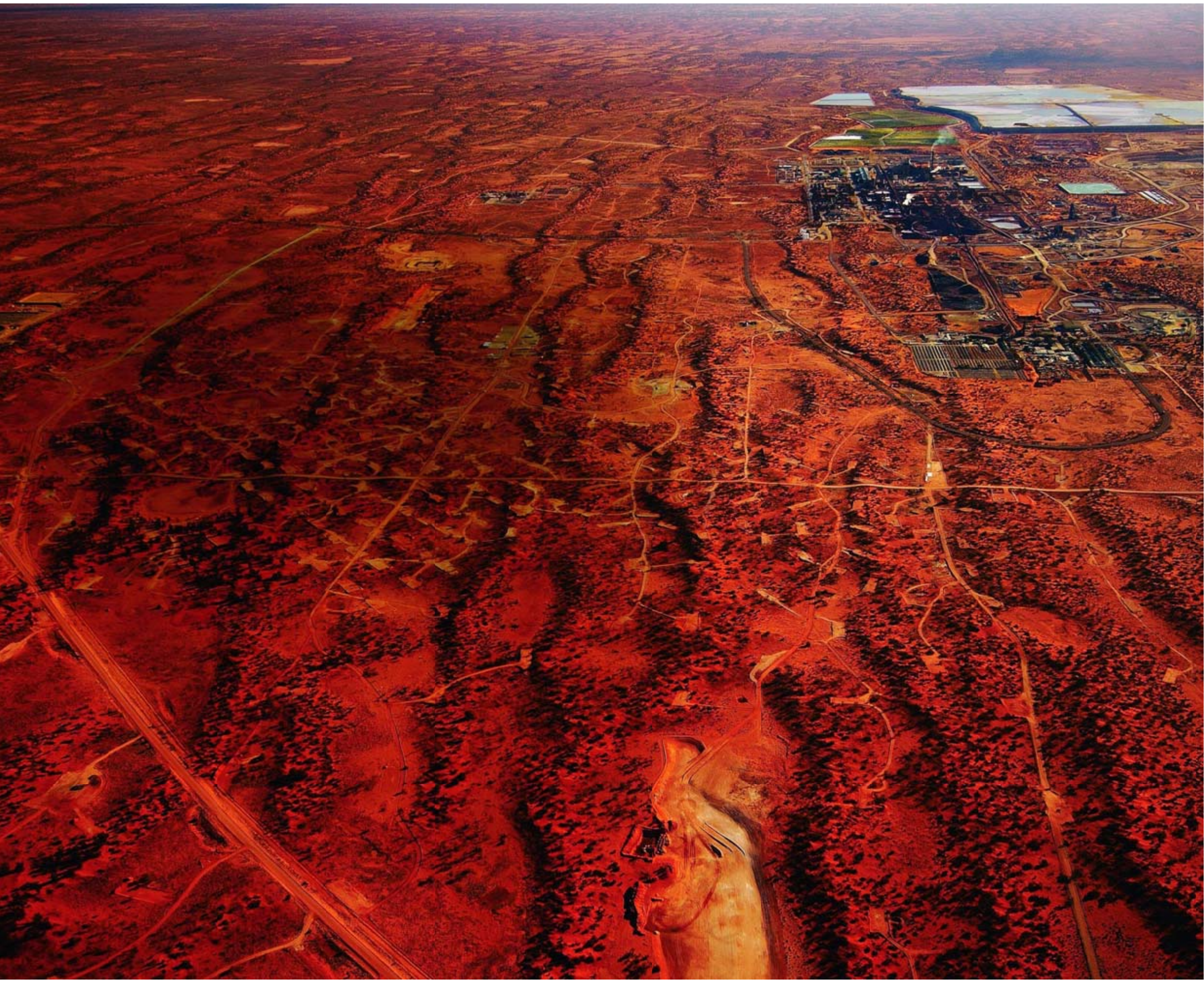
Olympic Dam

Mine Closure and Rehabilitation Plan 2013



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Contents

1 Executive summary 5

2 Introduction 6

2.1 Mining operation background 6
2.2 Legal and regulatory requirements 6
2.3 Radiological considerations 7
2.4 Mine Closure and Rehabilitation Plan purpose 7
2.5 Land tenure and use 7
2.6 Evolution and revisions of the Mine Closure and Rehabilitation Plan 8

3 Environmental characterisation 9

3.1 Physical environment 9
3.1.1 Climate 9
3.1.2 Topography 9
3.1.3 Local geology 9
3.2 Hydrogeology 10
3.2.1 Surface hydrology 12
3.2.2 Surface water resources 12
3.3 Biological environment 12
3.3.1 Flora 12
3.3.2 Fauna 12
3.4 Socio-economic and cultural environment (anthropic) 13
3.5 Radiation 13

4 Closure and Rehabilitation Framework 14

4.1 Operational Environmental Management Framework 14
4.2 Final land use 14
4.3 Closure outcomes and assessment criteria 14

5 Stakeholder and community 18

5.1 Stakeholder consultation strategy 18
5.2 Closure and rehabilitation stakeholders 18
5.2.1 Roxby Downs and surrounds 18
5.2.2 Non-Government organisations 19
5.2.3 Government 19
5.2.4 Upper Spencer Gulf 19
5.2.5 Pastoral community 19
5.3 Future stakeholder engagement for hand-over of facilities 19

6 Closure domains 20

7 Closure design principles 22

8 Closure implementation standards 23

9 Level of studies and engineering 26

10 TSF Closure modelling 27

11 Closure schedule 28

11.1 Final closure and rehabilitation 28
11.2 Progressive closure and rehabilitation 28
11.3 Relinquishment planning 29

12 Risk management 30

13 Post-closure monitoring, care and maintenance plan 33

13.1 Tailings storage facility 33
13.2 Open pit and rock storage facility 33
13.3 Rehabilitated sites 34
13.3.1 Components of EFA 34
13.3.2 Monitoring program 34
13.4 Care and maintenance of rehabilitated areas 36

14 Financial provisioning 37
14.1 Rehabilitation and closure accounting provision 37
14.2 Providing for unplanned closure scenario 37
14.3 Unplanned closure 37
14.4 Temporary closure (care and maintenance) 37

15 References 38

Appendix A Closure risk assessment 39
Appendix A-1 All domains 41
Appendix A-2 Closure Domain 1: Airport 44
Appendix A-3 Closure Domain 2: Town facilities 46
Appendix A-4 Closure Domain 3: Metallurgical plant and administration facilities 47
Appendix A-5 Closure Domain 4: Tailings Retention System 48
Appendix A-6 Closure Domain 5: Pilot Plant 50
Appendix A-7 Closure Domain 6: Open Pit 51
Appendix A-8 Closure Domain 7: Rock Storage Facility 52
Appendix A-9 Closure Domain 8: Miscellaneous disturbed areas 53
Appendix A-10 Closure Domain 9: Wellfields and associated infrastructure 55

Appendix B Tailings closure modelling 57

1 Executive summary

Olympic Dam is situated 560 kilometres (km) north of Adelaide in South Australia, and is a producer of copper, uranium, gold and silver. The ore reserve estimate as at June 2012 indicates that at the current underground mining and processing rates, Olympic Dam's remaining life will extend to 2087. 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 Mine Closure 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 Mine Closure 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.

Closure planning is a continually evolving process, and actions carried out in recent years to improve the accuracy and certainty of the Mine Closure and Rehabilitation Plan include:

- engagement of demolition consultants to refine major plant demolition plans, estimates and methodologies;
- development of preliminary TSF cover designs including design and performance criteria;
- undertaking a preliminary/desktop contaminated site assessment to define the level and extent of any ground contamination and improve volumetric estimates;
- developing a preliminary stakeholder engagement framework for commencing regulator engagement;
- conducting annual closure planning reviews including detailed review of the closure risks and the associated risk controls.

The integrated closure planning system followed within BHP Billiton 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 Mine Closure and Rehabilitation Plan.

This Plan has been developed in consideration of the South Australian Government *Mine Closure and Rehabilitation Plan – Olympic Dam Guidance Note for BHP Billiton* (undated) as provided in support of the South Australian Development Authorisation (Major Development Approval) for the Proposed Major Development, granted by the Indenture Minister pursuant to the Development Act 1993 (SA) and the Ratification Act, by notice in the South Australian Government Gazette dated 10 October 2011 (as amended from time to time). The guidance note specifically addressed requirements for condition 55 of the Major Development Approval

2 Introduction

In this plan, the term 'rehabilitation' refers to the re-establishment of biota on areas disturbed as part of the proposed development, and the processes necessary to achieve re-establishment. The term 'closure' relates more to the decommissioning of the various components of the development and the establishment of a landform that will ensure the final site does not leave unsuitable hazards to health, safety and the surrounding environment. As the two processes are closely related and interdependent, they are addressed in a single management plan.

2.1 Mining operation background

The Olympic Dam operation is situated 560 km north of Adelaide in South Australia and produces copper cathode, uranium, gold and silver. 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, 16 km south of the operation, 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 Billiton acquired full ownership of WMC Resources. Once WMC (Olympic Dam Corporation) Pty Ltd became a member of the BHP Billiton Group, the name was changed to BHP Billiton Olympic Dam Corporation Pty Ltd (hereafter referred to as BHP Billiton).

The operation consists of an underground mine which extracts the ore and feeds it to the on-site metallurgical processing plant. The metallurgical plant includes a concentrator, hydrometallurgical plant, slimes treatment plant, copper smelter and copper refinery.

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 Australian and South Australian government approval in October 2011 of the proposed Olympic Dam expansion, initial works on site expanded to include the commencement of the open pit (although at the substantially reduced rate of about 10 Mtpa compared to the 410 Mtpa assessed in the Environmental Impact Statement), construction of an associated waste rock storage facility and continuation of dewatering activities around the open pit. Due to prevailing economic circumstances, the company subsequently announced that it would return to studying various alternative mining and processing options. Pending further investigation into these alternative methodologies, expansion activities were suspended prior to the end of June 2013. Work to date on the open pit and RSF was stabilised and made safe, and dewatering was ceased.

Operations personnel generally live in the town of Roxby Downs with some commuting from other areas.

2.2 Legal and regulatory requirements

Key legal and other regulatory requirements that are relevant to the development of this Mine Closure and Rehabilitation Plan are listed in the Olympic Dam 2013 Environmental Management Program (Quality Document No. 49329). These include:

- *Roxby Downs (Indenture Ratification) Act 1982* (SA), as amended, and the Indenture which is ratified by that Act;
- *Environment Protection Act 1993* (SA);
- EPA Licence 1301;
- *Radiation Protection and Control Act 1982* (SA);
- Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005);
- EPA Guidelines for Environmental Management of Landfill Facilities (2007).

The Mine Closure and Rehabilitation Plan is also intended to satisfy:

- The requirements of Section 9 (Mine Closure and Completion Plan) of the Primary Industries and Resources of South Australia 2011 *Guidelines for miners: preparation of a mining lease proposal or mining and rehabilitation program (MARP) in South Australia*, Minerals Regulatory Guidelines MG2, Mineral Resources Group, V 4.11.
- BHP Billiton Group Level requirements across all business practices. These require that the closure planning (for decommissioning, remediation and rehabilitation) of all BHP Billiton's operations must be fully integrated into Life of

Asset planning.

Updates to the Mine Closure and Rehabilitation Plan are reported to the Minister for Mineral Resources Development in the BHP Billiton Annual Environmental Management and Monitoring Report (EMMR) (soon to become the Annual EPMP Report), which is submitted to the South Australian Government for review each year. The EMMR can be found on the Olympic Dam page of the South Australian Government Department of Primary Industries and Resources (PIRSA) website *http://www.pir.sa.gov.au/minerals/sa_mines/approved_mines/olympic_dam* (accessed 28/06/2013).

2.3 Radiological considerations

The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005) (referred to as the Mining Code), outlines requirements for the management of radiation in Australia and is applicable to all phases of operations and Olympic Dam, including closure (Mining Code 2.8.2(h)).

Compliance with the Mining Code is required as a condition of the existing licence (LM1) under the *Radiation Protection and Control Act* and includes:

- the development of a closure plan (the radiation aspects are integrated into the structure of this document);
- that BHP Billiton seek formal authorisation for any closure activities from the appropriate regulatory authority;
- the development of a radiation management plan (RMP) and a radioactive waste management plan (RWMP) specific to the closure activities when required.

While the Mining Code outlines the broad requirements, the further detail for radiation control is provided in guidance documents from the International Atomic Agency (IAEA), specifically:

- Best Practice in Environmental Management of Uranium Mining, IAEA Nuclear Energy Series No.NF-T-1.2, a publication of the IAEA (2010);
- Establishment of Uranium Mining and Processing Operations in the Context of Sustainable Development, IAEA Nuclear Energy Series No.NF-T-1.1, a publication of the IAEA (2009).

BHP Billiton would utilise the IAEA guidance documents for final closure and rehabilitation.

2.4 Mine Closure and Rehabilitation Plan purpose

The primary purpose of this Mine Closure and Rehabilitation Plan is to:

- describe the proposed post-closure landforms and land-uses and the performance criteria that will be used to measure successful closure and rehabilitation;
- demonstrate that there is an adequate level of engineering and planning in support of the Life of Asset closure cost estimate and hence the derivation of closure and rehabilitation accounting provision;
- demonstrate that risk-based closure planning at Olympic Dam is fully integrated into Life of Asset Planning to ensure that the appropriate level of study (and where necessary research), engineering and management will be implemented during the remaining life of the operation in order to achieve successful closure with acceptably low post-closure risks.

Within this context, the secondary purpose is to:

- identify and document the legal requirements, liabilities, obligations, commitments, design and completion criteria for closure;
- identify, document and manage risks associated with closure in consideration of BHP Billiton standards and the guidance note provided by the South Australian Government;
- provide the basis for the ongoing review of rehabilitation and closure assumptions, risks and risk controls, and the ongoing refinement of closure designs and planning;
- integrate closure planning with Life of Asset planning;
- identify and schedule opportunities for progressive rehabilitation (where practical);
- identify the need for further research, assessments and studies in order to ensure the reduction of the uncertainties around closure and the effective and optimum use of available resources and technology;
- ensure, through a consultative process, that the plan developed is technically achievable, agreed to and followed during the operating life to minimise rework and life-of-mine costs;
- address the social and community aspects associated with closure including socio-economic impacts following closure of the operation, long-term liabilities to BHP Billiton and the government and public, and support end land use opportunities that will benefit the post-closure community.

2.5 Land tenure and use

Ownership of the lease resides with the State of South Australia, who issued a Special Mining Lease (SML) to the WMC Resources/BP joint venture on 22 May 1986. The SML concerns the piece of land containing 17,788 hectares (ha) on which the Olympic Dam mine and processing plants are situated.

The land to which the SML relates is owned freehold by BHP Billiton. All developed land within the Roxby Downs township is held under freehold title by BHP Billiton and third parties. Undeveloped land within the township is held by BHP Billiton pursuant to licences to occupy, which are renewed automatically on an annual basis.

Although the viability of pastoral activities in the area is dependent on the region's erratic rainfall patterns, pastoral land-use remains the most extensive land use in the region.

2.6 Evolution and revisions of the Mine Closure and Rehabilitation Plan

Closure and rehabilitation planning is regarded as being initially conceptual, becoming progressively more detailed through an integrated and systematic process (see Figure 1). Planning for mine closure and rehabilitation must be sufficiently flexible to allow for operational changes as well as changes in technology and/or regulatory requirements. The planning process is also ongoing as more detailed information about site-specific closure risks and rehabilitation comes to hand, allowing certainty around closure success to be progressively increased. This evolutionary process is consistent with relevant government and industry guidelines and aligns with the BHP Billiton Group Life of Asset closure planning requirements.

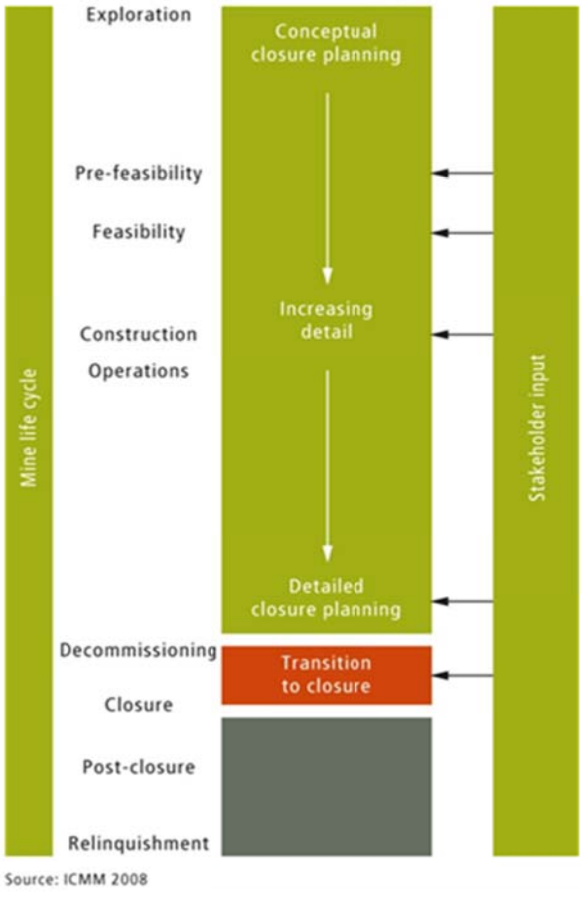

Figure 1: Closure planning process (from ICMM 2008)

Closure plans within BHP Billiton are reviewed for any material changes on an annual basis for the purposes of closure financial provisioning, undergoing major reviews every three to five years. This version is the fourth major revision of the Olympic Dam Mine Closure and Rehabilitation Plan, having evolved from over 10 years of operational closure planning, investigations, monitoring, risk assessment and management.

The Mine Closure and Rehabilitation Plan will continue to be reviewed and updated annually, in preparation for potential events such as a material change in operating parameters e.g. if the underground operation is converted to an open pit or the expansion activities increase significantly. Wherever possible and practical, closure planning and closure risk assessments will continue to involve relevant internal and external stakeholders.

3 Environmental characterisation

3.1 Physical environment

3.1.1 Climate

The climate is arid with average annual rainfall of 167 millimetres (mm) and annual average evaporation of approximately 3000 mm. 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.

