 Critical shear and rock armour size

For the 5 metre rill spading, predictions (Figure 3) show the "acceptable" rate of erosion being reached at a critical shear of 80 Pa when the K_R value consistent with rock is considered. This is considered the most realistic representation of the surface layer behaviour.

For the 1 metre rill spacing, predictions (Figure 4) show lower critical shear values required to achieve stability, with the lowest value of 60 Pa being more than adequate to control erosion when the rock K_R is used, and a value of approximately 75Pa being needed when the soil K_R value is adopted.

The simulations show that there are - in terms of erosion control - significant potential benefits from precision shaping of the TSF outer batters to reduce potential for flow concentration so that the 1 m rill spacing could be considered a realistic representation of flow pathways. The cost and difficulty of providing rock with larger D_{50} values (to achieve higher critical shear values) are not known, but it could be assumed that an increase in D_{50} may also result in an increase in the depth of rock layer (and total amount of rock) that may need to be applied to the TSF batter slopes. (The cost of additional rock may make more precise batter shaping economically worthwhile, but that analysis is considerably outside the scope of this study.)

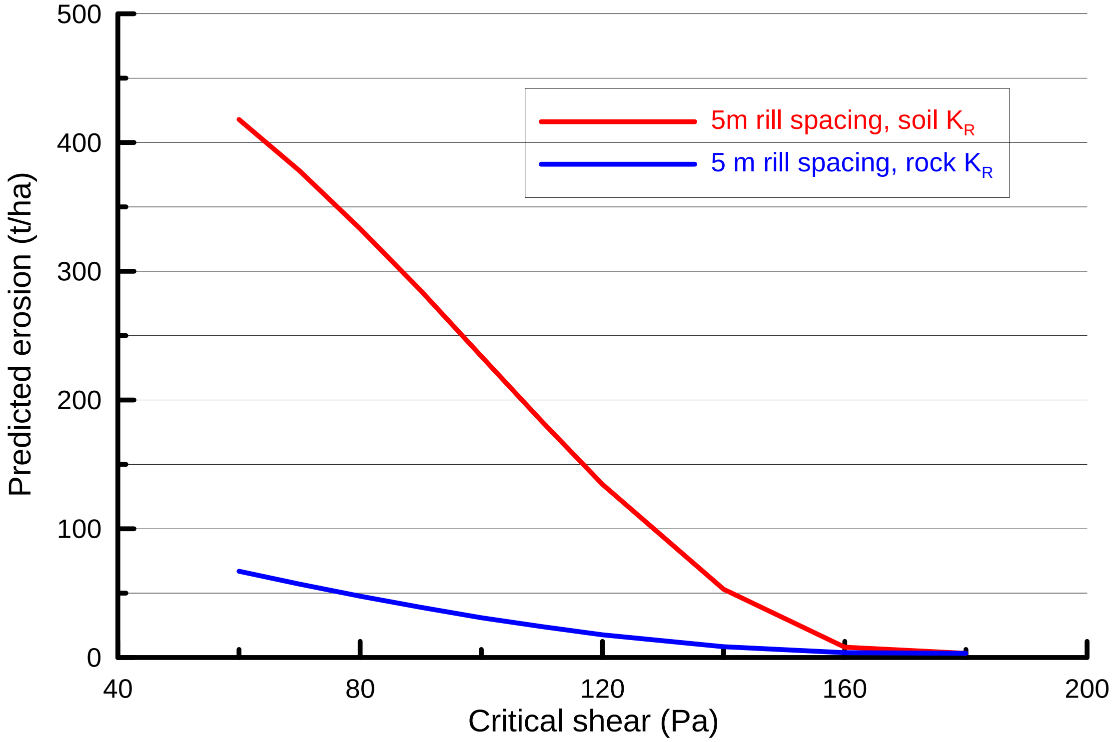


Figure 3: *Predicted impacts of critical shear on erosion predicted for a 1:10,000 year storm, 5 m rill spacing.*

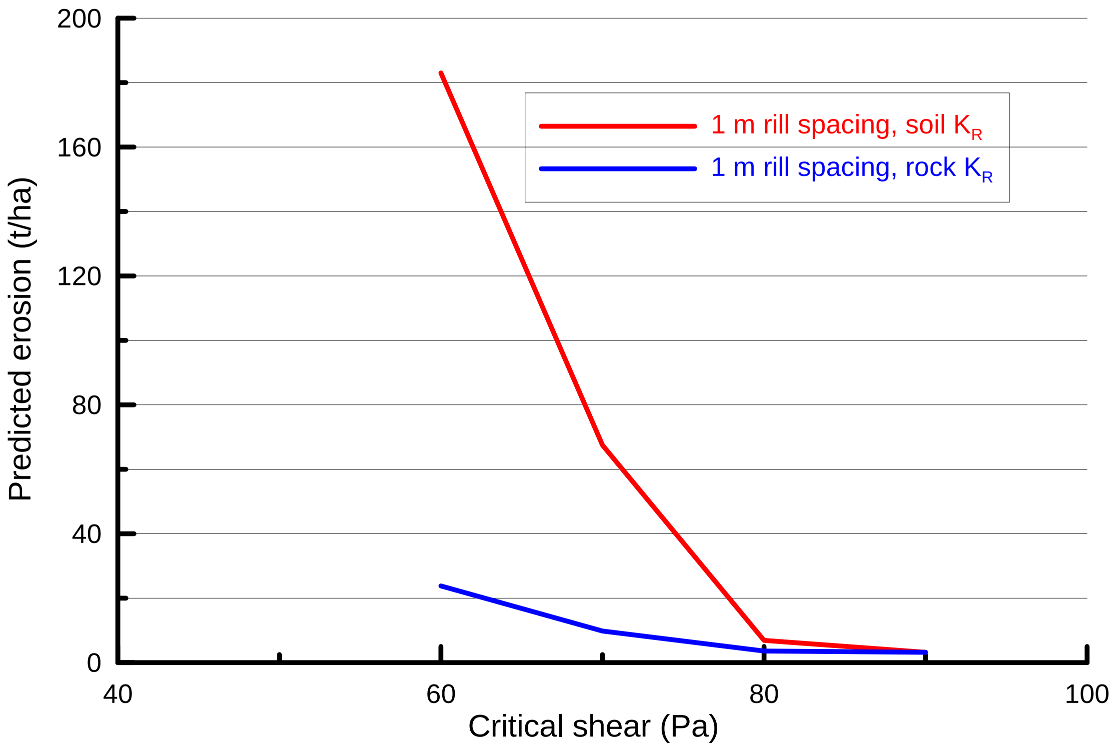


Figure 4: *Predicted impacts of critical shear on erosion predicted for a 1:10,000 year storm, 1 m rill spacing.*

From the data, it appears that a critical shear of approximately 80 Pa will be needed to provide confidence in the stability of TSF batter slopes over a 10,000 year period.

From the relationship between D_{50} and critical shear (Figure 5), this indicates that a rock D_{50} of approximately 125 mm will be required.

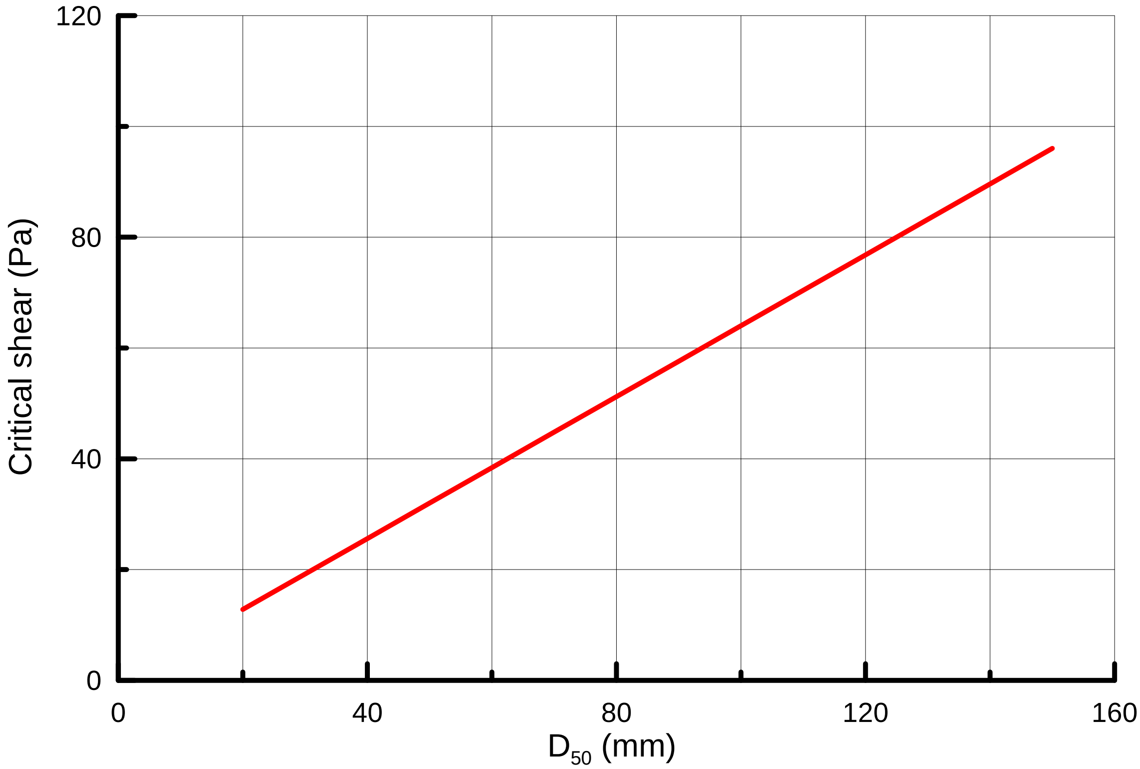


Figure 5: *Relationship between rock D50 and critical shear, for assumed rock specific gravity of 2.45 g/cc.*

2.2 Impacts of batter gradient

Simulations were carried out to consider impacts of changes in slope gradient. For failure of the rock armour layer, gradient had relatively little impact. For example, when batter gradient was reduced from 50% to 33.3%, the critical shear needed to produce an acceptable rate of erosion (for 5m rill spacing and rock K_R) reduced from 80 Pa to 74Pa.

This is consistent with other studies, which have generally found that the reduction in flow shear stress due to a reduction in gradient is largely balanced by the resultant increase in slope length and in (associated) flow discharges.

Because slope stability is relatively insensitive to batter gradient for these specific conditions, consideration of reductions in batter gradient to achieve batter stability is not recommended.

3. References

Flanagan, D. C., and Livingston, S. J. (1995). WEPP user summary. NSERL Report No 11, USDA-ARS-MWA.

Shields, A. (1936). Anwendung der Aenlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung, Mitteilungen der Preussischen Versuchsanstalt fur Wasserbau und Schiffbau, Berlin, Germany, translated to English by W.P.Ott and J.C. van Uchelen,California Institute of Technology, Pasadena, Calif.

APPENDIX D

TSF Closure Slope Stability Assessment

BHP Billiton Olympic Dam

Tailings Storage Facility
Cover System and Landform Design 2013

Appendix D:

TSF Closure Slope Stability Assessment

Report No. 809/5-01

Prepared for:

bhpbilliton
resourcing the future

Prepared by:

O'Kane
Consultants Pty Ltd
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

May 2013

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

D1 INTRODUCTION

O'Kane Consultants Pty Ltd. (OKC) completed slope stability analyses for the preferred closure design for the Olympic Dam Expansion Project (ODP) Tailings Storage Facility (TSF). Slope stability analyses verify that the preferred closure cover and landform design will result in acceptable slope stability factors of safety post-closure.

This appendix summarises the methodology used to conduct slope stability analyses and modelled results. Numerical modelling was carried out using the commercial software SLOPE/W (GEO-SLOPE, 2012a). The results of the stability analyses enhance the judgment associated with closure decisions.

D1.1 Objective and Approach

Slope stability analyses are required as part of the TSF closure cover design in order to verify that the preferred closure cover and landform design is safe enough with regard to post-closure landform slope.

Slope stability analyses were completed for the expanded TSF as part of the ODP Draft and Supplementary EISs. These analyses were in support of the proposed design and operation of the new TSF cells. The approach used for the post-closure slope stability analysis would follow that used in the EIS study for TSF operations. Pore-water pressure conditions input to the model came from seepage analyses for the preferred closure scenarios. Shear strength parameters were derived based on historical investigations and available test data.

D1.2 Organisation of Appendix

Section 2 of this appendix provides an overview of the numerical models that were used in the analysis, a description of the modelling methodology, and a description of model inputs. Results of the analysis are presented in Section 3. A list of references is provided in Section 4.

D2 MODEL DEVELOPMENT

D2.1 Model Description and Inputs

The commercial numerical software SLOPE/W (Geo-Slope, 2012a) is one component in a complete suite of finite element modelling software GeoStudio developed by Geo-Slope International Ltd.. Slope stability analyses were completed for both TSF operations and post-closure scenarios to assess geotechnical stability of various embankment configurations. SLOPE/W was used to conduct two-dimensional limiting equilibrium analyses using the limit equilibrium (Morgenstern-Price) method with a circular slip surface. The program incorporates a search routine to locate those failure surfaces with the least factor of safety (FoS) within user-defined search limits. Trial failure surfaces were defined with ‘entry and exit’ or ‘specified blocks’ parameters, resulting in a range of possible locations within which the most critical (lowest FoS) potential failure surface may be found. Calculated FoS values were then compared to the minimum required values reported in Australian Guidelines on Tailings Dams – Planning, Design, Construction, Operation and Closure (ANCOLD, 2012).

Analyses were carried out for static loading conditions and post-seismic conditions immediately following the Maximum Design Earthquake (MDE) event. The phreatic surface and pore-water conditions in the modelling domain for operations were obtained from SEEP/W (Geo-Slope, 2012b) analyses, which is similar to the results presented in ODP Supplementary EIS (ODP, 2011). The phreatic surface was set at the tailings base to represent long-term pore-water pressure conditions for post-closure scenarios. In general, the phreatic surface can drain down to the tailings base in a relatively short time (less than 20 years) when the rockfill embankment toe is allowed to drain.

D2.2 Material Properties

Table D2.1 presents shear strength parameters used for slope stability analyses. All parameters are based on information provided in the ODP Draft and Supplementary EISs except for parameters for the cover material and rock armour, which were estimated by experience. Table D2.1 includes cohesion, friction angle, and unit weight parameters for each material type used in the stability modelling.

Table D2.1
Summary of shear strength parameters for various materials used in SLOPE/W.

Material	Cohesion (c’) (kPa)	Friction angle (φ’)	Unit Weight (kN/m^3)
Foundation - Limestone	20	37	21
Foundation - Sediments	5	25	20
Rockfill	0	37	20
Deposited Tailings	0	25	21
Cover Material	0	32	21
Armoured Rock	0	37	21

D2.3 Seismic Load

The peak ground acceleration values for return periods of 475 years, 1,000 years and 10,000 years are 0.022 g, 0.032 g, and 0.10 g respectively (ODP, 2011). The seismic coefficient used in a pseudostatic analysis is generally taken as 50% of the peak ground acceleration (Duncan and Wright, 2005). However, a seismic coefficient of 0.10 g was used in the pseudostatic stability analysis in this report in order to be consistent with the seismic coefficient used in the stability analysis in the Supplementary EIS. Furthermore, a pseudostatic analysis using a seismic coefficient of 100% of the peak ground acceleration, for a return period of 10,000 years, of 0.10 g will result in a conservative FoS when compared to ANCOLD Tailings Guidelines.

D2.4 Geometry and Modelling Scenarios

The modelling domain has a foundation area of 1,100 m (length) x 50 m (height) and a TSF area of 1,000 m (length) x 65 m (height). Table D2.2 lists all modelling scenarios. A slope of 2H:1V was kept unchanged in all modelling cases for the rockfill embankment and the overlying armoured layer. For post-closure conditions, two meters of soil cover material is placed on top of tailings, while there is no soil cover placement for operations conditions.

Table D2.2
Modelling Scenarios in the stability analyses.

Scenarios No.	Foundation Material	Slope Material and Configuration
#1	Limestone	Rockfill embankment without cover, slope 2H:1V
#2	Limestone	Rockfill embankment with 0.4 m thick armoured layer (rockfill), slope 2H:1V
#3	Limestone	Rockfill embankment with 0.4 m thick armoured layer (armoured rock), slope 2H:1V
#4	Sediments	Rockfill embankment with 0.4 m thick armoured layer (armoured rock), slope 2H:1V
#5	Sediments (reduced thickness)	Rockfill embankment with 0.4 m thick armoured layer (armoured rock), slope 2H:1V

D3 MODELLING RESULTS AND RECOMMENDATIONS

Table D3.1 presents the modelling results of FoS's. All FoS values shown in Table D3.1 are greater than the minimum FoS required with the exception of Scenario #4 with post-closure static loading that has a FoS = 1.43 < 1.5. However, this lower FoS is considered to be within the range of accuracy due to the inherent uncertainties associated with both the estimated model parameters and geometry. Furthermore, this situation only occurs when the foundation sediments is relatively thick (larger than 10 m). The modelling result indicated that a FoS=1.54 > 1.5 when the foundation sediments is only 10 m thick, which is consistent with the FoS presented in the Supplementary EIS (ODP, 2011). The calculated FoS post-closure is almost the same as FoS under operation conditions because the critical failure surface during operations does not pass beyond the phreatic surface in the tailings deposits. Due to minimal change in material properties of the rockfill material and armoured rock, the factor of safety remains consistent between both material types.

Table D3.1
Slope stability analysis results – 65 m high centre-line rockfill embankment.