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).

3.1.2 Topography

The local terrain consists mainly of parallel sand dunes separated by corridors or swales. The sand dunes occur on an east-west alignment and vary in height up to 10 metres (m) and width to 300 m. The inter-dune corridor tablelands vary over the mining lease, but the soils generally comprise shallow brown clays or silty sandy sediments overlying limestone, with claypans occurring at low points.

These claypans act as natural drainage sinks. Also present in the region are a large variety of landforms and habitats including swamps, wetlands, claypans, sand plains and gibber plains.

3.1.3 Local geology

The ore body and main mine development occurs to a depth of some 650 m in Precambrian basement rocks. While the mine workings have caused a local drawdown of the groundwater, the ore body and its host rocks produce little or no groundwater flows into the workings, except where a major structure (e.g. a major fault) is intersected. 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 landscape is mainly one of low relief, dominated by dune fields, low tablelands and a system of playas and small salt lakes. The dune fields have developed in areas of lower topography, leaving the elevated areas (which are generally underlain by Arcoona Quartzite and Mesozoic remnants) relatively free of dunes. Most of the Andamooka Limestone is overlain by east-west sand dunes with average heights of four to five metres. The swale areas between the dunes are generally underlain by calcareous soils and Andamooka Limestone, which outcrops or sub-crops at some locations and is variably weathered.

Gypsiferous clays can be found between the calcareous soils and limestone over parts of the area.

The general lithology of the Olympic Dam deposit is shown in cross-section in Figure 2.

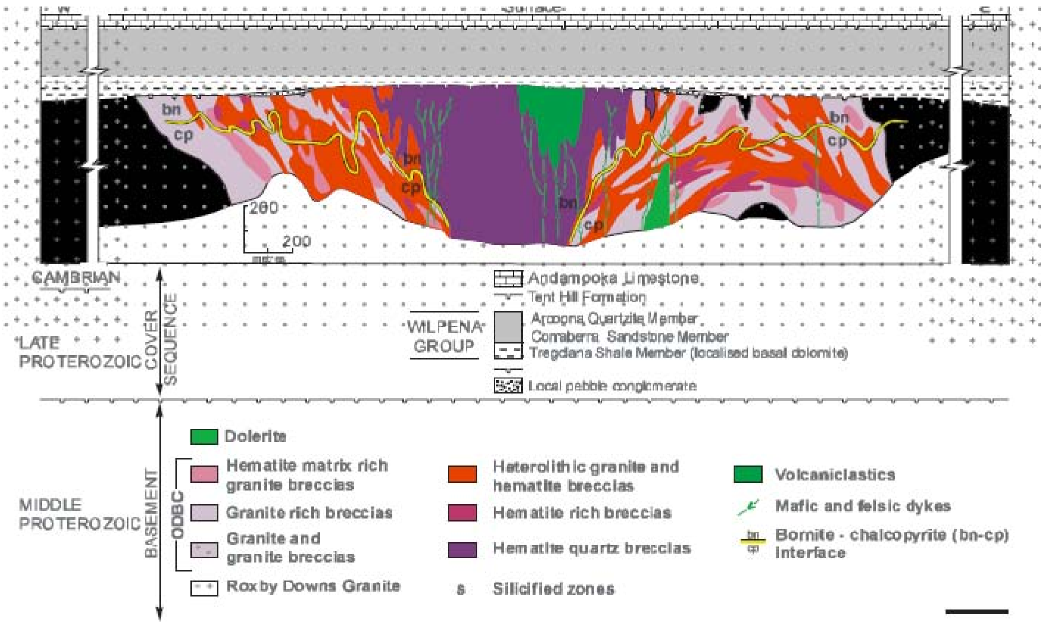

Figure 2: Cross-section of deposit geology

Mineralisation of the deposit can be broadly categorised as follows:

1. Copper-uranium (with some gold and silver) ore: This ore comprises most of the resource, and is primarily contained within haematitic breccias;
2. Gold ore: This ore type generally occurs as small zones hosted by either granite-rich or haematite-rich breccias. There are some rare, but extremely high-grade concentrations of free gold, especially around the margins of the quartz-haematite core.

The principal copper-uranium mineralisation is generally confined to individual elongate haematite-rich breccia zones. The deposit consists of a large number of individual ore zones distributed throughout the breccia complex. Copper mineralisation typically consists of fine to medium-grained disseminated sulphides. The principal copper sulphides are chalcopyrite, bornite and chalcocite. Zonation of the mineralisation also occurs, ranging from the rare but significant native copper to chalcocite, bornite, chalcopyrite and pyrite at depth. Uranium mineralisation is broadly associated with copper mineralisation. Most of the uranium within the deposit occurs as pitchblende, with minor amounts of coffinite and brannerite.

3.2 Hydrogeology

Water for potable and process uses at Olympic Dam and the Roxby Downs Township is sourced from two wellfields in the Great Artesian Basin: Wellfield A and B (Figure 3). In addition to these wellfields, Olympic Dam also sources saline water from saline wells on site, and through dewatering of the underground mine workings.

Two aquifer systems exist within the fractured basal sections of the recrystallised limestone and quartzite units at Olympic Dam. As is characteristic of fractured rock aquifers, groundwater occurs non-uniformly within fractures and vugs within both these units. The fractured rock nature of the aquifer provides a secondary transmissivity within the rock unit. Across site, the water table in the Andamooka Limestone typically occurs at depths of greater than 50 m in the area of Olympic Dam. The underlying Arcoona Quartzite hosts a semi-confined aquifer through a zone of moderately permeable rocks at depths of between 160 to 200 m below ground level.

The vertical connection between the Andamooka Limestone and the more permeable lower sections of the Arcoona Quartzite is constrained by the occurrence of fracture induced permeability in the upper Arcoona Quartzite.

Groundwater flow contours show that some hydraulic continuity exists between the groundwater aquifers in the vicinity of Olympic Dam and regionally throughout the Stuart Shelf. Groundwater flow contours also demonstrate that groundwater flows to the north east from Olympic Dam and ultimately discharges to Lake Torrens.

All groundwater in the vicinity of Olympic Dam is saline to hypersaline, with naturally occurring values for total dissolved solids (TDS) generally in the range of 20,000 to 30,000 milligrams per litre (mg/L). For comparison, seawater salinity is generally around 35,000 mg/L.

Groundwater throughout the Stuart Shelf is generally saline (from 25,000 to >200,000 mg/L TDS). To the south and west of Olympic Dam, there is limited pastoral and domestic use of water in the Andamooka Limestone via shallow bores. To the north and east, few, if any, bores penetrate the aquifer. A few small useable stock supplies are obtained from shallow bores (<30 m deep) which skim brackish water from localised areas of enhanced rainfall recharge.

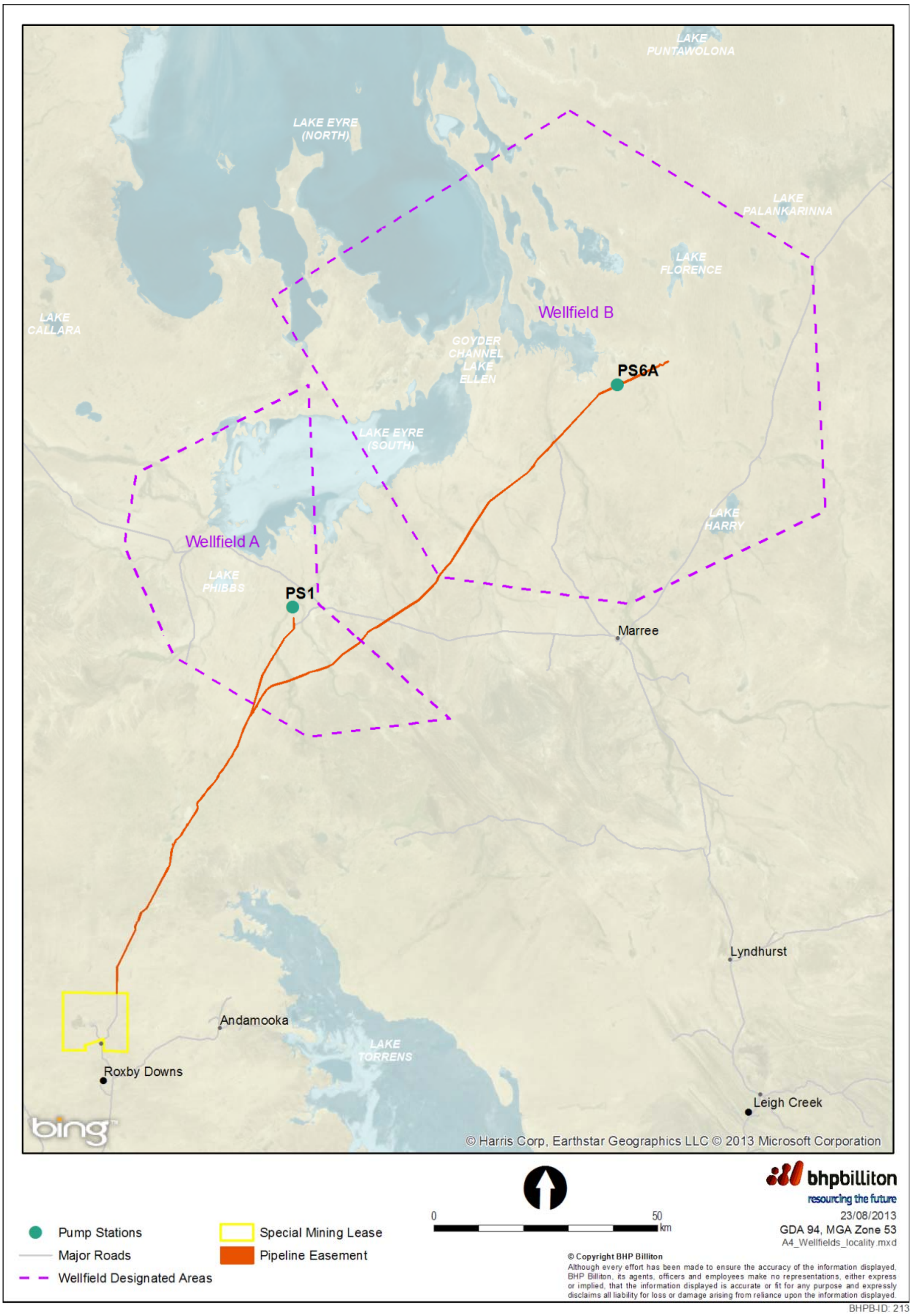

Figure 3: Regional plan showing Wellfields A and B

Saline groundwater is extracted from the Andamooka Limestone under the TRS indicating that seepage can be managed where permeability exists. Groundwater is also pumped from the deeper Lower Arcoona Quartzite (Corraberra

Sandstone) locally for a saline water supply. Underground operational dewatering and saline abstraction has resulted in a cone of depression in the Arcoona Quartzite.

3.2.1 Surface hydrology

The surface hydrology in the vicinity of the site is characterised by a mosaic of small catchments, which may range in area from 10 to 300 ha. The boundaries are generally defined by the east/west trending sand dunes. There are no defined lateral stormwater flow drainage lines. 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. There are no flow features of any significance within the area of the mine, and the location of the TRS does not interrupt any supply flows.

3.2.2 Surface water resources

The flat-lying dune field which controls surface water hydrology extends to at least 15 km from the site. The nearest defined surface watercourses are more than 15 km to the north and 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 mg/L TDS) and sustained by groundwater flow (BHP Billiton, 2009).

3.3 Biological environment

3.3.1 Flora

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.

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.

3.3.2 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 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 trapped 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.

3.4 Socio-economic and cultural environment (anthropic)

Roxby Downs has a population of approximately 4,500 permanent residents. The township is administered by a Town Administrator, pursuant to the Olympic Dam Indenture, who acts as the Roxby Council. While the Administrator rather than a fully elected local government council remains in place, BHP Billiton and the South Australian Government share the cost of the Council’s annual financial deficit.

A Community Board has been meeting since September 2003 and was established to encourage greater participation by local residents in the development of strategies for the future of Roxby Downs. The Community Board facilitated the development of the 10-year Community Plan through 18 months of consultation with the community to identify opportunities and issues for particular sectors of interest in the town.

Archaeological sites are evidence of past occupation and may include camp sites, quarries or stone tool workshops and scatters. Ethnographic sites are localities of significance to the traditions of Aboriginal people. As a result of the archaeological survey work conducted for the 1983 Environmental Impact Statement (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.

3.5 Radiation

Radionuclides occur naturally in the environment and have been extensively monitored in the Olympic Dam region since commencement of operations in the early 1980s. The data provides information for post-closure comparisons.

A significant quantity of data and information on environmental radiation has been collected, collated and reported for Olympic Dam to date. Much of the data is summarised in the Draft EIS 2009 and Supplementary EIS 2011 for the Olympic Dam Expansion, with other routine results reported to government in annual Environmental Management and Monitoring Reports and the Radiation Protection and Control Act Licence Annual Report.

Although radon and radionuclide concentrations have increased above natural background levels close to the operation, the impact of those increases has been shown to be negligible.

Monitoring has been undertaken for:

- gamma radiation;
- radon in air;
- radon emanation;
- radionuclides in dust;
- radionuclides in flora, fauna and soils;
- radionuclides in surface water and groundwater.

4 Closure and Rehabilitation Framework

The term ‘rehabilitation’ adopted by BHP Billiton is often used interchangeably in various references and guidelines with ‘restoration’ and ‘reclamation’. 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;
- establishing appropriate sustainable ecosystems (DITR 2006).

4.1 Operational Environmental Management Framework

BHP Billiton conducts all operational activities in an environmentally responsible and sustainable manner in alignment with the BHP Billiton Charter and Sustainable Development Policy. Among other things, the Sustainable Development Policy also:

- details the company’s aspirations towards zero harm to people, host communities and the environment and towards working to achieve leading industry practice;
- stipulates that all BHP Billiton operations would develop, implement and maintain management systems for sustainable development that drive continual improvement and ensure that the policy objectives are met.

The Closure and Rehabilitation Framework forms part of the site-wide Environmental Management Framework, which is the overarching strategy for capturing and translating the obligations, commitments and management measures presented in the EIS and other relevant documents.

The environmental management framework has, as its implementation mechanism, a project-wide Environmental Management System (EMS), consistent with the BHP Billiton Group Standards and Australian Standard AS/NZS ISO 14001:2001.

The Closure and Rehabilitation Framework, being a component, utilises other management plans in addition to this rehabilitation and closure plan. Key plans referenced in this document are the Tailings Retention System Management Plan, the Radiation Management Plan, and the Radioactive Waste Management Plan (RWMP). (Note that the RWMP has been integrated into the Environmental Protection and Management Program (EPMP)).

4.2 Final land use

For the purposes of conceptual closure planning and financial provisioning, the final land uses have been defined, as far as is reasonably achievable, as:

- Special mining lease -
  - land use for rehabilitation at original ground level – revegetated vacant crown land with potential for restricted grazing;
  - above ground tailings storage facilities and below ground open pit – vegetation free 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 special mining lease – land use consistent with neighbouring properties.

It is noted that alternative final land uses were discussed in Chapter 23, Rehabilitation and Closure, of the Olympic Dam Expansion Project EIS (BHP Billiton 2009). The options discussed included the ongoing use of the site for research and education; and as a managed and regulated tourist attraction.

The final closure land uses will be negotiated with the stakeholders and communities nearer the mine closure date. 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.

4.3 Closure outcomes and assessment criteria

The high level closure outcomes and assessment criteria for Olympic Dam are summarised in Table 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.

Table 1: Post-closure outcomes and assessment criteria

EM Program	Environmental Outcome	Assessment criteria	Applicable Domain
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 where necessary remediated to SA EPA requirements under the Environment Protection Act 1993, or relevant 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.	1 - 9
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 Billiton activities.	1 - 9
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.	1 - 9
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) limits for public exposure or the relevant criteria at the time of closure.	1 - 9
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 ^{238}U less than 25 Bq/m^2/y at non-human biota assessment sites	3, 4, 5, 6, 7 & 8
Generation of industrial wastes			
Embankment stability of TSF	Final landforms geotechnically stable.	No significant TSF embankment failure.	4
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).	4 & 7
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 stormwater maintained within designated stormwater management areas.	1 - 9
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.	1 - 9

EM Program	Environmental Outcome	Assessment criteria	Applicable Domain
		Landfill facility decommissioning and/or rehabilitation in accordance with SA EPA landfill guidelines and requirements.	
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 ^{238}U less than 25 $Bq/m^2/y$ at non-human biota assessment sites	3, 4, 5, 6, 7 & 8
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.	7
Employment and accommodation of people			
Community interactions and workplace interactions	Communities in which BHP Billiton operates value their relationship with us.	Safe conditions and controls to restrict inadvertent access to unsafe environments following rehabilitation	1 - 9

5 Stakeholder and community

5.1 Stakeholder consultation strategy

The involvement of stakeholders in developing agreed closure outcomes, performance criteria and future land use is an important component of the rehabilitation and closure planning process. One of the primary objectives of the Mine Closure and Rehabilitation Plan is to ensure that stakeholder needs, concerns and aspirations are taken into account when closure planning.

A consultation process is also required in order to develop overall mine closure and rehabilitation outcomes and criteria for end land use, cultural and heritage values, government regulation and other legal requirements. The process also provides the framework for on-going consultation in accordance with government and community expectations.

BHP Billiton has systems in place to identify stakeholder risks and concerns related to the operations. These concerns are addressed in an Annual Community Relations Plan. Future stakeholder engagement for closure planning would be undertaken in the same spirit as the current operational engagement, and using the established processes as a minimum. The main issues that the Community Relations Plan will need to address with regards to mine closure and rehabilitation planning are:

- complete identification of stakeholder groups, as well as their topics of interest and degree of influence;
- effective two-way communication of closure issues, specially related to potential economic activities after cessation of mining, land use objectives, potential residual risks and predicted post-closure performance;
- conflict resolution when different stakeholders have contradictory expectations (e.g. land use alternatives).

In order to ensure that consultation and engagement is carried out at the appropriate time, BHP Billiton External Affairs representative(s) participate in the annual closure planning review and closure risk assessment review.

A high-level stakeholder engagement plan for closure will be prepared at an appropriate lead time for stakeholder engagement regarding any scheduled progressive closure activities.

5.2 Closure and rehabilitation stakeholders

A consultation process is required to develop overall closure outcomes and criteria for end land use, cultural and heritage values, government regulation and other legal requirements.

Owing to the extensive remaining life of the mine and the current consultation processes for the operation and for the Olympic Dam expansion studies, discussions with interested parties and stakeholders about closure planning of the existing operations have not been undertaken. Stakeholder and public consultation will be held at appropriate stages during the evolution of the mine and the Mine Closure and Rehabilitation Plan to ensure community engagement in the process. The following is a list of stakeholders to involve in future closure consultation processes:

5.2.1 Roxby Downs and surrounds

- Roxby Downs and Olympic Village communities;
- Roxby Council;
- Olympic Dam employees, contractors and suppliers;
- the local communities of Roxby Downs, Woomera and Andamooka;
- the local providers of State Government services – specifically health, education and police;
- the wider communities of William Creek, Glendambo, Marree and Upper Spencer Gulf cities;
- Community boards – Roxby Downs Community Board, Woomera Board, and Andamooka Progress and Opal Miners Association;
- Arid Recovery partners (the South Australian Department for Environment & Natural Resources, the University of Adelaide and Friends of Arid Recovery);
- local businesses;
- Community Partner Organisations in Community Development Projects who may have longer terms associations with Olympic Dam.

5.2.2 Non-Government organisations

- SA Chamber of Mines and Energy
- Australian Uranium Association
- Friends of the Earth
- South Australian Conservation Council
- Wilderness Society

5.2.3 Government

- Various Australian and South Australian government Ministers, shadow Ministers and members of the Australian and South Australian Parliaments
- Relevant Australian and South Australian Government Departments and Agencies
- Great Artesian Basin Coordinating Committee;
- South Australian Natural Resource Management (NRM) Council
- South Australian Arid Lands NRM Board
- Northern and Yorke NRM Board
- Eyre Peninsula NRM Board

5.2.4 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
- Indigenous Groups
    - Barngarla Land Council
    - Kokatha Land Council
    - Kuyani Land Council
    - Nukunu Land Council
    - Andamooka Land Council
    - Port Augusta Native Title Working Group.

5.2.5 Pastoral community

- SA Pastoral Board
- Anna Creek Station
- Arcoona Station
- Billa Kalina Station
- Bosworth Station
- Callanna Station
- Cariewerloo Station
- Clayton Station
- Dulkaninna Station
- Etadunna Station (BHP Billiton)
- 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

5.3 Future stakeholder engagement for hand-over of facilities

Closure of the Roxby Downs town facilities includes the demolition and removal of all BHP Billiton 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.

6 Closure domains

The current areas of disturbance subject to closure planning are shown in Figure 4.

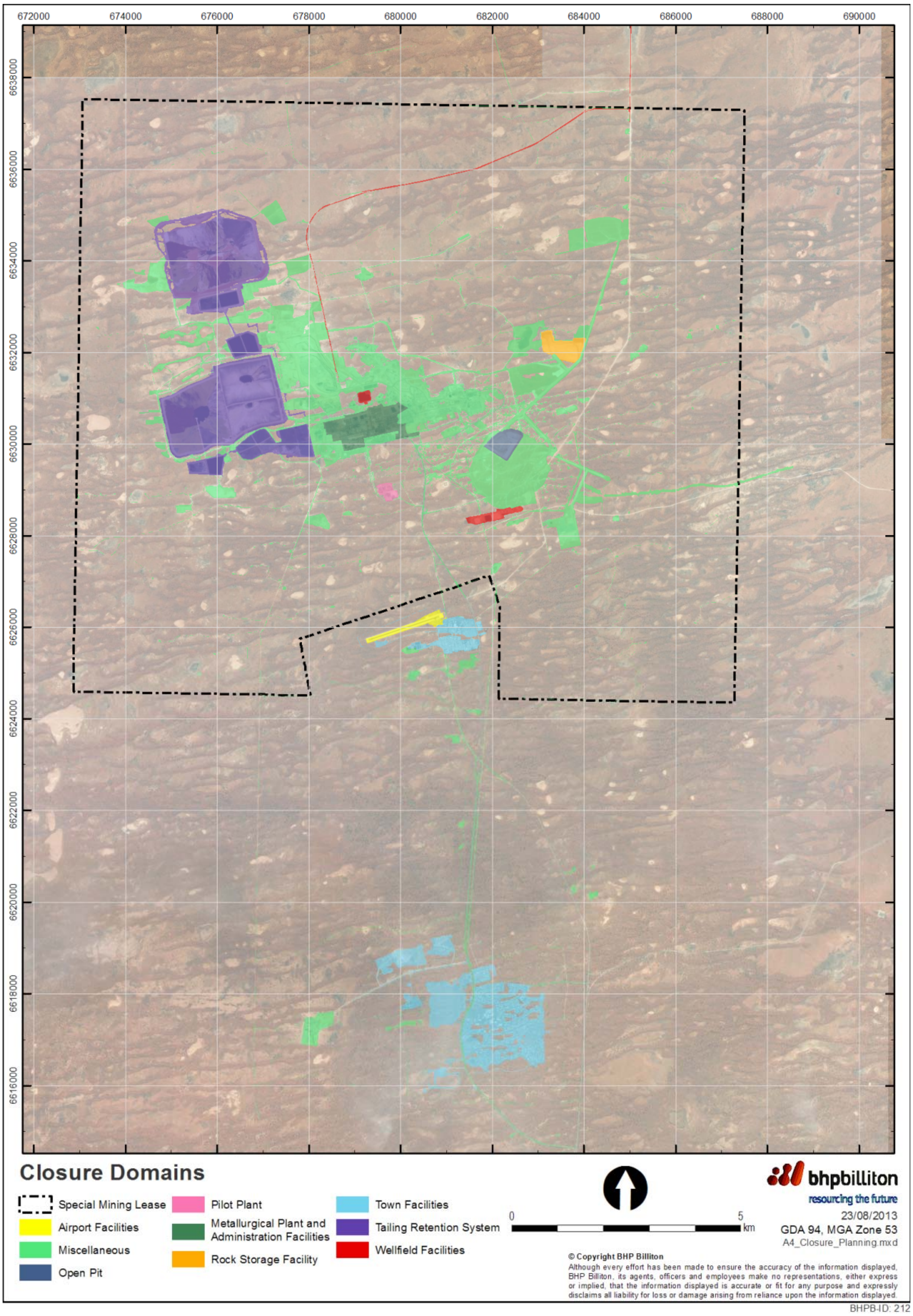

Figure 4: Olympic Dam - location disturbance areas at end of FY2013

For the purposes of rationalising closure planning across a large area with different operational and post-closure land uses, the site is broken into domains, or areas that have similar closure methodologies, landforms and land-uses. These are described in Table 2.

Table 2: Closure domains

Domain Number	Management Domain	Components
1	Airport	• Olympic Dam Airport
2	Town facilities	• Olympic Village note: Olympic Village includes Camps 1 and 4, unsealed roads, landfill and laydown areas; • Olympic Dam Sewage Ponds; • Roxby Downs town facilities.
3	Metallurgical plant and administration facilities	• administration buildings; • processing plant and supporting infrastructure (For example ponds, bunds, tanks and powerlines); • roads; • stockpile footprints; • stormwater diversion bunds and channels; • pilot plant area including tailings trial ponds, haul road.
4	Tailings Retention System	• tailings storage cells; • evaporation ponds; • pipe trace.
5	Pilot Plant	• Pilot Plant itself • associated tailings ponds • haul road • total disturbance area about 15 ha
6	Open Pit	• clearing and grubbing over approximately 360 ha • excavated area of approximately 27 ha to a maximum depth of 15m • dewatering infrastructure • mine haul roads • stormwater diversion bunds, as required • stockpiling of topsoil
7	Rock Storage Facility (RSF)	• current storage area approximately 50 ha • approximately 3.5 million m^3 of clays and unconsolidated materials • cleared crusher pad area of approximately 65 ha • separate sand stockpiles (used for flux in existing smelter and for Cement Aggregate Fill for decommissioned stopes)
8	Miscellaneous (including the underground mine and administration facilities)	• mine administrative offices; • shafts (Whenan, Robinson and Clark), decline, raise bores and associated surface infrastructure e.g. blow down ponds; • 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; • miscellaneous quarries and borrow pits; • waste management area; • roads; • power lines; • exploration sites; • monitoring sites; • Arid Recovery area; • Water and wastewater treatment facilities; • residual infrastructure, such as power lines, roads and hardstand.any disturbance areas associated with open pit mining area that are located outside of the actual pit boundaries.
9	Wellfields and associated infrastructure	• desalination plant; • water storage ponds; • M1A, M1B, M6A and M6B Pipelines; • water distribution pipelines; • Wellfields A and B; • access roads and tracks.

7 Closure design principles

Closure principles are specific measures against which the design of closure structures and other elements are measured. The design principles for Olympic Dam closure are summarised in Table 3.

Table 3: 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 less 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 ^{238}U less than 25 $Bq/m^2/y$ 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.

8 Closure implementation standards

The various elements within each domain will be closed and rehabilitated where applicable to a specified/agreed standard. The standards are listed in Table 4.

Table 4: Key rehabilitation and closure standard measures

Project component	Management approach
Pre-closure	
Clearing management e.g. for future TSF cells	• Clearing or other vegetation disturbance would only be undertaken in a controlled manner with permits in place. • Baseline information, such as vegetation type, condition and resources would be recorded prior to clearing of vegetation. • Where beneficial, seeds and other propagules would be collected.
Topsoil stockpile management	• Viable topsoil would be removed and managed to maintain viability. • Allow natural re-seeding of long-term topsoil stockpiles. • Stabilise stockpiles where necessary to minimise erosion. • Topsoils will be prioritised and matched to appropriate landform. • Dispersive soils, where not specifically required for rehabilitation of associated taxa or communities, would be buried in the backfill limestone quarry. • All topsoil stockpile footprints would be rehabilitated. • The surface of all areas to be actively rehabilitated would be ripped to alleviate compaction, prior to replacement of topsoil. • The potential for constructing store-and-release surfaces as habitat for certain taxa would be investigated.
Final closure	
Landforms other than TSF, RSF and open pit	• The ground surface landforms will mimic the regional dune and swale landform where practical and where adequate materials are available. Pastoral landforms may occur where grazing will not damage rehabilitation.
TSF and RSF (if constructed) landforms	• The TSF and RSF will mimic the breakaway style feature, i.e. steep (20° to 37° side slopes with flat top surface). • No reactive material will be placed within the outer slopes of the RSF.
Open pit landform (if constructed)	• The open pit cavity will remain as is at the completion of mining. • Any infrastructure located within the open pit at the completion of mining will be decommissioned and removed.
Decommissioning	• Develop decommissioning plan to safely decommission all electrical equipment, piping, and mechanical equipment. • Decommission all plant and equipment in accordance with decommissioning plan. • Groundwater wells no longer required would be plugged with concrete and decommissioned as per regulatory requirements.
Demolition of buildings, plant and infrastructure	• Demolish and remove minor infrastructure (e.g. pipe racks). • Demolish all structures, buildings and concrete footings to a depth of 500 mm. • Carry out a survey to capture all redundant services and update site drawings to reflect any changes. • Carry out a survey to capture any services that may need to remain, and develop a register accordingly. • Leave buried services >500 mm depth in place if they pose no environmental risk. • Remove all pipelines and services brought to surface during ripping. • Demolish all tanks and plant. • Dispose of all demolition debris as appropriate for the level of contamination.
Disposal of plant, equipment and demolition debris	• Future re-use of energy, rail and water infrastructure, would be determined prior to closure. • All above ground infrastructure and below ground tanks and footings would be removed and recycled or disposed of to landfill. • The potential to recycle the ferrous scrap steel from the site would be investigated and implemented where possible and practical. • Plant and infrastructure materials that cannot be taken off-site will be buried in the backfill limestone quarry or TSF cells depending on the level of contamination.
Disposal of soil and rockfill materials	• Uncontaminated fill – backfill water storage and/or evaporation ponds once empty. • Uncontaminated (hydrocarbon) demolition debris and plant in the backfill limestone quarry void. • Radioactive demolition debris and plant disposed in the TSF or in the underground mine workings. • Recycle ferrous scrap and other recyclable waste off-site following radiation clearance. • Radioactive soil and demolition debris materials in the TSF or underground. • Hydrocarbon contaminated soil and demolition debris in the TSF or in a suitably designed and constructed landfill.

Project component	Management approach
Disposal of hazardous materials	• Maintain Life of Asset hazardous materials register. • Determine required disposal action, document in register, and plan and dispose in hazardous waste facility depending on hazard classification.
Tailings storage cells	• Close TSFs in accordance with progressive closure plan/schedule to facilitate continuous improvement of TSF cover and demonstrate achievement of design principles. • Decommission 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). • Clean-up any contaminated soil around TSFs and dispose in TSF. • Grout decant outfall pipes and underdrain outfall pipes. • Cover tailings with appropriate soil/rockfill cover to: – Achieve final radiation, air quality (including radon), surface runoff quality, seepage, erosion and runoff closure performance criteria. – Prevent vegetation growth as a radiation pathway. • The TSF landforms will mimic the breakaway style feature, i.e. steep (20° to 25° side slopes with flat top surface. • Implement monitoring and care and maintenance programs.
TRS evaporation ponds	• Decommission evaporation pond plant and infrastructure and dispose. • Remove piping, pumps, liners, sediment and dispose in TSF. • Remove any contaminated soil materials and dispose to TSF. • Remove access tracks. • Batter slopes to stable erosion slope and rip along contours to relieve compaction. • Complete drainage and revegetation. • Implement monitoring and care and maintenance programs.
Topsoiling rehabilitation sites	• If topsoil is available: – inspect area and remove all rubbish and debris; – spread shallow topsoil to pond areas if available; – seed with local provenance species to blend with surrounding habitat.
Re-seeding rehabilitation sites	• A combination of hydro-mulching and direct seeding and planting would be used to revegetate rehabilitated areas. • Planting would be used for recalcitrant flora of local conservation significance. • Seed mixes would be developed for each major community type, with the proportions of each seed reflecting end-point criteria, seed quality and germination expectations. • Germination would be maximised by applying appropriate pre-treatments, such as scalding, smoke (water) treatment and scarification. • The RSF and Open pit would not be re-seeded, rather natural rehabilitation would occur.
Fauna habitat	• Where available, place fauna habitat structures e.g. logs, rocks and leaf litter/mulch in rehabilitated areas. • Target density would be determined by research and availability.
Fire control	• Develop revegetation strategy so that fire susceptibilities of rehabilitated areas are equivalent to analogue sites.
Surface drainage	• Re-contour rehabilitated sites to reinstate natural contours and drainage lines. • Reinstate natural contours and drainage lines on swales. • Where necessary provide surface water management features e.g. sedimentation basin, low cross-contour banks, spillway: – to return mine-scale surface water flows and quality to pre-mining; – to ensure that on a local scale concentrated flows do not damage rehabilitated areas or threaten their sustainability; – to ensure that ponding will drain sufficiently quickly and thus will not drown vegetation. • Contour rip all areas to relieve compaction and promote vegetation growth and infiltration. • Cross rip drainage lines to minimise erosion.
Roads and tracks	• Rip and seed all access tracks not needed for care and maintenance inspections and/or monitoring activities. • Re-contour dunes on dune crossings and remove clay/fill where present (e.g. haul roads) back to sand dune surface.
Closure of miscellaneous ponds	• Evaporate remaining liquor or remove to TSF. • Remove piping, pumps, liners, scuttle culverts and dispose. • 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 and revegetation.
Care and maintenance	• Install feral fauna controls if required. • Implement weed control where necessary, promoting natural seeding. • Manage grazing on newly revegetated areas using stock fencing if required.

Project component	Management approach
Shafts, raise bores and declines	• Remove miscellaneous concrete footings to a depth of around 500 mm. • Leave shaft foundations intact. • Cap shafts with concrete cover and cover if appropriate to do so i.e. if inspection of the cap is not required and a specific landform is desired. • 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. • Rehabilitate ponds (see Closure of miscellaneous ponds, above) at all raise bores. • Complete surface drainage, topsoiling and revegetation where appropriate and practical, and commence care and maintenance and monitoring.
Miscellaneous quarries and borrow pits	• Investigate and if possible obtain authorisation to use miscellaneous quarries and borrow pits for disposal of demolition debris and uncontaminated plant and equipment. • Transfer haul road base material onto pit walls and floor. • Cover any demolition debris to a suitable depth with appropriate cover material. • Complete surface drainage, topsoiling and revegetation where appropriate and practical, and commence care and maintenance and monitoring.
Backfill (limestone) quarry	• Bury uncontaminated plant, equipment and demolition debris, in selected area of quarry base. • Cover demolition debris to a suitable depth with any road and hardstand materials not suitable for surface rehabilitation purposes. • Construct appropriate surface drainage for the pit floor. • Transfer haul road base material onto pit walls and floor.
Roads	• Remove contaminated road base material (500 mm depth including road base and aggregate) to TSF for burial. • Remove remaining road base to backfill limestone quarry and/or TRS for use in rehabilitation. • Remove road base and other obstructions from drainage lines to minimise erosion. • Remove road base from dune crossings to adjacent borrow pits. • Remove barriers where they occur across drainage lines and carry out cross-contouring of drainage lines to minimise erosion.
Exploration areas	• Maintain register of any residual exploration areas disturbed at the mine as part of resource definition drilling activities. • Remove casing where appropriate. • Plug the holes at the surface with concrete.
Town facilities	• Remove all pipelines and services and those brought to surface during ripping (leave buried services >500 mm depth in place if they pose no significant environmental risk). • Remove contaminated materials to suitable landfill or TSF. • Remove bitumen surfaces, road base, concrete kerbing and footpaths to backfill limestone quarry and/or Town landfill. • Remove vegetation not indigenous to the area. • Where practical, salvage infrastructure (transportable elements). • Demolish fixed infrastructure.
Powerline and powerline corridor	• Remove powerline infrastructure. • Dispose of inert demolition debris within a suitable local landfill or in the backfill limestone quarry.
Miscellaneous areas	• Dispose of Waste Management Centre materials in suitable local landfill or in the backfill limestone quarry. • Rip up bitumen roads and underlying road base and dispose appropriately. • Remove lighting and other related infrastructure.
Wellfields and associated infrastructure	• Decommission production bores and cap (permanent). • Leave monitoring bores in place for post-closure monitoring. • Decommission lines and remove related surface infrastructure including breather valves, pump stations, powerlines and above ground piping. • 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. • Backfill ponds with any available wall materials and re-contour to blend with sand dunes or local landforms. • Deep rip compacted soil left by access tracks and hard-stand areas. • Remove related surface infrastructure.
Arid Recovery	• Investigate handing over to current partners – may entail financial support to ensure sustainability (e.g. endowment fund).