Modelling Scenario	Loading Condition	Calculated FoS	Minimum Required FoS*
#1	Static loading - Operations	1.59	1.3
#1	Static loading – Post-closure	1.59	1.5
#1	Pseudostatic - Operations	1.25	1.0
#1	Pseudostatic – Post-closure	1.25	1.1
#2	Static loading - Operations	1.59	1.3
#2	Static loading – Post-closure	1.55	1.5
#2	Pseudostatic - Operations	1.25	1.0
#2	Pseudostatic – Post-closure	1.22	1.1
#3	Static loading - Operations	1.59	1.3
#3	Static loading – Post-closure	1.55	1.5
#3	Pseudostatic - Operations	1.25	1.0
#3	Pseudostatic – Post-closure	1.22	1.1
#4	Static loading - Operations	1.41	1.3
#4	Static loading – Post-closure	1.43	1.5
#4	Pseudostatic - Operations	1.09	1.0
#4	Pseudostatic – Post-closure	1.11	1.1
#5	Static loading - Operations	1.56	1.3
#5	Static loading – Post-closure	1.54	1.5
#5	Pseudostatic - Operations	1.20	1.0
#5	Pseudostatic – Post-closure	1.20	1.1

Stability analyses for the proposed 65 m high rockfill embankment tailings storage facility cells are presented in Figures D3.1 – D3.3 for Scenarios #3 - #5. Scenarios #1 and #2 are not presented as they have similar critical failure surface to Scenario #3. The stability analyses indicate that the proposed cover system and landform design is stable when the slope is 2H:1V (26.6°). Since the rockfill and armoured rock material have a friction of 37°, surface failure will be not a concern on the slope of 26.6° (i.e. 2H:1V).

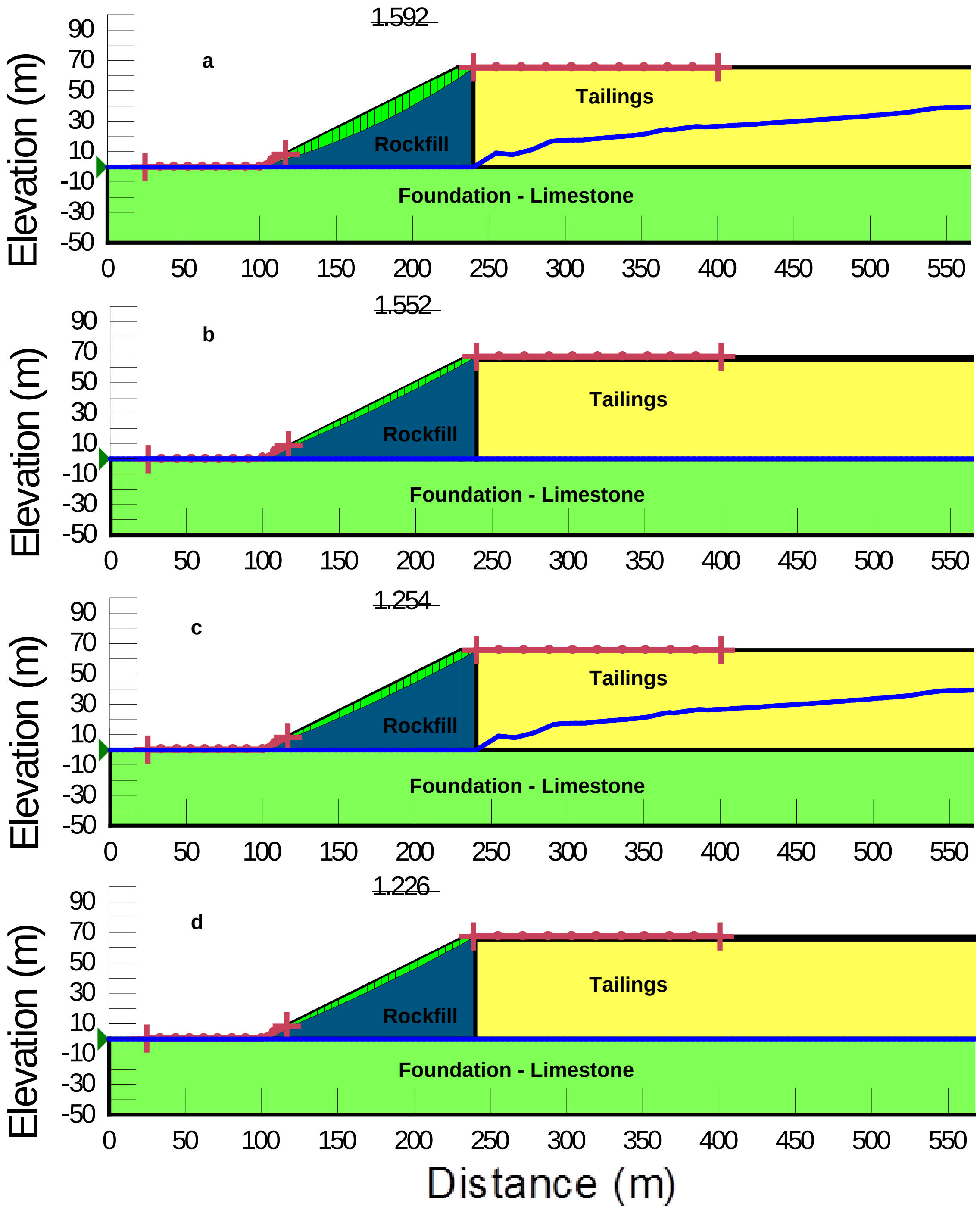


Figure D3.1 Stability analyses for Scenario #3 (Rockfill embankment with 0.4 m thick armoured rock layer overlying thick limestone foundation). a:static loading – operations; b:static loading – post-closure; c:pseudostatic – operations; d:pseudostatic – post-closure.

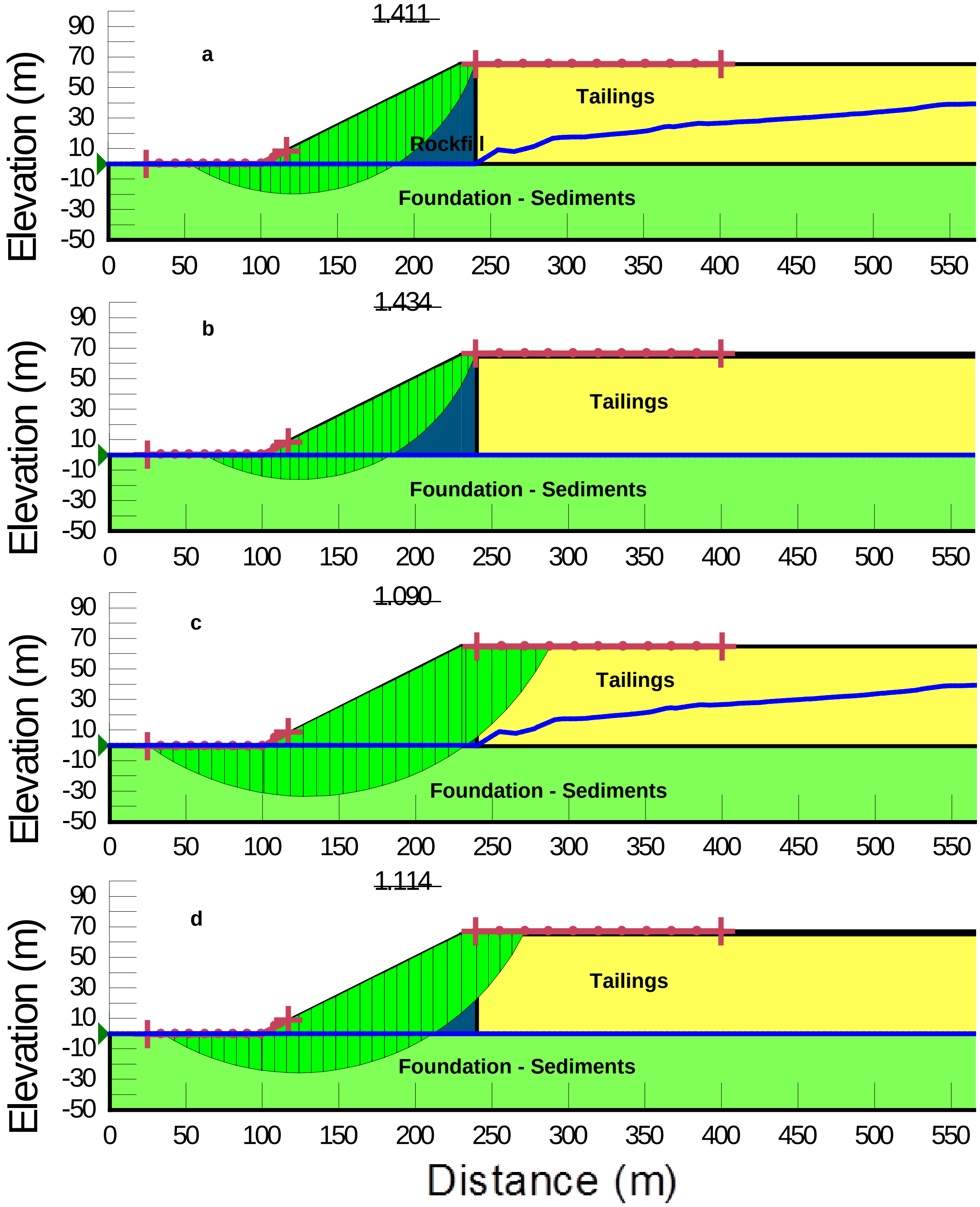


Figure D3.2 Stability analyses for Scenario #4 (Rockfill embankment with 0.4 m thick armoured rock layer overlying thick sediments foundation). a:static loading – operations; b:static loading – post-closure; c:pseudostatic – operations; d:pseudostatic – post-closure.