9 Level of studies and engineering

This Mine Closure and Rehabilitation Plan is based on an underground mine configuration and mining and production at 11 million tonnes per year (Mtpy) rates. BHP Billiton has gained government approval to introduce open pit mining to the current underground operation, as well as plant expansions to increase the processing rate. The possibility of the introduction of an open pit provides the potential for substantial overburden material and therefore significant opportunities for improving the closure design for the tailings storage facility cover (which historically has represented the major environmental, health and cost component of closure planning at Olympic Dam). A more detailed study of TSF closure, including a long term assessment of risk from closure to 10,000 years, modelling of alternative covers for the TSF, and proposed on-ground trials of preferred covers, has been carried out and is described further in section 10 and at Appendix A.

In the event of an alternative mine configuration being adopted, options for the provision of material for the TSF cover will be further investigated at that time.

In addition, given the long remaining mine life (approximately 70 years) at Olympic Dam, engineering for closure has not been progressed beyond concept level. This level of studies and engineering is nevertheless consistent with the guidance (ICME, 2008), and adequate and sufficient for estimating closure costs within desired limits of accuracy.

10 TSF Closure modelling

Both the Major Development Approval and the EPBC Act approval contained conditions related to mine closure. Specifically, the EPBC Act approval contains a requirement to:

> *32. Within two years of the date of this approval, or prior to construction of the tailings storage facility, whichever date is the earliest, the program required under condition 4 must be revised to include a mine closure plan. The mine closure plan must:*
>
> > *[…]*
> >
> > *c. be revised prior to construction of the tailings storage facility to include a comprehensive safety assessment to determine the long-term (from closure to in the order of 10,000 years) risk to the public and the environment from the tailings storage facility and rock storage facility. The safety assessment must include:*
> >
> > > *[…]*
> > >
> > > *ii. modelling of alternative covers for the tailings storage facility to develop a preferred cover using industry best practice models, including models that assess the long term erosion of the final proposed landforms.*
> >
> > *[…]*
> >
> > *h. propose on-ground trials during operations that demonstrate the feasibility and improve the viability of the proposed remediation strategies, including site trials of the preferred covers.*

Although tied to construction of the new (expanded) tailings storage facility, and therefore not yet required, the modelling of alternative covers and proposals for site trials have been completed.

O'Kane Consultants Pty Ltd. (OKC) was engaged 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 a conceptual cover system and landform designs and to determine locations for full scale cover trials on the existing Olympic Dam TSFs. Erosion assessments were also carried out to develop the final landforms and cover systems.

Material characteristics used for the assessment were 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.

A Water Erosion Prediction Program was used to simulate current and design batter slopes. 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.

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 full text of the report is provided in Appendix A

11 Closure schedule

11.1 Final closure and rehabilitation

This Mine Closure and Rehabilitation Plan is based on the current underground mine configuration and mining and production rates. It also includes the expansion components that were commenced prior to deferral of activies (including clear and grub of the open pit and construction of an initial base layer for the RSF). The current Life of Asset Base Plan indicates that the mining operations will cease in 2087, at which stage mine closure activities would commence.

Detailed planning for final mine closure execution (i.e. residual demolition, disposal and earthworks) would commence 5 to 10 years before the scheduled closure date for the mining and processing operations. Rehabilitation and closure (inclusive of progressive rehabilitation) will commence, at the latest 10 years prior to the expiry of the Australian Government approval (EPBC 2005/2270), or as amended by subsequent approvals.

BHP Billiton is currently studying and assessing alternative options for mining and processing of the Olympic Dam orebody. It is possible that the scheduled closure date could change if the mining and processing configurations are further modified. This closure plan will be revised to reflect any changes in operating parameters that give rise to a change in the final mine closure schedule.

11.2 Progressive closure and rehabilitation

BHP Billiton recognises that the progressive rehabilitation of mining disturbances while the operation is still active plays an important role in closure planning. BHP Billiton is committed to progressive rehabilitation where practical (i.e. where the rehabilitation opportunity meets criteria established to assess the value of progressively rehabilitating a particular area).

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 disturbed by mining activities;
- reduces the residual disturbance to be rehabilitated at final closure; and
- provides evidence to stakeholders that BHP Billiton 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. Progressive rehabilitation opportunities that have been identified for Olympic Dam include:

- general disturbed areas across the site that are no longer used or required;
- the metallurgical pilot plant facilities that are no longer used, but which fall within the expansion limits of an open pit configuration and which may be used for future trials (e.g. heap leaching) including:
  - pilot plant;
  - tailings ponds;
  - haul road;
- rock, sand or clay borrow pits that have been mined out;
- exploration areas that have not yet been rehabilitated;
- tailings storage facility Cells 1 to 3 which have reached their current design height (30 m)

Of these, some specific conditions have been identified:

- The earliest practical rehabilitation commencement date for TSF Cells 1 to 3 is 2025. These cells provide significant benefit in managing the tailings water inventory and hence in managing risk associated with potential seepage.The closure planning for the TSFs may also change if the mining operation is modified from underground to an open- pit, as this would give rise to a significant opportunity to reduce the disturbance footprint by incorporating the cells in a larger cell constructed to increased height using waste rock from the pit. The earliest practical commencement schedule incorporates:
  - a period for drainage and drying of the TSF cells
  - trial studies, construction and monitoring based on the closure modelling studies conducted by O'Kane consultants (see section 10 and Appendix A)
  - a further period for planning and studies in preparation for final cover construction

- The pilot trial area, currently scheduled for closure at the end of operating life currently falls within an area that may be used in future expansions, and hence is currently not a candidate rehabilitation site. The area may become a candidate for rehabilitation if a final decision is made in future studies that this area will definitely not be used for any future expansions.

11.3 Relinquishment planning

The current closure planning nominally allows for a post-closure care and maintenance and monitoring period leading up to relinquishment of 10 years.

While this may appear to be a short duration in terms of demonstrating the stability of landforms and tailings closure covers, it is not unreasonable given that evidence for these will be gathered from the studies, research, implementation and monitoring of Olympic Dam whilst in operation and progressive rehabilitation works.

It is however recognised that the actual relinquishment period will be determined by the duration required to fully demonstrate that the residual closure works achieve the closure performance criteria, and that the care and maintenance period may extend beyond 10 years.

A more accurate estimate of the relinquishment period will be established in the detailed planning period leading up to final closure, when the performance criteria and likely monitoring durations for the residual closure works can be established.

12 Risk management

Rehabilitation and closure risk register

Closure risk management requires an iterative approach that aims to eliminate or reduce 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.

A closure risk assessment for each domain has identified potential pre- and post-closure risk events related to the rehabilitation and closure of Olympic Dam. The risk assessment draws from internal assessments undertaken by BHP Billiton staff and the numerous risk assessment workshops conducted for the Olympic Dam Expansion Project EIS (BHP Billiton 2009). The risk events from these workshops have been ranked and classified using the risk criteria provided in Tables 5, 6 and 7 (these are a combination of the risk criteria provided by the South Australian Government in its guidance note to BHP Billiton and those commonly applied by BHP Billiton).

The South Australian Government provided example risk assessment tables to be completed and incorporated into this Plan. Appendix A provides these tables, with one table provided for those aspects common to all nine closure domains, along with separate tables that address risks specific to each domain. The outcomes of these risk and residual risk assessments guide the development of control strategies, monitoring programs and financial provisioning.

The tables in Appendix A define the actual and/or credible potential impact events associated with closure and post closure activities. The impact event analysis identifies the (DMITRE, 2012):

- Source / Event (the aspect of the mining operation that may cause an impact, e.g. erosion from the tailings storage facility)
- Pathway (how the source or event reaches the receptor, e.g. wind, rainfall erosion)
- Barrier (any features of the environment that impede the pathway to the receptor)
- Receptor (human, fauna, flora etc.)
- Impact / Consequences (scope, ability to remediate, duration, cumulative effects etc)

An initial risk assessment is then carried out that analyses the likely impact/consequences of each impact event. Following consideration of controls and management measures, remaining residual risks are evaluated. Residual risks remaining evaluated as high or moderate were then flagged as requiring an outcome, and an assessment of proposed outcomes compliance criteria is provided in the linked table.

Table 5: Likelihood look-up table

A	**Almost Certain**	Could occur more than once in a year, or is of a continuous nature, or the likelihood is unknown.
B	**Likely**	Could occur over a one or two year budget period and will probably occur during the mine lifetime. Has generally occurred in similar projects.
C	**Possible**	Could occur in most mines and has occurred in a minority of similar projects.
D	**Unlikely**	Could occur in some mines, but is not expected to occur.
E	**Rare**	Has almost never occurred in similar mines but conceivably could.

Table 6: Consequence look-up table

1	**Insignificant**	Possible impacts but without noticeable environmental consequence; no medical treatment required; or low level social impact.
2	**Minor**	Very local consequence with no significant long-term changes; medical treatment injury; may be simply rehabilitated or alleviated at some cost without outside assistance; not of significant concern to wider community.
3	**Moderate**	Significant local environmental changes but can be rehabilitated or alleviated with difficulty at significant cost and with outside assistance; days lost due to injury; or moderate, medium-term social impacts.
4	**Major**	Substantial and significant environmental changes only partially able to be rehabilitated or alleviated at major cost; single fatality; or significant public concern.
5	**Catastrophic**	Serious or extensive environmental changes (not able to be practically or significantly rehabilitated or alleviated); multiple fatalities; widespread health effects on public; extensive and long term social impacts with serious public or media outcry; or the consequences are unknown.

Table 7: Resulting risk level

			Likelihood				
			E	**D**	**C**	**B**	**A**
			Rare	**Unlikely**	**Possible**	**Likely**	**Almost certain**
Consequence	**1**	**Insignificant**	Low	Low	Low	Moderate	High
	2	**Minor**	Low	Low	Moderate	High	High
	3	**Moderate**	Moderate	Moderate	High	High	Extreme
	4	**Major**	High	High	Extreme	Extreme	Extreme
	5	**Catastrophic**	High	Extreme	Extreme	Extreme	Extreme

The risk assessment across the nine domains identified 64 possible risk events / situations (see Appendix A).

The initial risk assessment (i.e. the assessment excluding control strategies) identified:

- 8 extreme risks;
- 21 high risks;
- 16 moderate risks; and
- 21 low risks.

The residual risk assessment (i.e. the assessment incorporating control strategies) identified:

- 0 extreme risks;
- 5 high risks;
- 11 moderate risks; and
- 50 low risks.

Closure outcomes and measurement criteria have been developed for all of the high and moderate residual risks (see Appendix A). The high risks, and the assessment of their associated likelihood, relate to:

Impact event	Likelihood
Closure cost estimate and financial provision is incorrect	Unlikely
Slope failure of the Tailings Retention System	Rare
Erosion of the Tailings Retention System slopes	Unlikely
Tailings Storage Facility cover thickness not adequate for long term radiation safety and/or tailings containment	Rare
Injury to a member of the general public from whatever cause associated with the open pit	Unlikely

13 Post-closure monitoring, care and maintenance plan

A detailed post-closure monitoring and care and maintenance plan will be developed during the detailed planning for final closure to ensure that:

- there is sufficient and appropriate monitoring in place to be able to track and demonstrate the achievement of closure performance criteria for the various closure landforms;
- there is a management plan in place to model the post-closure performance to provide predictive assessments of the post-closure landforms e.g. drain-down of the TSFs;
- there are sufficient resources 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;
- there are adequate financial provisions to carry out the above activities, with a contingency allowance for post-closure 'risk events' (i.e. as per those discussed above and detailed in Appendix A).

Specific monitoring and care and maintenance planning will be required for the closed TSF cells and for other rehabilitated landforms. Preliminary requirements for post-closure inspections and monitoring are described below (see also Appendix A which lists the specific aspects to be monitored to address the high and moderate residual risks).

13.1 Tailings storage facility

Monitoring and inspections

A geotechnical assessment of the stability of each tailings storage cell would be carried out prior to closure, leading to the closure design for that facility.

After closure, monitoring and inspection of the TSFs post-closure would include:

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

The monitoring frequency would be based on the findings of the progressive rehabilitation trials. It is estimated that the inspection and monitoring frequency would be of the order of six monthly for the first two to three years following closure works, extending to annually until relinquishment. Radiation levels would be monitored more frequently.

An inspection and monitoring report would be compiled after each inspection, including follow up of any care and maintenance work recommended in previous reports. The report would be submitted to the appropriate regulatory agency responsible for the confirmation of TSF closure completion criteria (PIRSA). (Note that wherever possible, PIRSA would be invited to participate in the geotechnical inspection visits).

13.2 Open pit and rock storage facility

For the timeframe of this current closure plan, further work on the open pit and RSF has ceased. The open pit has not reached a sufficient depth to intersect the underlying groundwater aquifers 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 general public from whatever cause. To mitigate this risk:

- Appropriately sized and located hazard warning signs will be installed around the open pit and RSF perimeter;
- Access roads into the pit and onto the RSF will be deep ripped to discourage vehicle access and encourage revegetation; and
- Geotechnical studies would 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, an abandonment bund and/or fencing would be constructed around the perimeter of the pit outside the zone of potential pit-wall subsidence.

Monitoring and inspections associated with the open pit and RSF would be undertaken to ensure that appropriately sized and located warning signs were installed and maintained, that the entry roads to the open pit and RSF had been deep ripped and that an abandonment bund/fence was in place around areas of the open pit prone to subsidence. This monitoring would occur on a six monthly basis for the first two to three years following closure works, extending to annually until relinquishment.

13.3 Rehabilitated sites

The framework for the rehabilitation monitoring program would be based on Ecosystem Function Analysis (EFA), described in Kearns and Barnett, 1998.

The actual post-closure monitoring and care and maintenance timeframe will depend on the complexity of the closure landform, the post-closure land-use, and the completion criteria. For the purpose of closure financial provisioning, rehabilitation monitoring is estimated to occur for 10 years after closure. Post-closure monitoring activities for which costing has been included in the provision are summarised in Table 8.

Table 8: Approximate post-closure monitoring requirements

Item	Frequency
Ecosystem function analysis	1st, 2nd, 3rd, 5th and 10th years
Groundwater monitoring and analysis	Annually
TSF, RSF and open pit	Six monthly for the first 2-3 years – then annually
Waste disposal and capacity inspection	Annually
Fauna survey	1st, 2nd, 3rd, 5th and 10th years
Weed/feral animal control and inspection	Quarterly in first year and then annually to year 10
Radionuclides in groundwater and soil	Annually
Radon concentrations and gamma radiation	Continuous (using passive devised changed quarterly) until relinquishment
GAB recovery monitoring	Quarterly in first year and then annually to year 10

13.3.1 Components of EFA

EFA comprises three components (Kearns and Barnett, 1998):

- landscape function analysis (LFA), in which the site is assessed with respect to the control of vital resources, such as water, organic matter, nutrients and propagules;
- vegetation dynamics, in which species composition and growth characteristics are assessed in relation to LFA;
- habitat complexity, in which the habitat quality for a range of vertebrate fauna is assessed.

13.3.2 Monitoring program

An amended EFA monitoring program that addresses all three components would be prepared and conducted on an annual basis, following initial rehabilitation works and until satisfactory trajectories are determined. The amendments are described below. Additional monitoring related to other programs that would be carried out during and after rehabilitation and closure is listed in Table 9.

13.3.2.1 Soil profile reconstruction

To ensure that reconstructed soil profiles are prepared in accordance with the rehabilitation design and that there are no unconsidered limiting factors to plant re-establishment, each year's rehabilitation block would be sampled, prior to topsoil replacement. Sampling would involve digging one or more test pits in the newly prepared ground and assessing the exposed soil profile, having particular regard for soil compaction parameters. Sampling sites would be representative of the wider rehabilitated area, but would also include specific habitat types, such as sites that would be designed for store-and-release (if any), deep draining or high value flora.

13.3.2.2 Vegetation monitoring

Qualitative assessment of rehabilitation would be undertaken on a regular basis during the first growing season following establishment, and up to 15 months of age. Seed germination, plant establishment and survival, species richness and weed establishment would be key parameters monitored during this period.

Quantitative monitoring of rehabilitation would commence in the second spring following rehabilitation (15 months) and continue on an annual basis until the third assessment, at which time the monitoring interval would be extended to a triennial basis (once every three years).

The following procedure would be developed and implemented.

- Permanent belt transects of 20 contiguous 1 m x 1 m quadrats would be established using metal fence droppers with an orientation perpendicular to the contour ripping so as not to be influenced by a single rip line.
- A hand-held GPS would record the start and end coordinates of each transect.

- The start point of the transect line would be utilised as a permanent photographic point with the photo taken directly along the transect line.
- For each species within a quadrat the number present, percentage ground cover, and maximum plant height would be recorded. Summarised data would provide mean density values (no. plants per square metre), mean percentage ground cover, and mean maximum plant height, and an importance value index (or IVI), which considers frequency, density, and cover for each species recorded along a transect line.
- Rehabilitation blocks (as distinguished by vegetation type and rehabilitation age) would be sampled with adequate replication of permanent belt transects to ensure the data is representative of the vegetation present. This would be demonstrated via graphing of 'species-area curves'.

13.3.2.3 Soil and landform description

A soil and landform description would be made using the following data collected from five quadrats along each permanent belt transects:

- soil texture and upper soil profile (0-–30 centimetre (cm)) assessment;
- soil surface roughness and resistance to disturbance (semi-quantitative measure ranked from 1 to 5);
- observations on erosion type and severity (semi-quantitative measure from 1 to 5);
- incorporation and subsequent deposition of coarse organic debris and type (semi-quantitative measure from 1 to 5);
- per cent bare ground;
- per cent cryptogam cover;
- per cent litter cover and type.

13.3.2.4 Topsoil nutritional status

Topsoil would be sampled annually to determine long-term trends in soil nutrition. Three sub-samples would be collected along each permanent monitoring transect and a random selection of combined samples would be sent for laboratory analysis. The following parameters would be analysed:

- per cent organic carbon;
- pH;
- electrical conductivity;
- exchangeable sodium percentage (ESP);
- nitrate and ammonium nitrogen;
- phosphorus;
- potassium;
- exchangeable cations;
- trace elements (e.g. copper, zinc, manganese, boron).

13.3.2.5 Erosion monitoring

Post-closure monitoring would be undertaken to confirm all earthworks were stable, substrates where suitably hospitable to vegetation and surface water movement was not significantly impeded or causing large scale erosion. Erosion would be assessed by visual inspection of all disturbed areas on a six monthly basis during the first two years or immediately following significant rainfall or wind events. Annual inspection would occur after two years.

Table 9: Additional monitoring

Issue	Monitoring objective	Parameters
Health of non-human biota	To ensure that vegetation in the natural and rehabilitated environments does not pose an unacceptable risk to the health of non-human biota	• key metals on soils and vegetation (including radiation decay products)
Fauna re-establishment	To identify use of, and pressures on, fauna habitat in rehabilitated areas	• same method as per baseline surveys (for comparison) • quantitative assessment of ant and spider holes, lizard burrows, animal scats
Feral animals	To ensure feral animals do not compromise rehabilitation performance	• number/impact of feral animals
Grazing pressure	To ensure grazing impacts do not compromise rehabilitation performance	• visual indicators of excessive or selective grazing

Issue	Monitoring objective	Parameters
Weeds	To ensure weed impacts do not compromise rehabilitation performance	• numbers and diversity of weed species along transects and disturbed areas

13.4 Care and maintenance of rehabilitated areas

Ongoing care and maintenance will be carried out on rehabilitation areas that do not achieve the agreed rehabilitation standards to bring them up to the necessary standard. The rework will be determined by the cause of the lower than prerequisite standard, and by what residual work is required to achieve the agreed completion standards.

14 Financial provisioning

14.1 Rehabilitation and closure accounting provision

BHP Billiton 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 Billiton accounts for closure provisions and the Group wide closure provision is described in the publically accessible BHP Billiton Annual report.

BHP Billiton 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 Life of Asset planning. If the asset (project) is shut suddenly, BHP Billiton 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.

14.2 Providing for unplanned closure scenario

Site closure may be initiated in a number of different scenarios including: planned closure, unplanned or sudden closure and temporary closure (ANZMEC/MCA, 2000).

Although some of the objectives, processes and implementation timeframes would vary for each scenario, the BHP Billiton Group aspiration to ‘zero harm’ would still apply. BHP Billiton internal requirements and planning processes, together with BHP Billiton’s strong global resource diversity, would ensure that adequate financial provisioning would be in place to ensure that mine closure would be conducted to the satisfaction of the project’s stakeholders.

14.3 Unplanned closure

Best Practice (e.g. ICMM, 2008; ANZMEC/MCA, 2000) requires that closure planning recognise and allow for the risk of sudden, forced and/or early mine closure by preparing contingencies that take into account the site’s non-productive status.

In the event that the Olympic Dam operation is required to close earlier than forecast, the mining operations would continue to be treated as an operational asset under the BHP Billiton 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.

At the earliest possible time, a risk assessment would be conducted and any measures required to ensure ongoing health and environmental compliance would be implemented as soon as practicable. The Mine Closure and Rehabilitation Plan would be reviewed and revised, with the foundations of the new plan being a consultative risk assessment of the operations at the time, with the aim of identifying priority issues and assigning appropriate management resources to achieve an acceptable and timely outcome.

As the TSF cells will be closed progressively as soon as practicable after they have been filled, the residual closure activities in the event of unplanned closure will be significantly less compared with an operation that is not able to progressively rehabilitate.

14.4 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.

15 References

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

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Kinhill-Stearns Roger Joint Venture 1982, *Olympic Dam Project: Draft Environmental Impact Statement*, report to Roxby Management Services Pty Ltd, Adelaide.

Minerals Regulatory Guidelines MG2 V 4.11, January 2011 Mining Act 1971 35 - Guidelines for miners: preparation of a mining lease proposal or mining and rehabilitation program (MARP) in South Australia.

Mining Code 2005 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)

Appendix A Closure risk assessment

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Appendix A-1 All domains

Table A-1: Closure and rehabilitation risks common to all domains – initial and residual risk assessment (links to Table A-2 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
1	Economic	Public welfare	Closure cost estimate provision (and / or life of asset) is incorrect	1. Inadequate closure planning, stakeholder engagement, engineering and design, and cost estimates 2. Unplanned changes	Correct financial provisioning	Human	1. Increased closure costs 2. Reputational issues	C	4	Extreme	BHP Billiton conducts an annual review of its Olympic Dam Mine Closure and Rehabilitation Plan, reviewing closure works, risks, costs, stakeholder engagement and post-closure maintenance and monitoring, dependent on projected mine activities. This review process includes consideration of relevant closure progress identified in the Environmental Protection and Management Program (EPMP: OD49329) and the annual EPMP report.	D	4	High	Y
2	Economic / Social	Public welfare, land, air, water	Closure studies and execution works are not managed adequately	1. Inadequate closure planning, stakeholder engagement, engineering and design 2. Late commencement of studies and design	Appropriate management of closure studies and execution works	Human	1. Increased closure costs (un-optimised designs and plans) 2. Closure plan not well understood and requires re-work 3. Reputational issues 4. Regulatory non-compliance	C	4	Extreme	Annual review of Olympic Dam Mine Closure and Rehabilitation Plan and commissioning of highly experienced project managers.	D	3	Moderate	Y
3	Economic / Social / Natural	Public welfare, land, air, water	Some closure risks are not identified and thus not addressed in closure planning	1. Failure to identify all possible closure risks 2. Closure planning is not aligned with operations	Appropriate risk management, with risks reviewed annually	Human	1. Increased closure costs 2. Extended post-closure monitoring and care and maintenance period 3. Closure commitments not fulfilled, resulting in adverse impacts	C	4	Extreme	Annual review of Olympic Dam Mine Closure and Rehabilitation Plan including the risk assessment section and tables, and commissioning of highly experienced project managers to understand the changing closure risks as the project operations progress.	E	3	Moderate	Y
4	Economic / Social	Public welfare, land, air, water	Early closure is not considered in closure planning	1. Poor or inadequate closure planning 2. Incorrect assessment of asset value and/or life. 3. Loss of licence to operate through major HSEC incident or breach of operating licence	Regular and appropriate closure planning	Human	1. Inadequate closure provision 2. Risks of early closure not fully understood when making early closure decisions 3. Community outrage 4. Loss of employee morale	C	4	Extreme	BHP Billiton has integrated closure planning into their Life of Asset planning for Olympic Dam (with Life of Asset being a functional group within each operation, focused on the broader picture of the operation's total mine life). This planning includes the risk of sudden, forced, temporary and/or early mine closure.	D	1	Low	N
5	Economic	Public welfare	BHP Billiton is unable to relinquish the mining tenements and leases	1. Failure to execute closure works to agreed standard 2. Failure to demonstrate to government that in taking over closed site, risk to the government and public are acceptably low 3. Public/ NGOs pressure on government not to accept closed site	Adequate closure / realistic expectations	Human	1. In-perpetuity care and maintenance 2. Increased post-closure costs prior to obtaining relinquishment (incl. rehab, legal, stakeholder) 3. Reputational issues	C	4	Extreme	Annual review of Olympic Dam Mine Closure and Rehabilitation Plan and commissioning of highly experienced project managers to successfully close the site. A high-level stakeholder engagement program for closure will be developed at the appropriate time and this program will be provided to DMITRE for review and comment. The program will incorporate a Community Relations Plan and a closure commitments and obligations register.	C	1	Low	N
6	Social	Public safety	Vehicle collisions on public roads	Decommissioning vehicles	Seat belts / driver education	Human	Injury/ fatality	D	4	High	Speed restrictions, licencing, maintenance of vehicles and driver fatigue training	E	3	Moderate	Y
7	Social	Public safety	Drop load on person (off-site)	Transport and handling of heavy loads	Adequate safety procedures	Human	Injury/ fatality	D	4	High	Proper securing of loads as per normal operating procedures and safety exclusion zones around the handling of heavy loads	E	2	Low	N
8	Social	Public health	Increase in noise output, exceeding limits	Air, wind	Distance between mine site and residential properties	Human	Public annoyance	C	2	Moderate	Decommissioning plan would include guidelines to limit noise and would consider all relevant legislation and regulations. Any activities expected to generate significant noise would be conducted during the daytime.	D	2	Low	N
9	Social	Public health	Increase in dust output, exceeding limits	Wind	Distance between mine site and residential properties	Human	Public annoyance and possible health impacts	C	2	Moderate	Decommissioning plan would include guidelines to minimise dust generation including the use of water trucks and restricting dust generating activities in windy conditions. Dust monitoring would be a component of the plan.	D	2	Low	N
10	Social	Public safety	Increase in traffic (off-site)	Vehicles used for decommissioning activities		Human	Public annoyance	C	2	Moderate	The majority of decommissioning activities will be conducted during the day; will occur under a Traffic Management Plan and will have Police escorts where required.	D	2	Low	N
11	Social	Public safety	Entrance into site by the general public resulting in injury	Vehicle / on foot	Fencing, monitored entrance gate, isolated site	Human	Injury	C	3	High	Security fencing would remain around the mine site, and hazardous sites during closure. Routine security patrols would also be conducted around the mine site during the closure period and up to relinquishment.	D	3	Moderate	Y

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
12	Natural	Land	Loss of inert materials on-site or off-site	Haul vehicles used for decommissioning activities	Covered loads	Native flora and fauna	Loss of habitat for native flora and fauna, public annoyance	D	2	Low	Haul loads would be covered to secure loads. Sites would be remediated and rehabilitated as per the Decommissioning Plan prepared and submitted to DMITRE for review and comment at least 12 months prior to planned closure (or within one month of unplanned closure).	D	1	Low	N
13	Natural	Land	Inadvertent clearing or damage to land outside the approved zone	Vehicles used for decommissioning activities	Driver education	Native flora and fauna	Loss of habitat for native flora and fauna	D	2	Low	The Decommissioning plan would specify no-go zones. Sites would be remediated and rehabilitated as per the Decommissioning Plan prepared and submitted to DMITRE for review and comment at least 12 months prior to planned closure (or within one month of unplanned closure).	D	1	Low	N
14	Natural	Land	Introduction of unwanted species that impacts native biota	Vehicles used for decommissioning activities	Routine monitoring and control of unwanted species	Native flora and fauna	Loss of habitat for native flora and fauna	C	2	Moderate	All vehicles from known infested areas are required to adhere to wash down procedures (as per the internal BHP Billiton Environmental / Indigenous Heritage Clearance Permit (EIHCP) procedure: OD 56830). Post decommission vegetation monitoring will identify changes in the flora and corrective action will occur if required.	D	2	Low	N
15	Natural	Land, water	Fuel spill on-site	Re-fuelling, breach of fuel tanks	Bunding design, build and maintenance	Native flora and fauna, surface water	Soil contamination and contamination of downstream water bodies (i.e swales and clay pans)	D	2	Low	As per BHP Billiton procedures (Hazardous Materials Management – OD 100614) , fuel storage and refuelling would take place in designated, bunded areas.	D	2	Low	N
16	Natural	Land, water	Erosion of rehabilitated landforms (other than TSF, RSF and open pit)	Rainfall, surface water movement into swales and clay pans	Design and build of stable landforms	Surface water	Turbidity and / or contamination to downstream receiving environments (i.e. swales and terminal clay pans)	C	3	High	Decommissioning plan (to be developed at least 12 months prior to planned closure or within one month of unplanned closure) will include instruction to reinstate natural contours (i.e. dune/swale systems with terminal clay pans) , recommending the use of surface water management features where necessary. Revegetation will minimise the risk of erosion.	D	2	Low	N

Table A-2: Closure and rehabilitation risks common to all domains - development of closure outcomes and measurement criteria (links to Table A-1)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
1	Closure cost estimate provision (and / or life of asset) is incorrect	Sufficient accounting provision provided to close Olympic Dam in a manner consistent with the Decommissioning Plan.	Fulfilment of closure commitments as per the Decommissioning Plan, or an alternate arrangement as agreed by BHP Billiton and relevant Regulators / Stakeholders	Fulfilment of closure commitments as documented in the Decommissioning Plan (which will include closure commitments and an obligations register)	All areas relevant to the 8 closure domains	Fulfilment of commitments and obligations	Decommissioning Plan to be developed at least 12 months prior to planned closure or within one month of unplanned closure. Annual post closure review of plan and closure costs and up until relinquishment	The Decommissioning Plan (which will include closure commitments, an obligations register and estimated closure costs)
2	Closure studies and execution works are not managed adequately	Closure studies and execution of site closure is managed to achieve the commitments and obligations as per the Decommissioning Plan.	Fulfilment of closure commitments as per the Decommissioning Plan, or an alternate arrangement as agreed by BHP Billiton and relevant Regulators / Stakeholders	Fulfilment of closure commitments as documented in the Decommissioning Plan (which will include closure commitments and an obligations register)	All areas relevant to the 8 closure domains	Fulfilment of commitments and obligations	Decommissioning Plan to be developed at least 12 months prior to planned closure or within one month of unplanned closure. Annual post closure review of plan	The Decommissioning Plan (which will include closure commitments, an obligations register)
3	Some closure risks are not identified and thus not addressed in closure planning	All significant closure risks are included in the Decommissioning Plan, allowing BHP Billiton to fulfil its closure commitments and obligations.	Fulfilment of closure commitments as per the Decommissioning Plan, or an alternate arrangement as agreed by BHP Billiton and relevant Regulators / Stakeholders	Fulfilment of closure commitments as documented in the Decommissioning Plan (which will include closure commitments and an obligations register)	All areas relevant to the 8 closure domains	Fulfilment of commitments	A technical closure design risk assessment will be undertaken by 2020 and will be reviewed triennially. The Decommissioning Plan will be developed at least 12 months prior to planned closure or within one month of unplanned closure. Annual post closure review of plan	The outcomes of the initial and triennial technical closure design risk assessment (to be incorporated into this Mine Closure and Rehabilitation Plan). The Decommissioning Plan (which will include closure commitments and an obligations register)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
6	Vehicle collisions on public roads	No fatalities due to vehicle collisions during the closure period.	0 fatalities	Public injuries/ fatalities resulting from vehicle use during decommissioning activities.	Hiltaba Village, Roxby Downs and public road systems surrounding the SML.	0 fatalities	All incidents will be reported immediately and at least within 24 hours. Incident reports will be assessed against the closure outcome annually.	Incident reports
11	Public safety	No unplanned general public entrance to the site that results in injury.	0 general public injuries on site during closure	Access to the site and injuries to the general public	SML	0 injuries	All incidents will be reported immediately and at least within 24 hours. Incident reports will be assessed against the closure outcome annually.	Incident reports

Appendix A-2 Closure Domain 1: Airport

Table A-3: Initial and residual risk assessment (links to Table A-4 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
17	Natural	Land / Social	Failure to remediate soil contamination and/or avoid weed infestation	1. Contaminants used and stored at the airport 2. Fleet and machinery used for closure activities	Bunding design, build and maintenance Routine monitoring and control of unwanted species	Human, native flora and fauna	1. Soil contamination and contamination of downstream water bodies (i.e swales and clay pans) 2. Loss of habitat for native flora and fauna via competition	C	3	High	Contaminated areas assessed and remediated in accordance with NEPM 1999 and SA EPA requirements under the Environment Protection Act, or relevant criteria at the time of closure. All vehicles from known infested areas are required to adhere to wash down procedures (as per the internal BHP Billiton Environmental / Indigenous Heritage Clearance Permit (EIHCP) procedure: OD 56830). Post decommission vegetation monitoring will identify changes in the flora and corrective action will occur if required.	C	2	Moderate	Y
18	Natural	Land, fauna flora	Failure to adequately rehabilitate the airport runway	Poor closure planning and rehabilitation	Appropriate management to ensure the runway is adequately rehabilitated	Native flora and fauna, human	1. Loss of habitat for native flora and fauna 2. Visual amenity	C	2	Moderate	Rehabilitation of the decommissioned runway, , inspections of the rehabilitated runway on completion and quarterly thereafter for the first two years, then annually until relinquishment. Corrective action (i.e. further rehabilitation works) until erosion resistant landforms are achieved.	D	1	Low	N
19	Natural / Social	Public safety	Power lines not adequately decommissioned and / or removed	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure the powerlines are adequately decommission ed	Human	1. Injury / fatality 2. Inefficient resource usage	D	4	High	Decommissioning and removal of powerlines. Inspection after removal to ensure the powerlines have been removed. Corrective action if they have not been removed.	D	2	Low	N
20	Natural / Economic	Social welfare/ Land	Inadequate provision for waste disposal	1. Inability to use current landfill facilities in township 2. Insufficient volume in on-site quarries	Closure planning to ensure appropriate waste management	Human	1. Increased cost of waste disposal 2. Stresses on local waste management services and facilities	C	2	Moderate	A waste control management plan will be developed as part of the decommissioning plan, estimating the volumes of waste materials for off-site disposal. Planning to manage this waste volume will then occur prior to closure. The waste management performance will be monitored and reported annually post-closure and up until relinquishment.	D	2	Low	N
21	Natural / Economic	Land, resources	Loss of control of recyclable waste	1. Poor waste management procedures 2. Failure to follow procedures	Appropriate management with regard to recyclable wastes	Natural resources	1. Loss of economic benefit 2. Inefficient resource usage	C	1	Low	Ferrous scrap and other recyclable materials are to be recycled off site. The waste management control plan developed as part of the decommissioning plan will provide details and the performance in this regard will be monitored and reported annually post-closure and up until relinquishment.	C	1	Low	N
22	Natural	Land	Failure to remove all of the facility structures	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure all facility structures are removed	Human, native flora and fauna	1. Visual amenity 2. Loss of habitat for native flora and fauna	C	2	Low	Inspections would be conducted following demolition works to ensure work completed to Decommissioning Plan. The performance in this regard will be monitored and reported annually post-closure and up until relinquishment.	D	2	Low	N