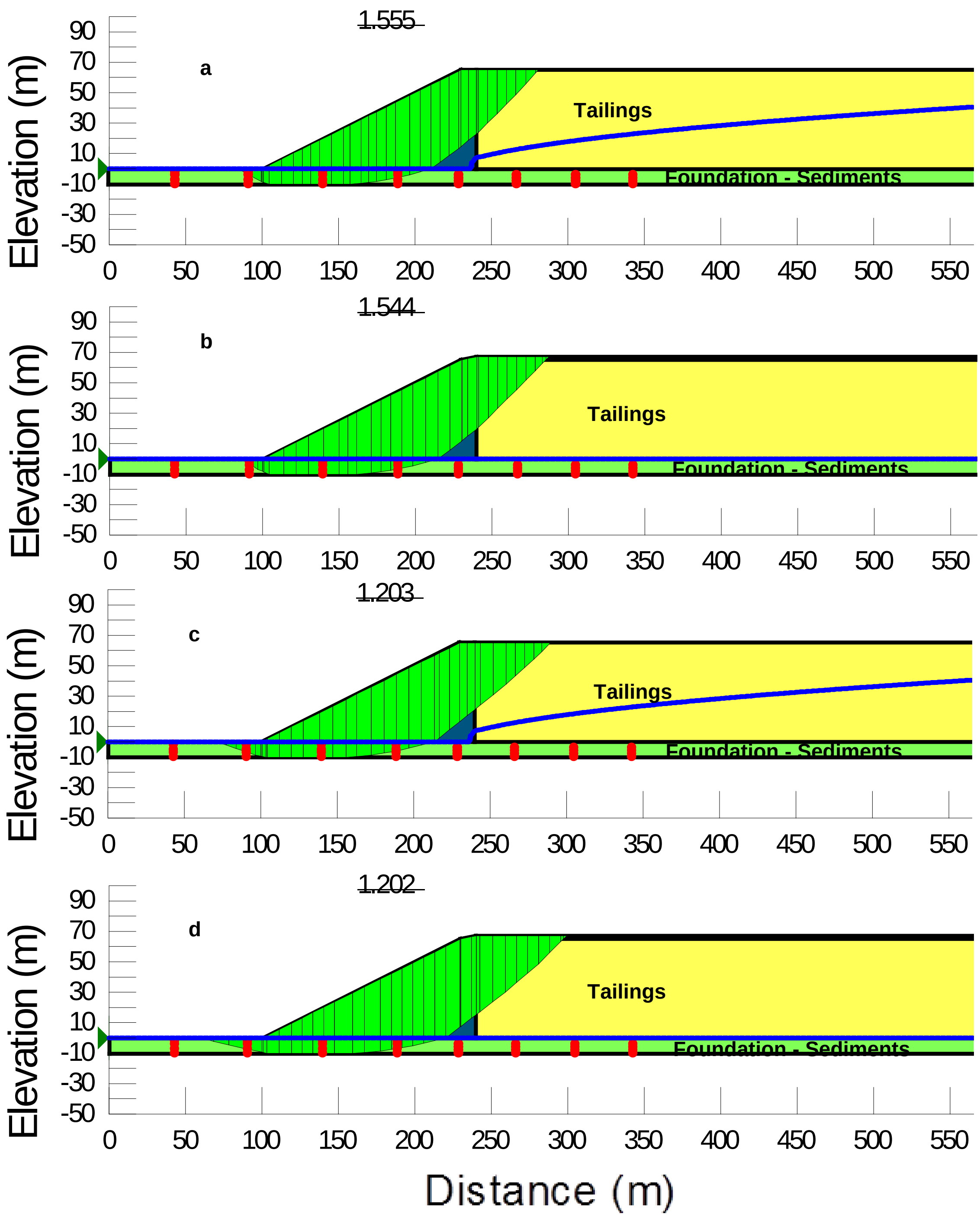


Figure D3.3 Stability analyses for Scenario #5 (Rockfill embankment with 0.4 m thick armoured rock layer overlying thin sediments foundation). a:static loading – operations; b:static loading – post-closure; c:pseudostatic – operations; d:pseudostatic – post-closure.

The above slope stability analyses indicate that a slope of 2H:1V along the rockfill embankment with an armoured layer of 0.3 – 0.5 m is adequate to maintain a FoS greater than minimum required FoS. However, it is recommended that TSFs should be built on hard foundation (i.e. limestone). If TSFs have to be built on sediments foundation, thickness of the sediments foundation should be controlled less than 10 m. These measures will reduce risk of TSF failure due to slope instability. It is also recommended that shear strength parameters of the proposed cover material and armoured layer material be tested and the post-closure slope stability analyses should be re-analysed upon the tested shear strength parameters of the cover material and armour material available.

D4 REFERENCES

Australian National Committee on Large Dams (ANCOLD). 2012. Guidelines on tailings dam planning, design, construction, operation and closure.

BHP Billiton 2011. Olympic Dam Expansion Supplementary Environmental Impact Statement 2011, Section 5.3 Tailings Storage Facility, pp 129-139.

Duncan, J.M. and Wright, S. 2005. Soil strength and slope stability. John Wiley & Sons, Inc., Hoboken, New Jersey.

Geo-Slope 2012a. Stability modelling with SLOPE/W – An Engineering Methodology. July 2012 Edition. GEO-SLOPE International Ltd., Calgary, Alberta.

Geo-Slope 2012b. Seepage modelling with SEEP/W – An Engineering Methodology. July 2012 Edition. GEO-SLOPE International Ltd., Calgary, Alberta.

APPENDIX E

Failure Modes and Effects Analysis Tables

FMEA Worksheet - BHP-B Olympic Dam TSF Proposed Cover System and Landform Design - 14 February 2013 DRAFT

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences: Environmental Impact	Consequences: Special Considerations	Consequences: Legal and Other Obligations	Consequences: Consequence Costs	Consequences: Community / Media / Reputation	Consequences: Human Health and Safety	Level of Confidence	Highest Risk Rating	Mitigation / Comments
1	Differential settlement in tailings mass.	Development of cracks in cover leads to net percolation rates above 1% criterion, which in turn leads to contaminant plume exiting lease boundary.	L	Mi	Mi	Mi	Mo	Mi	L	H	Moderate	Tailings must be dewatered sufficiently prior to cover construction. K **eep central decant operational during cover construction to remove expelled pore-waters. Need to develop an appropriate construction plan that takes into account areas of low-strength. Complete a geotechnical stability assessment before cover construction. Consider measuring undrained shear strength of tailings prior to construction.**
2	Differential settlement in tailings mass.	Disruption to surface water management system leads to net percolation rates above 1% criterion, which in turn leads to contaminant plume exiting lease boundary.	M	L	L	L	L	L	L	H	Low	Tailings must be dewatered sufficiently prior to cover construction. K **eep central decant operational during cover construction to remove expelled pore-waters. Need to develop an appropriate construction plan that takes into account areas of low-strength. Complete a getechnical stability assessment before cover construction. Consider measuring undrained shear strength of tailings prior to construction.**
3	Differential settlement in tailings mass.	Disruption to surface water management causes greater erosion (gullying) and exposure of tailings (possible radon gas emissions, radiation exposure, and surface water contamination).	L	Mo	Mo	Mo	Mo	Mo	Mi	H	Moderate	Tailings must be dewatered sufficiently prior to cover construction. K **eep central decant operational during cover construction to remove expelled pore-waters. Need to develop an appropriate construction plan that takes into account areas of low-strength. Consider measuring undrained shear strength of tailings prior to construction.**
4	Improper infilling / compaction of contaminated waste disposed of in tailings mass.	Damage to integrity of cover system leading to preferential flowpaths, increased net percolation and basal seepage.	L	L	L	L	L	L	h	H	Low	Must follow appropriate procedures during waste placement, including compaction and filling voids with sand-like material. Cut up large waste items prior to disposal.
5	Earthquake/seismic event - relatively minor.	Minor differential settlement of cover system and minor slumping in outer embankment slope, but no exposure of tailings.	M	L	L	L	Mi	L	L	M	Moderate	Ensure final landform is stable against the design earthquake event. Routine monitoring / site inspections post-closure recommended.
6	Earthquake/seismic event - relatively major.	Failure of outer embankment resulting in release of tailings to the environment.	NL	C	M	C	C	C	Mi	H	Mod. High	Ensure final landform is stable against the design earthquake event. Routine monitoring / site inspections post-closure recommended.
7	Slope failure of TSF embankments due to increased pore-water pressure conditions.	Slumping of embankment material leads to exposure of tailings and radiation exposure.	L	L	L	L	Mi	L	L	H	Low	Ensure closure landform design meets the specified geotechnical stability criteria. Include slope stability monitoring as part of post-closure monitoring program.
8	Chronic wet/dry cycling of cover profile.	Development of cracks in cover leads to net percolation rates above 1% criterion, which in turn leads to contaminant plume exiting lease boundary.	NL	Mi	Mi	Mi	Mo	Mi	L	H	Low	Very low probability of this failure mode having a significant effect on cover performance given the cover material (well-graded ROM overburden waste) and cover thickness (minimum 1 m).
9	Chronic wet/dry cycling of cover profile.	Capillary rise of salts, metals, and/or radionuclides that leads to contamination of water that seasonally ponds in centre of cover system.	L	Mi	Mi	Mo	Mi	Mo	Mi	H	Moderate	Critical that cover material is placed only after upper tailings have been adequately dewatered. Critical that cover thickness in central decant area is at least 1.0 m thick; 1.5 m of cover material would be better. Collect and analyse quality of water that seasonally collects on cover system.
10	Growth of deep-rooted vegetation (to base of cover).	Roots form macropores and increase the hydraulic conductivity of the cover material, leading to increased net percolation and increased contaminant loading.	E	L	L	L	L	L	L	H	Moderate	Vegetation will volunteerly develop over the 1,000 yr assessment period. Vegetation could actually improve cover performance by increasing AET rates. Inclusion of rock mulch layer should not be considered as it will reduce evaporation from surface, which will increase net percolation. Removal of established vegetation on TSF cover will be required indefinitely.