Table A-4: Development of closure outcomes and measurement criteria (links to Table A-3)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
17	Failure to remediate soil contamination and/or avoid weed infestation	1. 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. 2. 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.	Contaminated areas assessed and remediated in accordance with NEPM 1999 and SA EPA requirements under the Environment Protection Act, or relevant 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.	1. Contaminants in accordance with NEPM 1999 and SA EPA requirements under the Environment Protection Act, or relevant criteria at the time of closure. 2. Weed species and ecosystem diversity	Areas impacted by the airport and downstream environs	Fulfilment of NEPM 1999 and SA EPA requirements under the Environment Protection Act, or relevant criteria at the time of closure.	Following remediation works and annually thereafter until relinquishment.	The Decommissioning Plan (which will include closure commitments and an obligations register)

Appendix A-3 Closure Domain 2: Town facilities

Table A-5: Initial and residual risk assessment (links to Table A-6 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
23	Natural / Economic	Land, resources	Loss of control of recyclable waste	1. Poor waste management procedures 2. Failure to follow procedures	Appropriate management of recyclable wastes	Natural resources	1. Loss of economic benefit 2. Inefficient waste disposal	C	1	Low	Ferrous scrap and other recyclable materials are to be recycled. Road base materials are to be used to line specific landfill sites and / or disposed of in the TRS. Volume of recyclable materials will be dependent on the number of facilities to be decommissioned, which will be determined via future stakeholder consultation.	C	1	Low	N
24	Natural	Land	Failure to remove non-native vegetation	Wind, animal	Adequate pest management	Native flora and fauna	Infestation of weeds and non-native flora into region	D	2	Low	Decommissioning Plan includes the removal of non-indigenous vegetation from Olympic Village. A post-works survey and rectification will occur as required for the period up until relinquishment.	D	2	Low	N
25	Natural	Groundwater surface water	Seepage from Olympic Dam sewage ponds	Infiltration, runoff	HDPE liner, clay, limestone	Receiving environment groundwater	Contaminated downstream receiving environment and potentially groundwater impacting third party users	C	2	Moderate	Ponds are HDPE lined and underlain by clay and limestone (and thus natural attenuation occurs – see BHP Billiton 2009; Section 12.6.2; BHP Billiton 2011 Section 12.3). Ponds will be capped on closure to reduce infiltration.	D	1	Low	N

Table A-6: Development of closure outcomes and measurement criteria (links to Table A-5Table 5)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
None required								

Appendix A-4 Closure Domain 3: Metallurgical plant and administration facilities

Table A-7: Initial and residual risk assessment (links to

Table A-8 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
26	Social	Public safety	Failure to decontaminate materials / equipment being used elsewhere	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure adequate decontamination	Human	Minor radiation exposure to public	D	2	Low	BHP Billiton will enforce strict procedures as per their Radiation Clearance Guidelines (OD 2382) to ensure the testing and decontamination of materials and/or equipment to be used elsewhere. Materials that are not decontaminated to levels less than the Mining Code levels will be disposed of in the TSF.	D	1	Low	N
27	Natural / social	Land, public safety	Leakage / spill of EPA listed waste	1. Failure to follow procedures 2. Rainfall 3. Breach of storage vessel	Appropriate management / adequate storage	Native flora and fauna, human, water	1. Contaminated land and downstream receiving environment 2. Loss of habitat for native flora and fauna	C	3	High	Listed wastes will be stored, handled and disposed of as per EMP/ EPA trade waste processes. The Decommissioning Plan will require contaminated soil and demolition debris to be disposed in the TSF or in a suitably designed and constructed landfill. Post-closure sampling of soils for contaminants in the vicinity of the decommissioned metallurgical plant, and remediation if required, will be undertaken annually up until relinquishment.	D	3	Moderate	Y
28	Natural / Economic	Land, resources	Loss of control of recyclable waste	1. Poor waste management procedures 2. Failure to follow procedures	Appropriate management of recyclable wastes	Natural resources	1. Loss of economic benefit 2. Inefficient resource usage	C	1	Low	Ferrous scrap and other recyclable materials are to be recycled off site following radiation clearance.	C	1	Low	N
29	Natural	Land	Failure to remove all of the plant and facility structures	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure all plant and facility structures are removed	Human, native flora and fauna	1. Visual amenity 2. Loss of habitat for native flora and fauna	C	2	Low	Inspections would be conducted following demolition works to ensure work completed to Decommissioning Plan and all of the plant and facility structures are removed.	D	2	Low	N
30	Natural	Land	Erosion	Rainfall	Newly stabilized and rehabilitated landforms	Human, native flora and fauna	1. Visual amenity 2. Loss of habitat for native flora and fauna	C	2	Low	Post closure inspections will be conducted periodically and following periods of heavy rainfall to check for erosion and areas will be rehabilitated if required to the point that they mimic natural contours and drainage lines. These inspections and works will occur up until relinquishment. The management approach will be as per those relevant items (rehabilitated sites and surface drainage) listed in Table 4 of the Closure Plan.	D	2	Low	N

Table A-8: Development of closure outcomes and measurement criteria (links to Table A-7)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
27	Leakage / spill of EPA listed waste	All contaminated waste materials to be properly disposed of in specially constructed landfill areas (designed and constructed to EPA standards or the applicable standard current at the time), including the TSF.	Soil quality measurements will be equal or better than background control data, at all sampled points by year 10 post closure or at relinquishment.	Soil quality, including radionuclides	Hydrometallurgical Plant, Smelter and Acid Plant, Refinery sites and at random sites as will be defined in the Decommissioning Plan.	Below closure performance limits as specified in the Decommissioning Plan	Annually	Soil quality characteristics as reported in Appendix I1.2 Draft EIS (2009) and additional sites as per the Decommissioning Plan to be developed at least 12 months prior to planned closure or within one month of unplanned closure.

Appendix A-5 Closure Domain 4: Tailings Retention System

Table A-9: Initial and residual risk assessment (links to Table A-10 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
31	Natural, social	Land, public safety	Slope failure	1. Inadequate engineering design or construction technique 2. Stormwater 3. Earthquake	Appropriate design	Native flora and fauna, air, human	1. Exposure of tailings and radionuclides 2. Contamination of land and downstream receiving environment	D	4	High	The TRS has been geotechnically surveyed and designed to ensure structural integrity, with no reactive material on outer slopes (as per BHP Billiton 2009 Section 5.5.6 and Appendix F1; and BHP Billiton 2011 Section 5.3 and Appendix F5). Post closure monitoring of the TRS will check for structural integrity up until relinquishment.	E	4	High	Y
32	Natural, social	Land, public safety	Slope erosion	1. Inadequate engineering design or construction technique 2. Stormwater 3. Earthquake	Appropriate design	Native flora and fauna, air, human	1. Exposure of tailings and radionuclides 2. Contamination of land and downstream receiving environment	C	4	Extreme	The TRS has been geotechnically surveyed and designed to ensure structural integrity, with no reactive material on outer slopes. Post closure monitoring of the TRS will check for erosion damage.	D	4	High	Y
33	Natural, social	Land, public safety	TSF cover thickness not adequate for long term radiation safety &/or tailings containment. Erosion of cover	1. Inadequate engineering design or construction technique 2. Wind 3. Stormwater	Appropriate design	Native flora and fauna, air, human	1. Exposure of tailings and radionuclides 2. Contamination of land and downstream receiving environment	D	4	High	With the introduction of the open pit mining at Olympic Dam, sufficient material to cap the TRS will be available on site (see BHP Billiton 2009 Section 5.4.6, 5.5.6 and Appendix F1; and BHP Billiton 2011 Section 5.3 and Appendix F5). BHP Billiton will continue research and, at the appropriate time, trialling of various capping materials and thicknesses. As per BHP Billiton 2009 Section 23.8.4, the nominal cap thickness to minimise radon emanation post-closure is 0.5 – 1.5 m depending on the type of material used.	E	4	High	Y
34	Natural, social	Land, public safety	Excessive water infiltration / preferential flow paths leading to excessive seepage	Rainfall / stormwater	Appropriate thickness and traffic compacted cover	Groundwater, fauna, flora, human	Seepage of contaminants to groundwater and potential surface expression	C	3	High	The TRS will be covered to an appropriate thickness with soil and rock fill, traffic compacted to minimise infiltration and preferential flow paths. This issue was afforded considerable attention in BHP Billiton 2009 Section 5.4.6, 5.5.6 and Appendix F1; and BHP Billiton 2011 Section 5.3 and Appendix F5. Monitoring during progressive closure and capping of TSF cells will further refine the capping design and the latest design will be provided in the Decommissioning Plan.	D	3	Moderate	Y
35	Land, Economic	Land, resources	TRS pipes are not adequately decontaminated or disposed in TRS	Poor execution of pipeline decontamination / disposal	Appropriate management to ensure decontamina tion / disposal	Land	1. Contamination of soil 2. Economic impact of re-works	C	2	Moderate	Testing of water quality from the decontaminated pipes, disposal of pipe into the TRS if they are not / cannot be decontaminated and commissioning of highly experienced project managers to ensure works are completed as per the Decommissioning Plan.	D	2	Low	N
36	Natural	Land	Progressive rehabilitation of the decommissioned TSF cells does not occur	Failure to follow Closure Plan (Section 10.2)	Appropriate management to ensure progressive rehabilitation as per plan	Land	1. Extended exposure of tailings and radionuclides 2. Increased opportunity for air-borne contamination via wind erosion	B	2	High	Progressive rehabilitation to occur as per Section 10.2 of the Closure Plan	C	2	Moderate	Y

Table A-10: Development of closure outcomes and measurement criteria (links to Table A-9)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
31 / 32	Slope failure / Slope erosion	No compromise of existing and future land uses on adjoining areas as a result of slope failure / erosion from the TSF post-closure.	The entire outer wall will be constructed of run-of-mine competent rock (as per BHP Billiton 2009 Section 5.5.6), therefore erosion causing exposure of tailings would require slope failure / erosion at least 10 m deep on slopes.	Visual inspection to confirm TRS slopes are stable and erosion channels are <10m deep..	TRS. Details will be provided in the Decommissioning Plan	No slope failure or significant erosion with channels >10m deep..	Six monthly for the first two to three years following closure works, extending to annually until relinquishment; and immediately following a >1:100 storm event or earthquake.	BHP Billiton 2009 Section 5.5.6 and engineering drawings from decommissioning plan

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
33	TSF cover thickness not adequate	No adverse impacts to public health as a result of radioactive emissions from the final TSF landform. No significant adverse radiological impacts to ecological communities as a result of radioactive emissions from the final TSF landform.	A dose limit for radiation doses to members of the public of 1 mSv/y above natural background Deposition of closed site originated ^{238}U less than 25 $Bq/m^2/y$ at non-human biota assessment sites	Radiation	TRS. Details will be provided in the Decommissioning Plan	Below agreed performance levels and legislative requirements.	Six monthly for the first two to three years following closure works, extending to annually until relinquishment.	Air quality characteristics as reported in Draft EIS – Section 13.3.5, 22.6.6 , Appendix F1, Section 10 and Appendix S, Section S2.5 (2009) and BHP Billiton 2011 Section 26.5.2
34	Excessive water infiltration / preferential flow paths leading to excessive seepage	No significant adverse impact on vegetation as a result of seepage from the TSF post-closure. No compromise of existing and future land uses on adjoining areas as a result of seepage from the TSF post-closure.	Surface and groundwater quality commensurate with agreed future land use (for third party users), and groundwater mound beneath TSF is reducing and trending towards pre-mining levels.	Infiltration into the TRS and the height of the groundwater mound beneath TRS.	TRS. Details will be provided in the Decommissioning Plan	No significant or medium-term infiltration into the TRS and reduction in height of groundwater mound with it trending towards pre-mining levels.	Six monthly for the first two to three years following closure works, extending to annually until relinquishment.	Engineering drawings from Decommission Plan
36	Progressive rehabilitation of the decommissioned TSF cells does not occur	No adverse impacts to public health as a result of particulate emissions from failure to progressively rehabilitate decommissioned TSF cells.	NEPM (ambient air) limits for public exposure or the relevant criteria at the time of closure and a dose limit for radiation doses to members of the public of 1 mSv/y above natural background.	Dust (TSP, PM_{10}, $PM_{2.5}$) and radiation	Radially towards Roxby Downs. Details will be provided in the Decommissioning Plan	Below agreed performance levels and legislative requirements.	Annually	Air quality characteristics as reported in Draft EIS – Section 13.3.5, 22.6.6 , Appendix F1, Section 10 and Appendix S, Section S2.5 (2009) and BHP Billiton 2011 Section 26.5.2

Appendix A-6 Closure Domain 5: Pilot Plant

Table A-11: Initial and residual risk assessment (links to Table A-12 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
37	Social	Public safety	Failure to decontaminate materials / equipment being used elsewhere, leakage or spill of radioactive material	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure adequate decontamination	Human	Minor radiation exposure to public	D	2	Low	BHP Billiton will enforce strict procedures as per their Radiation Clearance Guidelines (OD 2382) to ensure the testing and either disposal of contaminated equipment via burial (e.g. in the TSF) or decontamination of materials and/or equipment to be used elsewhere. Materials that are not decontaminated to levels less than the Mining Code levels will be disposed of in the TSF.	D	1	Low	N
38	Natural / social	Land, public safety	Leakage / spill of EPA listed waste	1. Failure to follow procedures 2. Rainfall 3. Breach of storage vessel	Appropriate management / adequate storage	Native flora and fauna, human, water	1. Contaminated land and downstream receiving environment 2. Loss of habitat for native flora and fauna	C	2	Moderate	Listed wastes will be stored, handled and disposed of as per EMP/ EPA trade waste processes. The Decommissioning Plan will require contaminated soil and demolition debris to be disposed in the main TSF or in a suitably designed and constructed landfill.	D	2	Low	N
39	Natural	Land	Failure to remove all of the plant and facility structures	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure all plant and facility structures are removed	Human, native flora and fauna	1. Visual amenity 2. Loss of habitat for native flora and fauna	C	2	Low	Inspections would be conducted following demolition works to ensure work completed to Decommissioning Plan and all of the plant and facility structures are removed.	D	2	Low	N
40	Natural	Groundwater	Seepage from pilot tailings ponds	Infiltration	HDPE liner, clay, limestone	Groundwater human	Contaminated groundwater impacting third party users	C	2	Moderate	Ponds are HDPE lined and underlain by clay and limestone (and thus natural attenuation occurs – see BHP Billiton 2009; Section 12.6.2; BHP Billiton 2011 Section 12.3). In the event that excavation of the open pit continues and reaches the level of the aquifer, any contamination to the groundwater would report to the open pit – see BHP Billiton 2009 Section 12.6.1, 12.6.2, Appendix K6, Section 8.2.5 and BHP Billiton 2011 Section 12.2.1 and 12.2.3.	C	1	Low	N
41	Natural / Economic	Land, resources	Loss of control of recyclable waste	1. Poor waste management procedures 2. Failure to follow procedures	Appropriate management of recyclable wastes	Natural resources	1. Loss of economic benefit 2. Inefficient resource usage	C	1	Low	Ferrous scrap and other recyclable materials are to be recycled off site following radiation clearance.	C	1	Low	N

Table A-12: Development of closure outcomes and measurement criteria (links to Table A-11)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
None required								

Appendix A-7 Closure Domain 6: Open Pit

Refer to Table 2, closure domain 6 for a description of the current open pit

Table A-13: Initial and residual risk assessment (links to Table A-14 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
42	Social	Public safety	Injury to a member of the general public from whatever cause	1. Inadequate warning signage 2. Off-track behaviour gaining entrance to pit 3. Pit wall failure / slumping / subsidence	Warning signage Earthen bunds Closure design	Human	Injury/ fatality	C	5	Extreme	1. Appropriately sized and located hazard warning signs will be installed around the pit perimeter and maintained by BHP Billiton up until relinquishment. 2. Road access to the pit will be discouraged by deep ripping access road/s and installing an earthen bund or similar at perimeter of pit and maintained by BHP Billiton up until relinquishment. 3. Geotechnical studies would 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 the safety exclusion zone. Based on these studies, an abandonment bund and/or fencing would be constructed around the perimeter of the pit outside the zone of potential pit-wall subsidence. This would restrict public access to the edge of the open pit. Also, benching of the pit wall throughout the operational phase would reduce the pit slope angle.	D	4	High	Y
43	Natural	Avifauna	Fatality of avifauna due to ingestion of in-pit waters	In-pit waters	Evaporation and depth of the pit	Avifauna	Injury/ fatality	E	4	High	For the timeframe of this current closure plan, the depth of the pit will be insufficient to allow the formation of a pit lake post closure (as groundwater aquifers will not have been truncated and evaporation will far outweigh rainfall).	E	1	Low	N
44	Natural	Groundwater	Acid rock drainage and leachate production from exposed walls entering groundwater	Rainfall and infiltration to groundwater	Evaporation and depth of the pit	Groundwater, human	Contamination of groundwater and ultimately impacts to third party groundwater users	E	4	High	For the timeframe of this current closure plan, the depth of the pit will be insufficient to allow the formation of a pit lake post closure (as groundwater aquifers will not have been truncated and evaporation will far outweigh rainfall).	E	1	Low	N
45	Natural, Social	Groundwater, resources	Inappropriate dumping of wastes into the pit void	Poor closure planning and waste management	Appropriate management to avoid inappropriate dumping of wastes	Groundwater, human	1. Seepage of contaminants from the waste into groundwater 2. Visual amenity	D	2	Low	Implementation of the Mine Closure and Rehabilitation Plan with regard to waste management, inspections of closed sites and commissioning of highly experienced project managers.	E	2	Low	N

Table A-14: Development of closure outcomes and measurement criteria (links to Table A-13)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
42	Injury to a member of the general public from whatever cause	No adverse impacts to public health as a result of the open pit.	0 fatalities	That appropriately sized and located warning signs have been installed, that the entry road/s to the pit have been ripped and blocked and that the abandonment bund/fence is in place and maintained up until relinquishment.	Pit perimeter, entry road/s	Appropriate signage, ripping and road barrier in place and abandonment bund/fencing in place.	Six monthly for the first two to three years following closure works, extending to annually until relinquishment.	Design drawings of signage, road/s barrier, abandonment bund / fencing and subsidence geotechnical report.

Appendix A-8 Closure Domain 7: Rock Storage Facility

Refer to Table 2, closure domain 7 for a description of the current RSF

Table A-15: Initial and residual risk assessment (links to Table A-16 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis: Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	Initial Risk Assessment: L/hood	Cons	Initial Risk	Control / Management Strategies	Residual Risk Assessment: L/hood	Cons	Residual Risk	Outcome Required (Y/N)
46	Natural, social	Land, public safety	Slope failure	1. Inadequate engineering design or construction technique 2. Stormwater 3. Earthquake	Appropriate design	Native flora and fauna, air, human	Smothering of vegetation / fauna habitat	C	2	Moderate	For the timeframe of this current closure plan, no reactive material will be placed within the RSF, and therefore any slope failure would be controlled by constructing geotechnically stable outer batters using angle of repose disposal of materials into the RSF (see BHP Billiton 2009 Sections 5.4.6 and 23.8.2). In any event, no batters of the RSF for the timeframe of this current closure plan would be final outer batters for the RSF (i.e. they will be smothered as the RSF progresses over time).	D	2	Low	N
47	Natural, social	Land, public safety	Slope erosion	1. Inadequate engineering design or construction technique 2. Stormwater 3. Earthquake	Appropriate design	Native flora and fauna, air, human	Smothering of vegetation / fauna habitat	C	2	Moderate	For the timeframe of this current closure plan, no reactive material will be placed within the RSF, and therefore any slope erosion would be controlled by constructing geotechnically stable outer slopes, typically between 30-37°(see BHP Billiton 2009 Sections 5.4.6 and 23.8.2). Also, the upper surfaces would be covered with a coarse mulch layer that is stable and resilient over time and counters the erosive effects of wind and water (plus encouraging natural revegetation).	D	2	Low	N
48	Natural, social	Land, public safety	Water infiltration leading to contamination of groundwater	Rainfall/ stormwater	Evaporation, traffic compaction on RSF	Native flora and fauna, human	Seepage of contaminants to groundwater and potential for surface expression	C	2	Moderate	A traffic compacted layer of non-reactive rock will be placed at the base of the RSF. Also, for the timeframe of this current closure plan, no reactive material will be placed within the RSF, and therefore any infiltration to the groundwater would not be contaminated.	D	1	Low	N
49	Social	Public safety	Radon emanation from the RSF	Air	Appropriate design	Human	Exposure to elevated radon levels.	D	2	Low	For the timeframe of this current closure plan, no reactive material will be placed within the RSF, and therefore there is no risk of radon emanation.	E	1	Low	N
50	Social	Public safety	Injury to a member of the general public from whatever cause	1. Inadequate warning signage 2. Off-track behaviour gaining entrance to the RSF 3. Rock falls	Warning signage Ripping of RSF access roads Closure design	Human	Injury/ fatality	C	4	Extreme	1. Appropriately sized and located hazard warning signs will be installed around the RSF perimeter to warm of rock falls and steep slopes and maintained up until relinquishment. 2. Road access to the RSF will be discouraged by deep ripping of access road/s and this will be maintained up until relinquishment..	D	3	Moderate	Y

Table A-16: Development of closure outcomes and measurement criteria (links to Table A-15)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria: What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
50	Injury to a member of the general public from whatever cause	No adverse impacts to public health as a result of the rock storage facility.	0 fatalities	That appropriately sized and located rock fall and steep slope warning signs have been installed, and that the access roads to and on the RSF have been deep ripped.	RSF perimeter, access roads	Appropriate signage in place and deep ripping has occurred.	Six monthly for the first two to three years following closure works, extending to annually until relinquishment.	Design drawings of signage.

Appendix A-9 Closure Domain 8: Miscellaneous disturbed areas

Table A-17: Initial and residual risk assessment (links to Table A-18 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
51	Natural / Economic	Social welfare/ Land	Inadequate provision for waste disposal	1. Inability to use current landfill facilities in township 2. Insufficient volume in on-site quarries	Appropriate closure planning	Human	1. Increased cost of waste disposal 2. Stresses on local waste management services and facilities	C	3	High	A waste control management plan will be developed as part of the decommissioning plan, estimating the volumes of waste materials for off-site disposal. Planning to manage this waste volume will then occur prior to closure.	D	3	Moderate	Y
52	Natural / Economic	Land, resources	Loss of control of recyclable waste	1. Poor waste management procedures 2. Failure to follow procedures	Appropriate management to avoid inappropriate dumping of wastes	Natural resources	1. Loss of economic benefit 2. Inefficient resource usage	C	1	Low	Ferrous scrap and other recyclable materials are to be recycled off site following radiation clearance.	C	1	Low	N
53	Natural	Land	Failure to plug exploration drill sites	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to plug exploration drill sites	Human	Injury	D	2	Low	Drill holes are plugged at the surface with concrete. A register is maintained of any residual exploration areas and will be updated to indicate rehabilitation.	E	2	Low	N
54	Natural / Social	Fauna	Economic loss to Arid Recovery	Lack of financial assistance	Money	Native fauna, human	1. Potential closure of Arid Recovery 2. Less maintenance 2. Loss of a valuable monitoring, scientific and community resource	C	3	High	BHP Billiton would investigate handing Arid Recovery over to the current partners and if required establish an endowment fund for financial support.	D	2	Low	N
55	Natural / Social	Public safety	Power lines not adequately decommissioned and / or removed	1. Poor decommissioning plan 2. Failure to follow procedures	Appropriate management to ensure powerlines are decommissioned	Human	1. Injury / fatality 2. Inefficient resource usage	D	4	High	Annual review of Olympic Dam Mine Closure and Rehabilitation Plan and commissioning of highly experienced project managers.	D	2	Low	N
56	Natural	Groundwater, surface water	Seepage from waste and wastewater treatment ponds/facilities	Infiltration, runoff	HDPE liner, clay, limestone	Receiving environment groundwater	Contaminated downstream receiving environment and potentially groundwater impacting third party users	C	2	Moderate	Ponds are HDPE lined and underlain by clay and limestone (and thus natural attenuation occurs – see BHP Billiton 2009; Section 12.6.2; BHP Billiton 2011 Section 12.3).). When open pit reaches the level of the aquifer, any contamination to the groundwater would report to the open pit – see BHP Billiton 2009 Section 12.6.1, 12.6.2, Appendix K6, Section 8.2.5 and BHP Billiton 2011 Section 12.2.1 and 12.2.3.	D	1	Low	N
57	Natural	Land	Uncontrolled surface collapse into underground mine	1. Inadequate engineering design 2. Inadequate backfilling of mined stopes	Appropriate management and design	Native flora and fauna	Loss of habitat for native flora and fauna	E	2	Low	Stopes are backfilled with an aggregate of crushed stone, tailings and cement when depleted of ore, which has sufficient strength to provide support.	E	1	Low	N
58	Natural	Land / public safety	Inadequate rehabilitation of the quarry / access roads	Poor or inadequate closure planning	Appropriate closure planning	Native flora and fauna, human	Loss of habitat for native flora and fauna, injury to public due to steep quarry slopes	C	3	High	Sites would be remediated and rehabilitated as per decommissioning rehabilitation procedures. Slopes of the quarry walls would be made stable and at least at natural angle of repose (about 37^{o}).	D	2	Low	N
59	Social	Public safety	Access to underground mine	1. Failure to backfill all stopes or cap all shafts / raise bores 2. Failure to rehabilitate properly	Appropriate management regarding access to underground mine	Human	Fatality/ injury associated with fall into cavity or oxygen depletion	D	4	High	The Decline Portal, mined stopes, shafts and raise bores will be backfilled, sealed and / or capped with a concrete cover.	E	2	Low	N
60	Social	Public safety	Explosion of unused or misfired explosives	1. Failure to backfill all stopes or cap all shafts / raise bores	Appropriate management regarding unexploded materials	Human	Fatality/ injury associated with explosion	D	4	High	The Decline Portal, mined stopes, shafts and raise bores will be backfilled, sealed and / or capped with a concrete cover.	E	2	Low	N
61	Social	Public safety	Exposure to radioactive materials	1. Failure to backfill all stopes or cap all shafts / raise bores	Appropriate management to ensure stopes and shafts are backfilled	Human	Exposure to high dose resulting in long-term health issue	D	4	High	The Decline Portal, mined stopes, shafts and raise bores will be backfilled, sealed and / or capped with a concrete cover.	E	2	Low	N

Table A-18: Development of closure outcomes and measurement criteria (links to Table A-17)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
51	Inadequate provision for waste disposal	No significant adverse impacts from solid wastes following closure.	Landfill facility decommissioning and/or rehabilitation in accordance with SA EPA landfill guidelines and requirements.	1. Amount of expected off-site waste and the capacities for off-site waste disposal	Site and Roxby Downs	Appropriate disposal of all off-site waste	Annually	Waste volume and capacity calculations and waste disposal strategy to be included within the Decommissioning plan.

Appendix A-10 Closure Domain 9: Wellfields and associated infrastructure

Table A-19: Initial and residual risk assessment (links to Table A-20 if outcome is required)

Risk No.	Environ Aspect	Environ Value	Impact Event Analysis					Initial Risk Assessment			Control / Management Strategies	Residual Risk Assessment			
			Source / Event	Pathway	Barrier	Receptor	Likely Impact / Consequence	L/hood	Cons	Initial Risk		L/hood	Cons	Residual Risk	Outcome Required (Y/N)
62	Natural	Water	Failure to plug flowing Artesian bores	Water	Appropriate management to ensure flowing bores are plugged	Groundwater	Loss of groundwater from flowing Artesian bores	D	2	Low	BHP Billiton has capped most, if not all, non-production flowing Artesian bores under its control. Should any other flowing bores be decommissioned, they too will be capped.	D	2	Low	N
63	Natural	GAB and associated ecosystems	Excessive groundwater abstraction from the GAB wellfields	Groundwater	Appropriate abstraction	GAB	Reduction in flows at mound springs and loss of dependant ecosystems	D	4	High	The Closure phase will not abstract groundwater from the GAB above licensed limits and the Decommissioning Plan will include the capping of GAB production bores and water extraction shall cease.	D	2	Low	N
64	Natural	Land	Failure to adequately decommission and close the on-site desalination plant	Poor closure planning and rehabilitation	Appropriate management to ensure on-site plant is closed and decommissioned	Native flora and fauna, human	1. Loss of habitat for native flora and fauna 2. Visual amenity	C	2	Moderate	Annual review of Olympic Dam Mine Closure and Rehabilitation Plan, inspections of rehabilitated sites and commissioning of highly experienced project managers.	D	1	Low	N
65	Natural / Economic	Land, resources	Water pump stations and pressure valves not adequately disposed	1. Poor waste management procedures 2. Failure to follow procedures	Appropriate management to ensure adequate disposal	Natural resources	1. Loss of economic benefit 2. Inefficient waste disposal	C	1	Low	Ferrous scrap and other recyclable materials are to be recycled, other materials to be disposed of in an appropriate manner.	C	1	Low	N
66	Natural	Land	Failure to adequately decommission and close the production wells	Poor closure planning and rehabilitation	Appropriate management to ensure production wells are closed and decommissioned	Groundwater, Native flora and fauna, human	Sub-surface aquifer leakage Use of the well resulting in adverse impacts to the GAB	D	3	Moderate	Annual review of Olympic Dam Mine Closure and Rehabilitation Plan, inspections of production wells post-operation to ensure they are decommissioned and closed.	E	3	Moderate	Y

Table A-20: Development of closure outcomes and measurement criteria (links to Table A-19)

Risk No.	Source / Event	Proposed Closure Outcome	Completion Criteria	Outcome Measurement Criteria				
				What will be measured and monitored	Locations	Target Values	Frequency of Monitoring	Background or Control Data
66	Failure to adequately decommission and close the production wells	No significant adverse impacts on the GAB from groundwater extraction following closure.	Groundwater levels in the GAB extraction areas are trending back to pre-mining extraction levels.	Groundwater levels associated with Wellfields A and B	Wellfields A and B (exact monitoring locations will be provided in the Decommissioning Plan)	GAB groundwaters	Six monthly for the first two to three years following closure works, extending to annually until relinquishment.	BHP Billiton annual GAB Wellfields Report

Appendix B Tailings closure modelling

BHP Billiton Olympic Dam

Tailings Storage Facility –

Cover System and Landform Design 2013

Report No. 809/5-01

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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

Executive Summary ..... **ii**

Table of Contents ..... **iv**

List of Tables ..... **vi**

List of Figures ..... **vii**

List of Drawings ..... **viii**

1 INTRODUCTION **1**

1.1 Project Objectives and Scope 2

1.2 Report Organisation 2

2 BACKGROUND **3**

2.1 Definition of Net Percolation 3

2.2 Overview of ODP TSF Proposed Design 3

2.3 Minimising Radiological Impacts at the TSF Post-Closure 4

3 TSF CLOSURE CRITERIA AND DESIGN ALTERNATIVES **6**

3.1 TSF Closure Criteria 6

3.2 TSF Closure Design Parameters 9

3.3 Cover System Design Alternatives 9

3.4 Final Landform Design Alternatives 10

4 COVER SYSTEM DESIGN NUMERICAL ANALYSES **12**

4.1 Soil-Plant-Atmosphere Numerical Modelling 12

4.1.1 Purpose and Approach 12

4.1.2 Model Description and Inputs 12

4.1.3 Model Results 14

4.1.4 Model Limitations 20

4.2 Tailings Consolidation Modelling 20

4.2.1 Purpose and Approach 20

4.2.2 Model Results 21

4.3 Summary of Numerical Analyses 22

4.3.1 Soil-Plant-Atmosphere 22

5 LANDFORM DESIGN NUMERICAL ANALYSES **23**

5.1 Erosion / Landform Evolution Modelling 23

5.1.1 Purpose and Approach 23

5.1.2 Model Description and Inputs 23

5.1.3 Model Results (100-year) 23

5.1.4 Model Results (10,000-year) 24

5.2 Slope Stability Modelling 24

5.2.1 Purpose and Approach 24

5.2.2 Model Results 24

6 TSF CLOSURE PREFERRED DESIGN **24**

6.1 Risk Assessment (FMEA) 27

6.2 Key Construction Issues 28

7 COVER SYSTEM FIELD TRIAL **30**

7.1 General Approach 30

7.2 Proposed Location and Layout 31
7.3 Recommended Monitoring Program 32
7.3.1 Net Percolation 32
7.3.2 Meteorology...33
7.3.3 Actual Evapotranspiration..33
7.3.4 Changes in Soil Water Storage 34
7.3.5 Runoff Volumes 34
7.4 Detailed Design, Construction Specifications and Quality Control 35
7.5 Construction and Monitoring Schedule 35
8 OUTER EMBANKMENT COVER SYSTEM TRIAL..36
8.1 General Approach 36
8.2 Measurements...37
8.3 Proposed Location and Layout 37
8.4 Construction and Monitoring Schedule 38
9 REFERENCES...39

APPENDIX A: Preliminary Soil-Plant-Atmosphere and Seepage Modelling of Cover System Alternatives

APPENDIX B: Tailings Consolidation Analysis

APPENDIX C: Landform Erosion Assessment

C1: Initial WEPP Simulations

C2: WEPP Simulations for Extreme Events

APPENDIX D: TSF Closure Slope Stablity Assessment

APPENDIX E: Failure Modes and Effects Analysis Tables

APPENDIX F: Drawings

LIST OF TABLES

Table 3.1 General closure criteria for the TSF cover system 6

Table 3.2 Landform closure criteria for the TSF cover system 7

Table 3.3 Surface water management closure criteria for the TSF cover system. 8

Table 3.4 Seepage and ground water management closure criteria for the TSF cover system. 8

Table 3.5 Closure criteria for **emissions** from the TSF. 9

Table 4.1 Summary of average climate parameters for the 100-year ODP climate database 13

Table 4.2 Key material properties input to VADOSE/W for soil-plant-atmosphere cover design simulations 14

Table 4.3 Predicted average annual water balance components for the modelled cover system alternatives 15

Table 4.4 Input parameters evaluated with the 2D-quasi S-P-A models 16

Table 7.1 Overview of key design attributes of proposed TSF cover system field trial 31

Table 7.2 Anticipated timeframes for construction and monitoring of TSF cover system field trial 35

Table 8.1 Outer embankment cover system trial – trial plot configurations 36

Table 8.2 Anticipated timeframes for construction and monitoring of TSF cover system field trial 38

LIST OF FIGURES

Figure 2.1 Schematic of hydrologic processes that influence performance of sloping mine waste cover systems. ... 3

Figure 3.1 Rendering of water-shedding landform design option including moisture store-and-release concept. ... 11

Figure 3.2 Rendering of water-containment landform design option including moisture store-and-release concept. ... 11

Figure 4.1 Pond depths simulated during year of largest rainfall event with and without preferential flow paths considered. ... 17

Figure 4.2 Geometry used to simulate seepage models. ... 18

Figure 4.3 Change in basal flux rate with time for four seepage models. ... 19

Figure 4.4 Final basal flux rates across base of TSF for two seepage scenarios. ... 19

Figure 6.1 Processes that could impact the sustainable performance of mine waste cover systems (adapted from INAP, 2003). ... 25

Figure 6.2 Preferred closure cover system design for the ODP TSF. ... 26

Figure 6.3 Preferred closure landform design for the ODP TSF. ... 26

LIST OF DRAWINGS

809/5-100 Proposed Location of TSF Cover Trial

809/5-101 Proposed TSF Cover Trial Layout

809/5-102 Proposed TSF Cover Trial – Typical Sections

809/5-103 Proposed TSF Top Surface Cover Trial – Fill Depths

809/5-104 Proposed TSF Outer Slope Cover Trial

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.