FMEA Worksheet - BHP-B Olympic Dam TSF Proposed Cover System and Landform Design - 14 February 2013 DRAFT

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences: Environmental Impact	Special Considerations	Legal and Other Obligations	Consequence Costs	Community / Media / Reputation	Human Health and Safety	Level of Confidence	Highest Risk Rating	Mitigation / Comments
11	Growth of deep-rooted vegetation (into tailings).	Uptake of metals and/or radionuclides by vegetation, which is then ingested by local fauna.	E	L	L	L	L	L	L	H	Moderate	Vegetation will volunteerly develop over the 1,000 yr assessment period. Vegetation could actually improve cover performance by increasing AET rates. Inclusion of rock mulch layer should not be considered as it will reduce evaporation from surface, which will increase net percolation. Removal of established vegetation on TSF cover will be required indefinitely.
12	Inadequate QA/QC program for cover construction and/or inexperienced personnel supervising construction.	Possible effects include cover placement on wet tailings, cover profile too thin, use of cover material not meeting gradation specs - results in cover system not meeting 1% net percolation criterion.	M	M	Mi	Mi	M	M	Mi	H	High	Critical to develop appropriate specifications for construction and design an appropriate construction QA/QC program. Must have experienced / qualified personnel supervising construction.
13	Insufficient volume of design size material for outer embankment closure surface treatment.	Presuming smaller size material is used, this results in erosion gullying, and localized failure of outer embankment.	L	Mo	Mi	Mo	Mo	Mo	L	M	Mod. High	Mine Planning needs to be informed of gradation specs and volumes of materials required for TSF closure. Flatten embankment slopes if design material is unavailable.
14	Insufficient site-specific cover and/or outer embankment material characterisation to complete appropriate design preconstruction.	Change in design needed to achieve specified closure criteria.	L	L	L	L	C	L	L	H	Mod. High	Mine Planning needs to be informed of gradation specs and volumes of materials required for TSF closure. Run additional numerical analyses for cover system if gradation of ROM waste changes. Flatten embankment slopes if design material is unavailable.
15	Cover system constructability.	Additional cost to overcome trafficability issues or difficult access for cover material extraction.	H	L	L	L	M	L	L	H	High	Tailings must be adequately dewatered prior to cover construction. Include a contingency in the TSF closure capital cost for possible hiccups in construction. Implement a detailed material characterisation plan as ROM waste overburden material is generated.
16	ROM waste overburden segregates upon placement.	Preferential flowpaths in cover profile lead to greater net percolation and thus basal seepage rates. Also potential for radon gas transport through macropores.	H	Mi	Mi	Mi	C	Mi	L	H	Critical	Implement a detailed material characterisation plan as ROM material is generated. Limit cover material lift thickness to 1 m. If segregated zones are identified during construction, then implement additional measures to mix placed cover material.
17	Bearing capacity in tailings is not sufficiently high to allow proper cover placement.	Loss of cover material into tailings, requiring additional time and material to construct.	M	L	L	L	Mo	L	L	H	Mod. High	Tailings must be dewatered sufficiently prior to cover construction. K **eep central decant operational during cover construction to remove expelled pore-waters. Need to develop an appropriate construction plan that takes into account areas of low-strength. Consider measuring undrained shear strength of tailings prior to construction.**
19	Over-compaction of upper cover profile in some areas due to repeated equipment passes.	Results in higher runoff volumes to seasonal water collection area, which leads to higher net percolation and basal seepage volumes.	H	L	L	L	Mi	L	L	H	Moderate	Heavily trafficked areas need to be ripped. Develop an appropriate material placement plan including delineated haul truck routes.
20	Surface water management system pathways are not sufficiently meandering.	Erosion of cover material leads to creation of gullies within the cover and eventually leads to exposure of tailings.	L	Mi	Mi	Mo	Mo	Mo	Mi	H	Moderate	Critical to have a robust surface water management system design. Routine site inspections post-closure are recommended.

FMEA Worksheet - BHP-B Olympic Dam TSF Proposed Cover System and Landform Design - 14 February 2013 DRAFT

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences						Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact	Special Considerations	Legal and Other Obligations	Consequence Costs	Community / Media / Reputation	Human Health and Safety			
21	Blockage of surface water drainage channels due to sedimentation.	Surface runoff waters concentrate in a few areas leading to increased erosion.	H	L	L	L	Mi	L	L	H	Moderate	Some minor earthworks / repairs of the cover system may be required in first 10 years post-closure, until cover surface stabilises. Selective placement of erosion protection measures as required.
22	Overtopping of embankment crests during an extreme wet period.	Leads to erosion, gullying and instability of outer embankment slopes.	L	M	M	Mo	M	M	Mi	M	Mod. High	Include a perimeter bund with spillway and freeboard allowance in the closure landform design to account for 1:1,000 year design storm event. Spillway do drain into drainage channel (Access roadways) to natural ground.
23	Development of a semi-permanent central pond on the TSF cover system.	Increased seepage in pond leads to increased basal seepage and results in contaminant loading beyond limits.	M	Mi	Mi	Mi	Mi	Mi	L	M	Moderate	Routine site inspections post-closure are recommended. If evaporation alone does not remove ponded water after 1 year, then use pumps to remove water.
24	Seasonal water collection area in centre of reclaimed TSF attracts vegetation and wildlife.	Pond acts as a sink to incoming organics, creating a vegetation habitat and attracting wildlife.	E	L	L	L	L	L	L	H	Moderate	A small pond will temporarily form in the centre of the closure landform following extreme wet periods. If vegetation is not allowed on the TSF cover, then it will need to be removed as part of post-closure maintenance.
25	Climate change leads to higher rainfall than predicted by current models.	Erosion of surface water management system leads to development of rills and gullies in cover leading to exposure of tailings.	L	Mi	Mi	Mo	Mo	Mo	Mi	M	Moderate	Proposed closure cover system and landform design is robust enough to mitigate potential effects of this failure mode.
26	Climate change leads to higher rainfall than predicted by current models.	Increased net percolation leads to increased basal seepage and results in contaminant loading beyond limits.	L	Mi	Mi	Mi	Mi	Mi	L	M	Low	Proposed closure cover system and landform design is robust enough to mitigate potential effects of this failure mode.
27	Climate change leads to higher rainfall than predicted by current models.	Overtopping of the embankment crests leads to erosion, gullying and instability of outer slopes	L	M	M	Mo	M	M	Mi	M	Mod. High	Include a freeboard allowance in the closure landform design to account for climate change-affected 1:1,000 year design storm event.
28	Chronic wind erosion of cover surface / loss of sediments to surrounding landscape.	Decreased air quality due to particulates and detrimental effects on local flora.	E	Mi	L	Mi	Mi	Mi	L	H	Mod. High	Although this failure mode is expected, the consequences to the local ecosystem should not be significant.

FMEA Worksheet - BHP-B Olympic Dam TSF Proposed Cover System and Landform Design - 14 February 2013 DRAFT

Failure Mode ID	Failure Mode Description	Effects and Pathways	Likelihood	Consequences						Level of Confidence	Highest Risk Rating	Mitigation / Comments
				Environmental Impact	Special Considerations	Legal and Other Obligations	Consequence Costs	Community / Media / Reputation	Human Health and Safety			
29	Animal activity on surface of landform (burrowing animals or termites).	Holes or macropores created in the cover, which leads to increased net percolation and contaminant loading.	L	L	L	L	L	L	L	M	Low	Very low probability of this failure mode having a significant effect on cover performance given the cover material (ROM overburden waste - lacks carbon and nutrients) and cover thickness (minimum 1 m). Post-closure site inspections of TSF cover are recommended.
30	Animal activity on surface of landform (burrowing animals or termites).	Animal activity brings tailings to the surface or exposes tailings through large holes—potential for radiation exposure/ingestion of tailings.	L	L	Mi	L	L	Mi	L	M	Low	Very low probability of this failure mode having a significant effect on cover performance given the cover material (ROM overburden waste - lacks carbon and nutrients) and cover thickness (minimum 1 m). Post-closure site inspections of TSF cover are recommended.
31	Anthropogenic activities that result in holes in the cover system.	Results in higher net percolation rates and/or radiation exposure such that cover system does not meet performance criteria.	M	Mi	L	Mi	L	Mi	Mo	M	Mod. High	Erect fences and signs once rehabilitation of the TSF cells is complete. Routine site inspections post-closure are recommended.
32	Generation and release of hazardous gases.	Lethal gases or lack of oxygen emanating from facility resulting in risk to humans and wildlife.	NL	L	M	Mo	Mo	M	C	H	Mod. High	Tailings are of sufficiently low permeability and embankment walls sufficiently thick to limit TSF respiration and generation of gases above safe levels. Signage and fencing recommended.

APPENDIX F

Drawings

PROPOSED LOCATION OF TSF COVER TRIAL
1:15000

112.5 0 225 450m
SCALE 1:15000

CLIENT/PROJECT:
bhpbilliton
resourcing the future

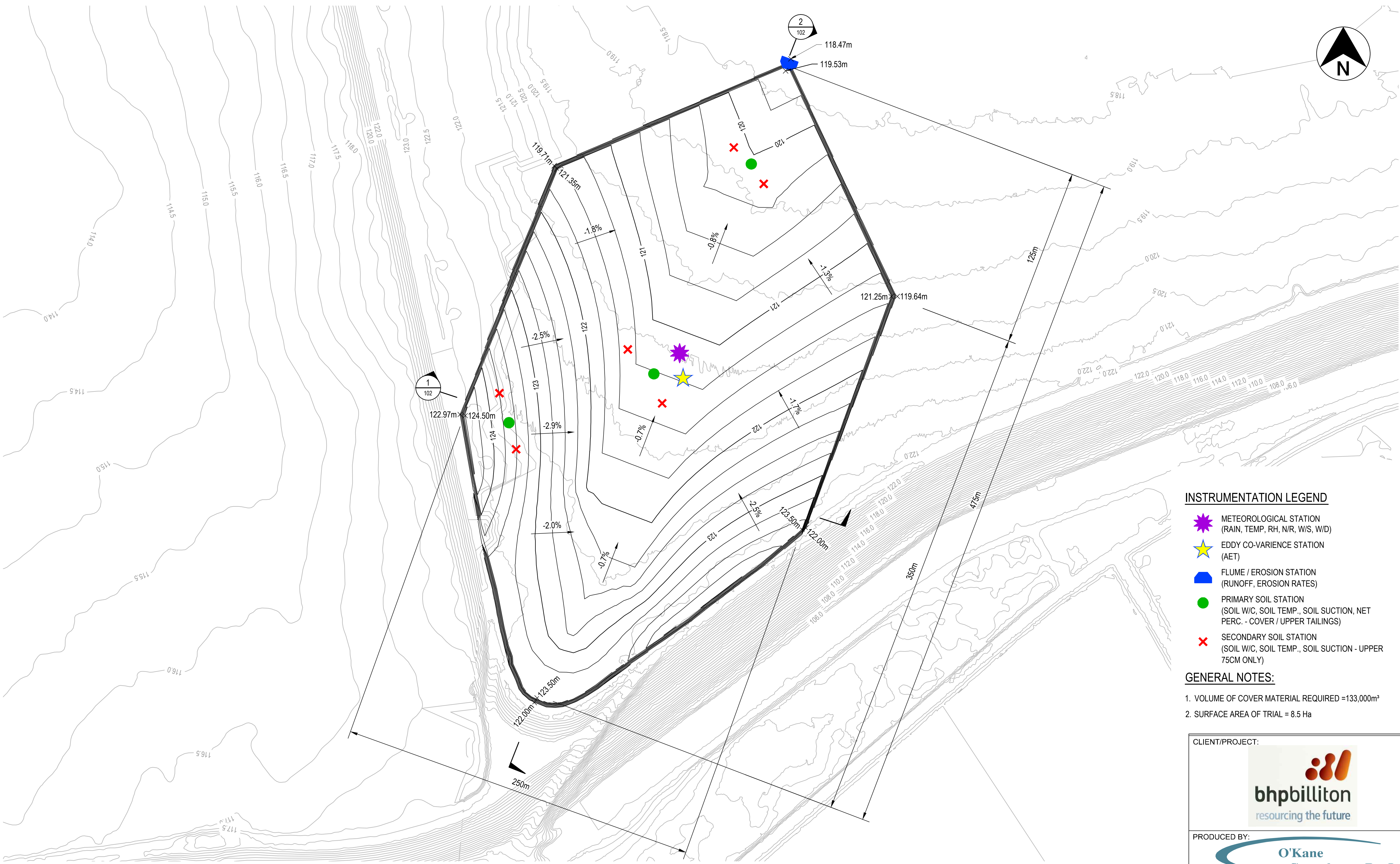
PRODUCED BY:
O'Kane Consultants Pty Ltd.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

DRN. BY:	S. WALKER	DATE:	31.01.13
APPD. BY:	B. AYRES	DATE:	31.01.13
SCALE:	AS SHOWN	REPORT NUM:	809/5

PROPOSED LOCATION OF TSF COVER TRIAL

DRG NUM: 809-5-100 Rev: 0



INSTRUMENTATION LEGEND

- METEOROLOGICAL STATION (RAIN, TEMP, RH, N/R, W/S, W/D)
- EDDY CO-VARIENCE STATION (AET)
- FLUME / EROSION STATION (RUNOFF, EROSION RATES)
- PRIMARY SOIL STATION (SOIL W/C, SOIL TEMP., SOIL SUCTION, NET PERC. - COVER / UPPER TAILINGS)
- SECONDARY SOIL STATION (SOIL W/C, SOIL TEMP., SOIL SUCTION - UPPER 75CM ONLY)

GENERAL NOTES:

1. VOLUME OF COVER MATERIAL REQUIRED =133,000m³
2. SURFACE AREA OF TRIAL = 8.5 Ha

CLIENT/PROJECT:

bhpbilliton resourcing the future

PRODUCED BY:

O'Kane Consultants Pty Ltd.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

PROPOSED TSF COVER TRIAL LAYOUT
1:2500

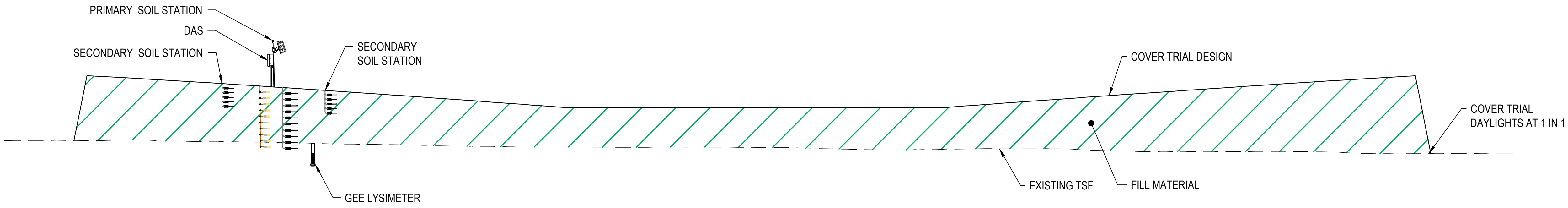
25 0 25 50 75 100 125m
SCALE 1:2500

REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

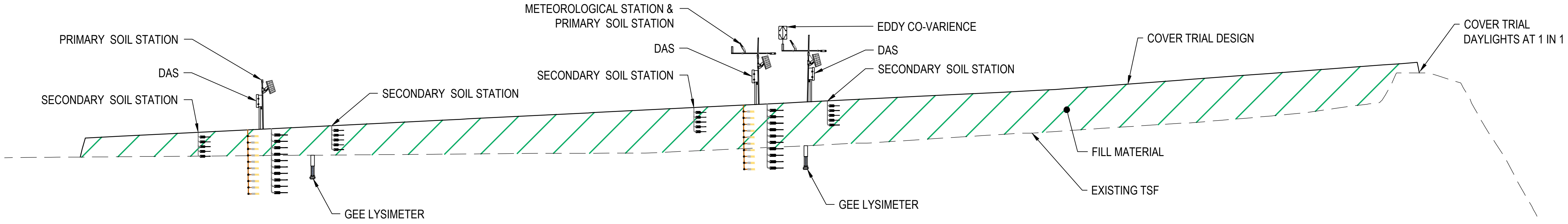
DRN. BY:	S. WALKER	DATE:	31.01.13
APPD. BY:	B. AYRES	DATE:	31.01.13
SCALE:	AS SHOWN	REPORT NUM:	809/5

PROPOSED TSF COVER TRIAL LAYOUT

DRG NUM: 809-5-101 Rev: 0



SECTION 1
NTS 101



SECTION 2
NTS 101

GENERAL NOTES:

1. TYPICAL SECTION HAVE A 5x EXAGGERATION FOR CLARITY
2. ALL INSTRUMENTATION IS INDICATIVE AND NOT TO SCALE.

CLIENT/PROJECT:

bhpbilliton
resourcing the future

PRODUCED BY:

O'Kane Consultants Pty Ltd.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

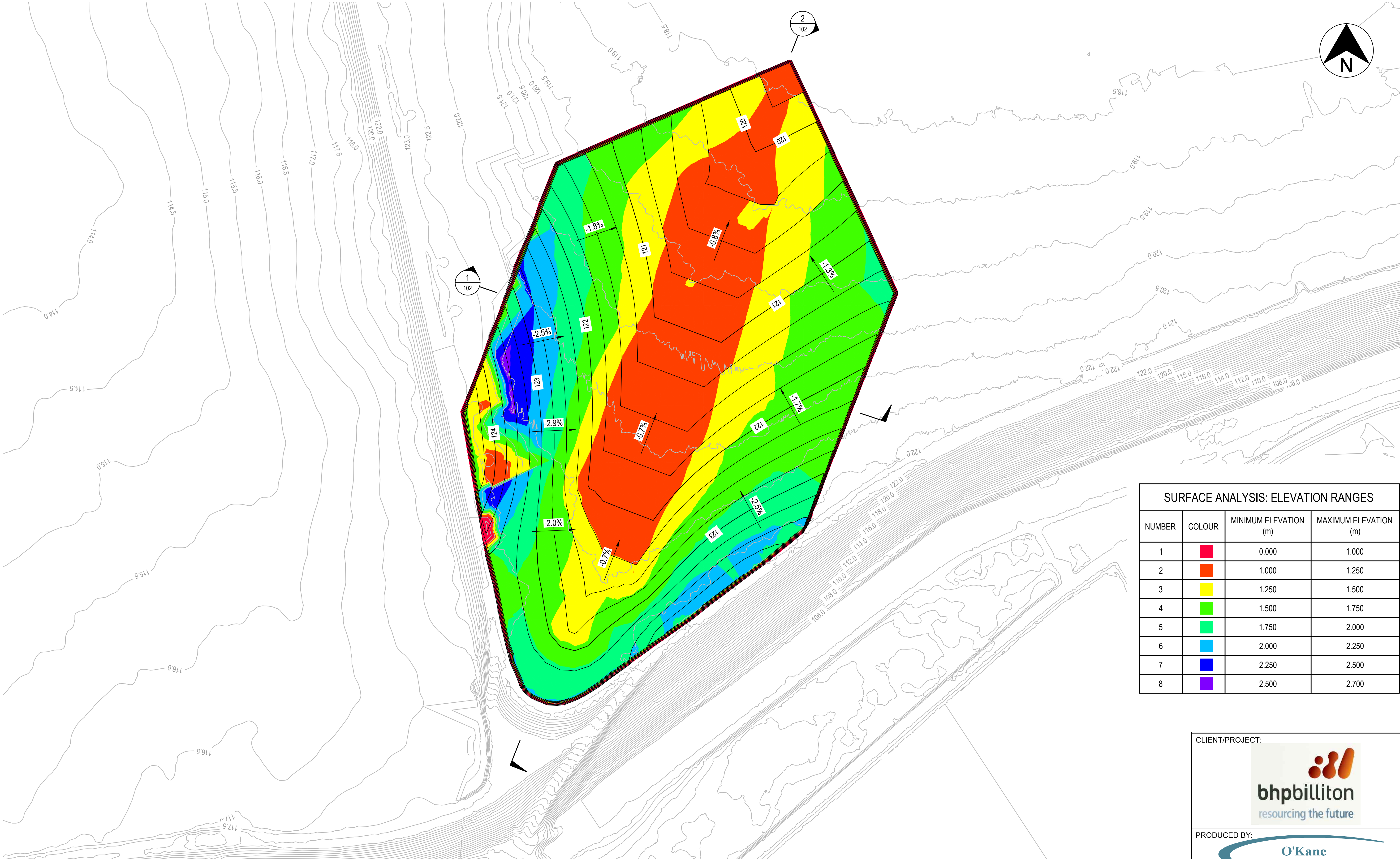
PROPOSED TSF COVER TRIAL - TYPICAL SECTIONS
NTS

REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

DRN. BY:	S. WALKER	DATE:	31.01.13
APPD. BY:	B. AYRES	DATE:	31.01.13
SCALE:	NTS	REPORT NUM:	809/5

PROPOSED TSF COVER TRIAL - TYPICAL SECTIONS

DRG NUM: 809-5-102 Rev: 0



SURFACE ANALYSIS: ELEVATION RANGES

NUMBER	COLOUR	MINIMUM ELEVATION (m)	MAXIMUM ELEVATION (m)
1	red	0.000	1.000
2	orange	1.000	1.250
3	yellow	1.250	1.500
4	green	1.500	1.750
5	light green	1.750	2.000
6	light blue	2.000	2.250
7	blue	2.250	2.500
8	purple	2.500	2.700

CLIENT/PROJECT:

bhpbilliton
resourcing the future

PRODUCED BY:

O'Kane Consultants Pty Ltd.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

PROPOSED TSF COVER TRIAL - FILL DEPTHS
1:2500

25 0 25 50 75 100 125m
SCALE 1:2500

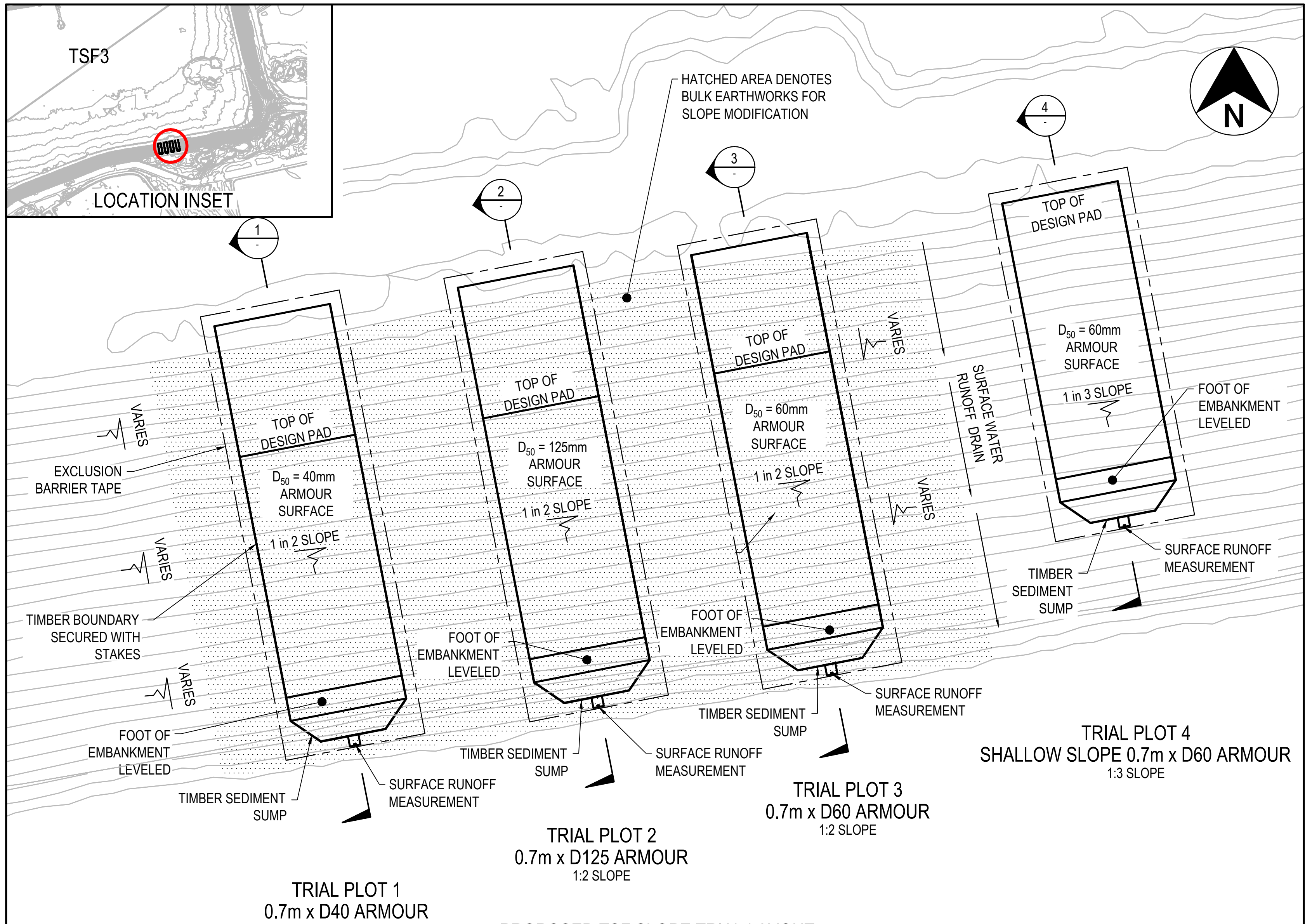
REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

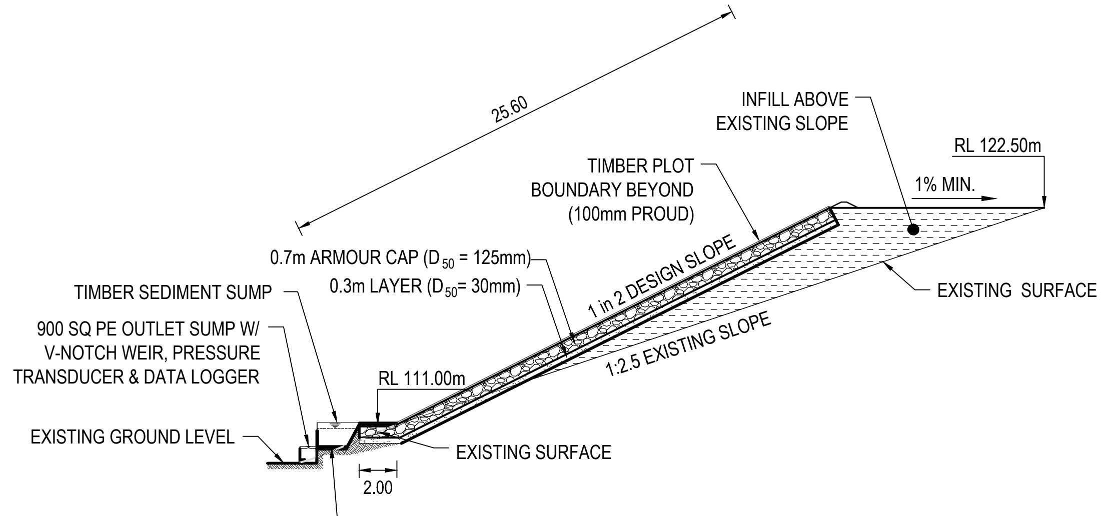
DRN. BY:	S. WALKER	DATE:	31.01.13
APPD. BY:	B. AYRES	DATE:	31.01.13
SCALE:	AS SHOWN	REPORT NUM:	809/5

PROPOSED TSF COVER TRIAL - FILL DEPTHS

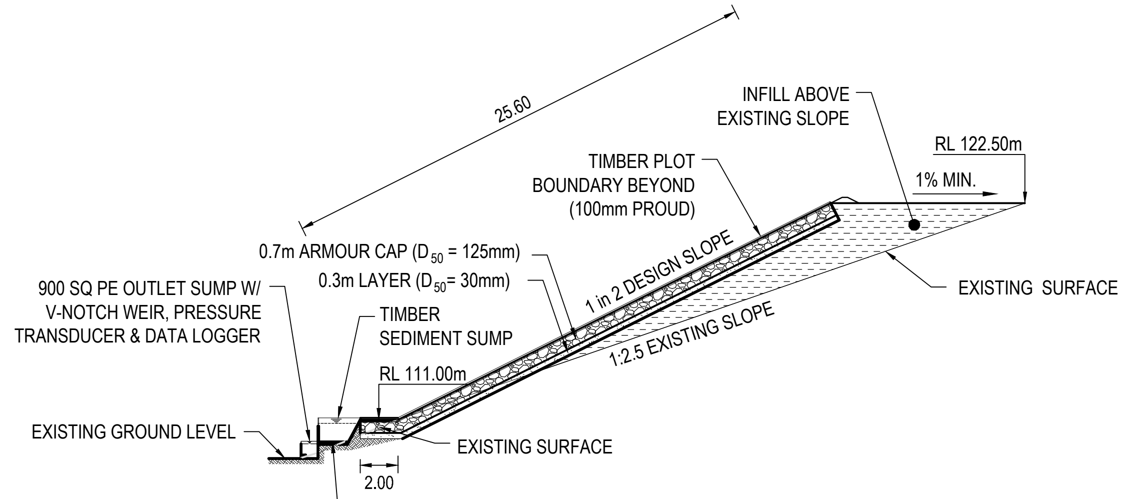
DRG NUM: 809-5-103 Rev: 0



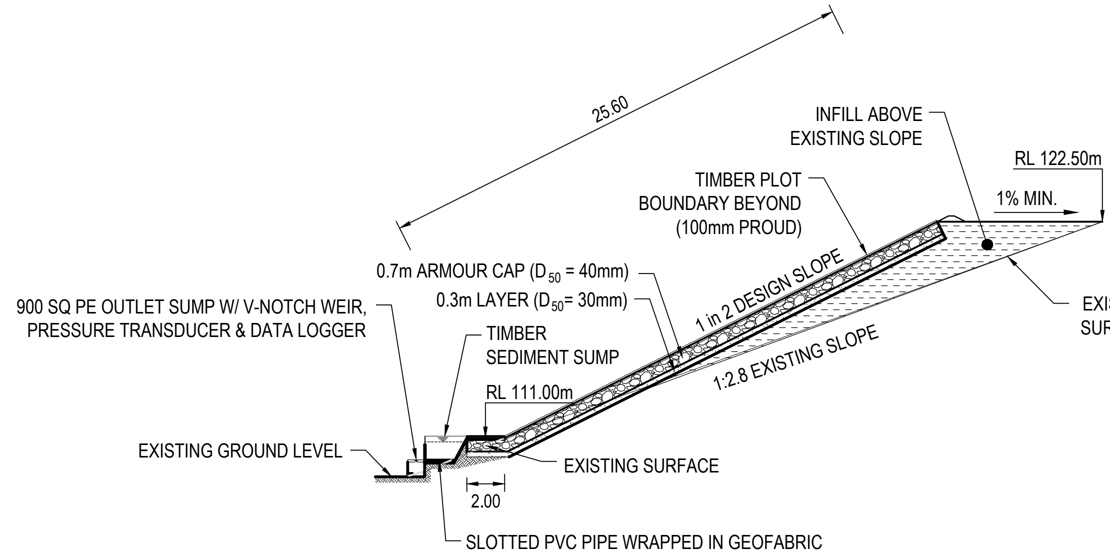
PROPOSED TSF SLOPE TRIAL LAYOUT
1:500



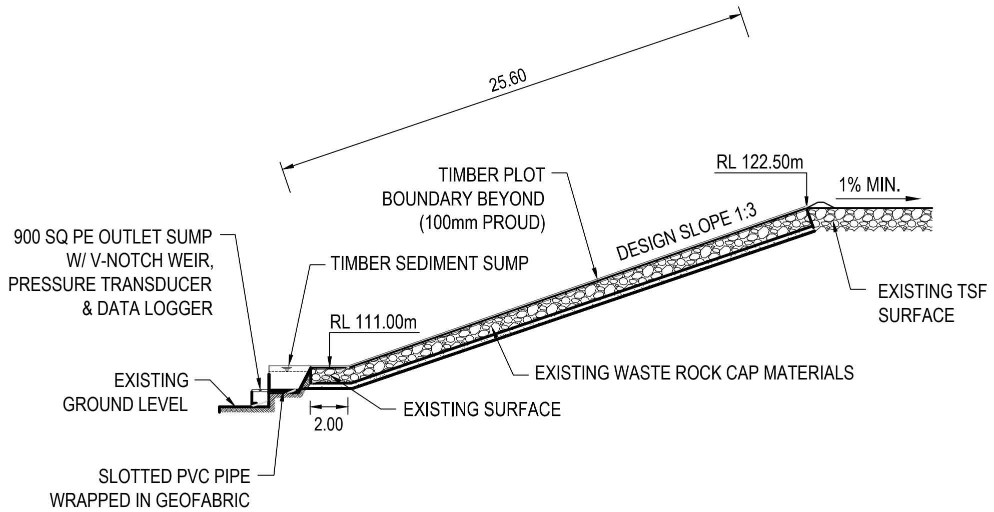
SECTION: PROPOSED TRIAL PLOT 2
1:400



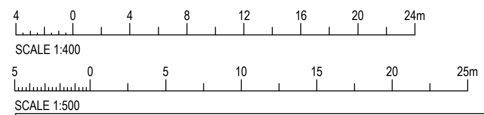
SECTION: PROPOSED TRIAL PLOT 3
1:400



SECTION: PROPOSED TRIAL PLOT 1
1:400



SECTION: PROPOSED TRIAL PLOT 4
1:400



CLIENT/PROJECT: bhpbilliton resourcing the future

PRODUCED BY: O'Kane Consultants Pty Ltd.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	21.05.13

DRN. BY:	S. WALKER	DATE:	21.05.13
APPD. BY:	A. KEMP	DATE:	21.05.13
SCALE:	AS SHOWN	REPORT NUM:	809/5

PROPOSED TSF SLOPE TRIAL LAYOUT

DRG NUM: 809-5-104 Rev: 0

Appendix E: Post Closure Monitoring Schedule

Item	Number Monitoring Events	Monitoring Year Post Closure (Years Post Closure)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Ecosystem Function analysis	7																				
Surface water monitoring and analysis	7																				
Groundwater monitoring and analysis	7																				
Geotechnical Monitoring TSF	7																				
Geotechnical Monitoring RSF	7																				
Fauna survey	7																				
Weed/feral animal control & inspect	42																				
Radionuclide's monitoring	20																				
GAB recovery monitoring	23																				