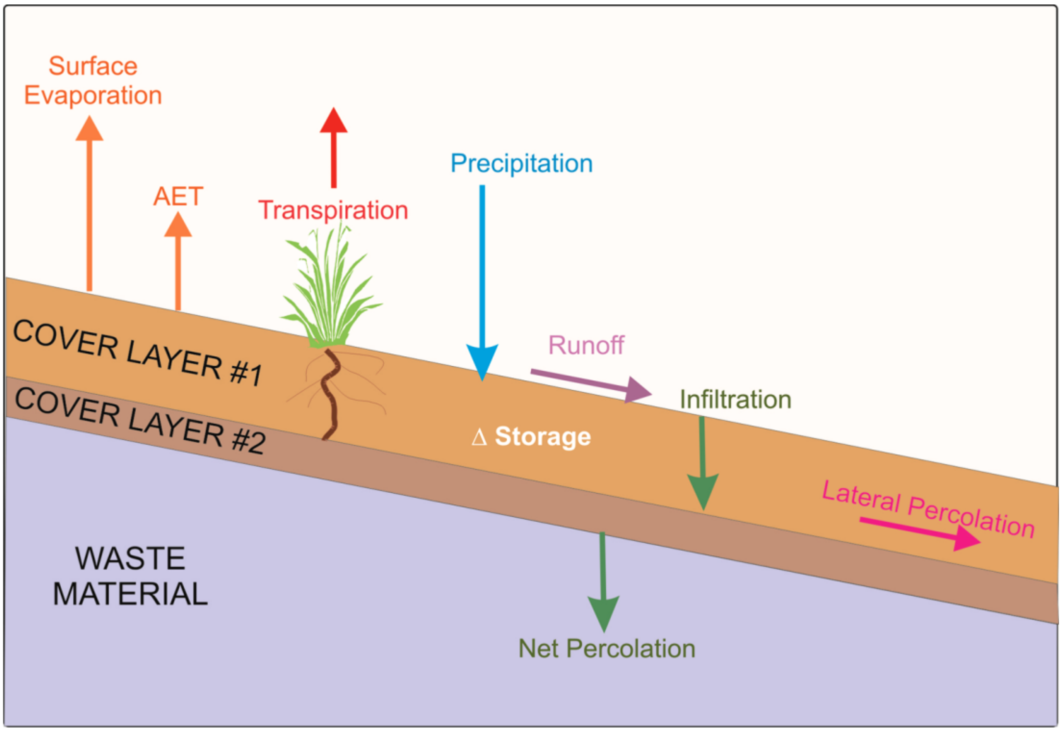

Figure 2.1 Schematic of hydrologic processes that influence performance of sloping mine waste cover systems.

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.

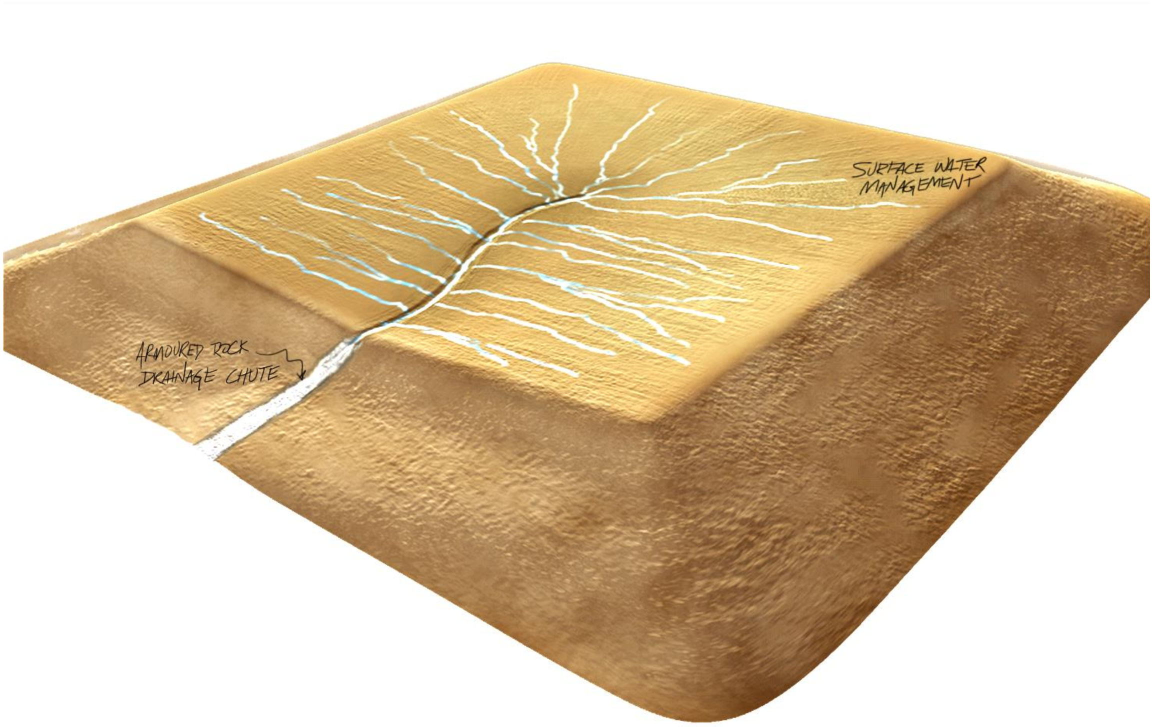

Figure 3.1 Rendering of water-shedding landform design option including moisture store-and-release concept.

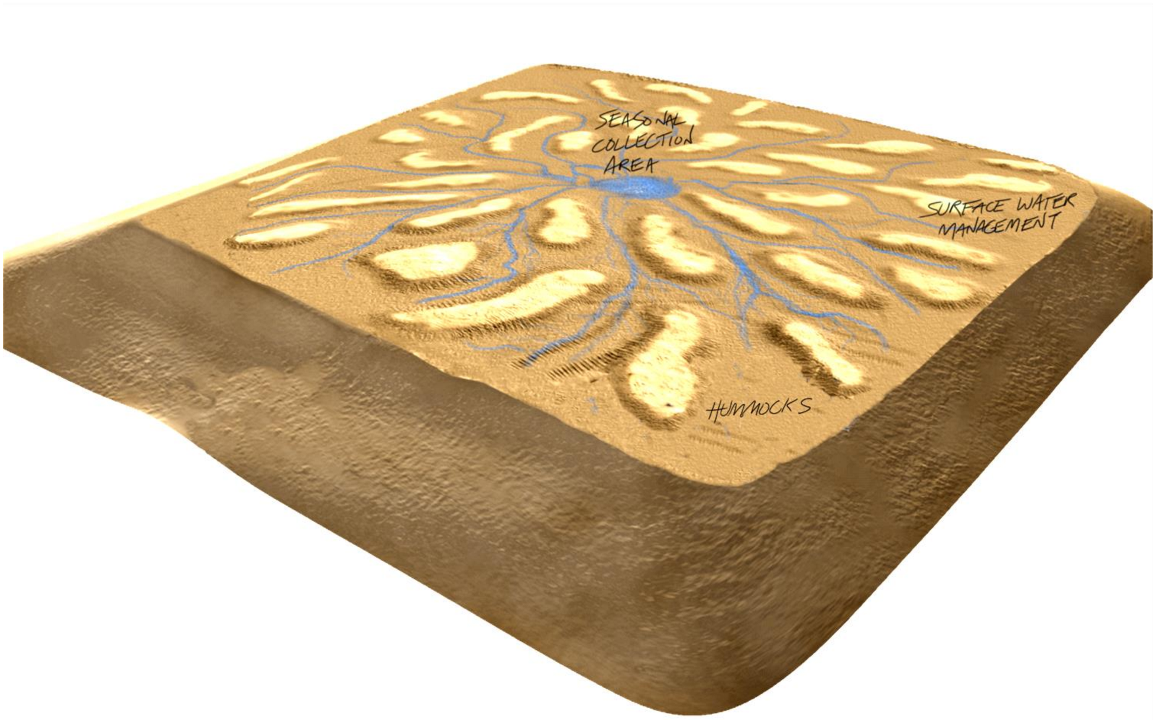

Figure 3.2 Rendering of water-containment landform design option including moisture store-and-release concept.

**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.

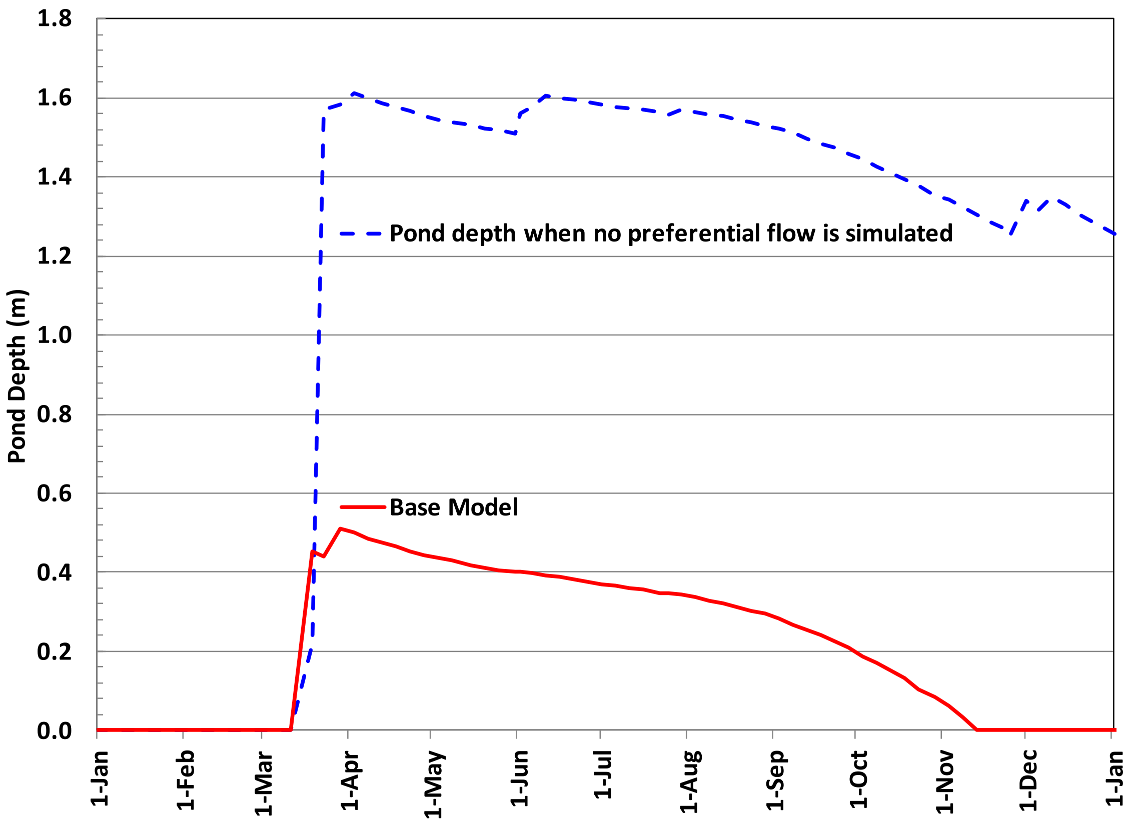

Figure 4.1 Pond depths simulated during year of largest rainfall event with and without preferential flow paths considered.

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.

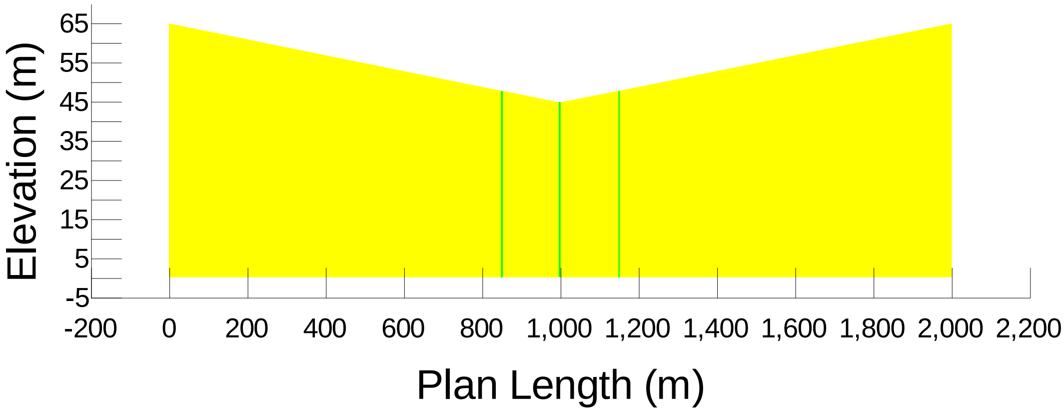

Figure 4.2 Geometry used to simulate seepage models.

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).

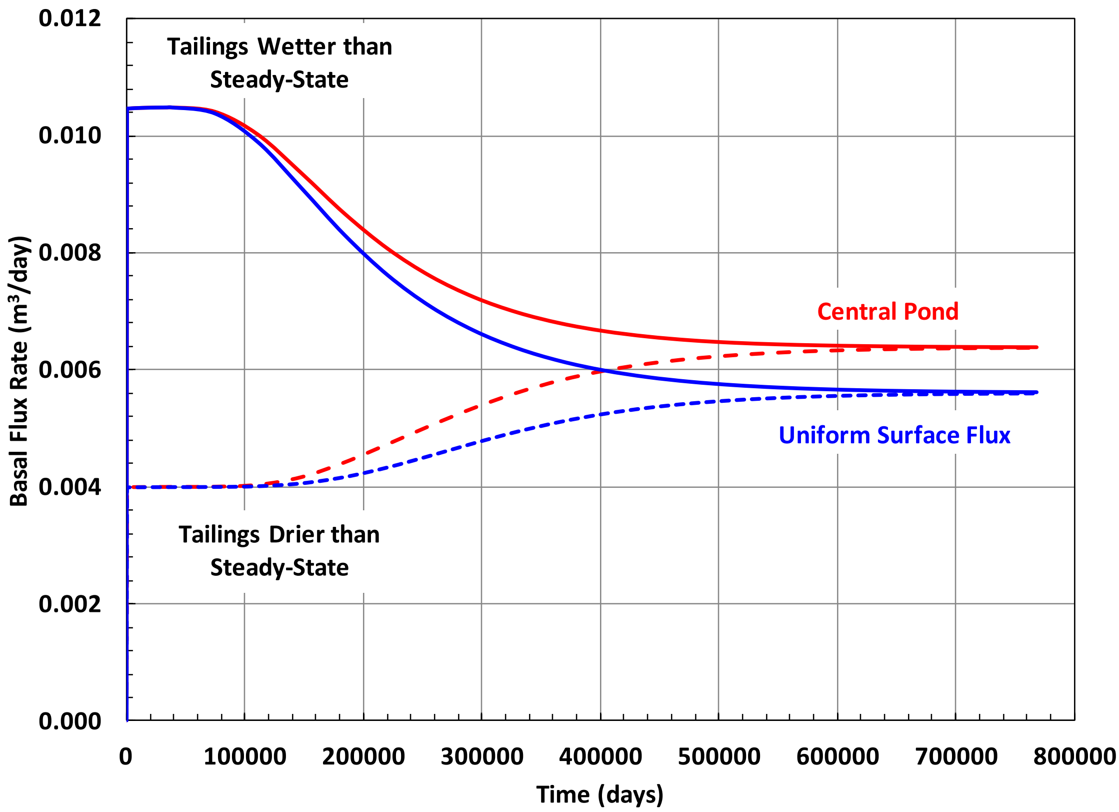

Figure 4.3 Change in basal flux rate with time for four seepage models.

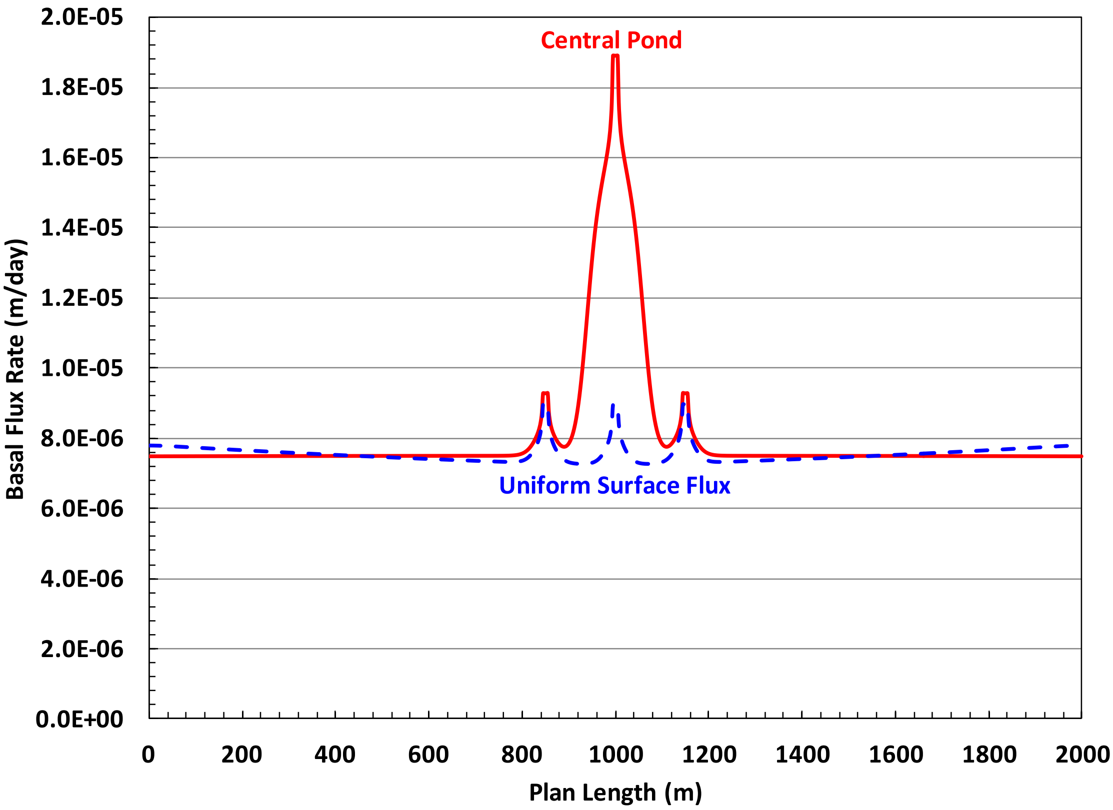

Figure 4.4 Final basal flux rates across base of TSF for two seepage scenarios.

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).

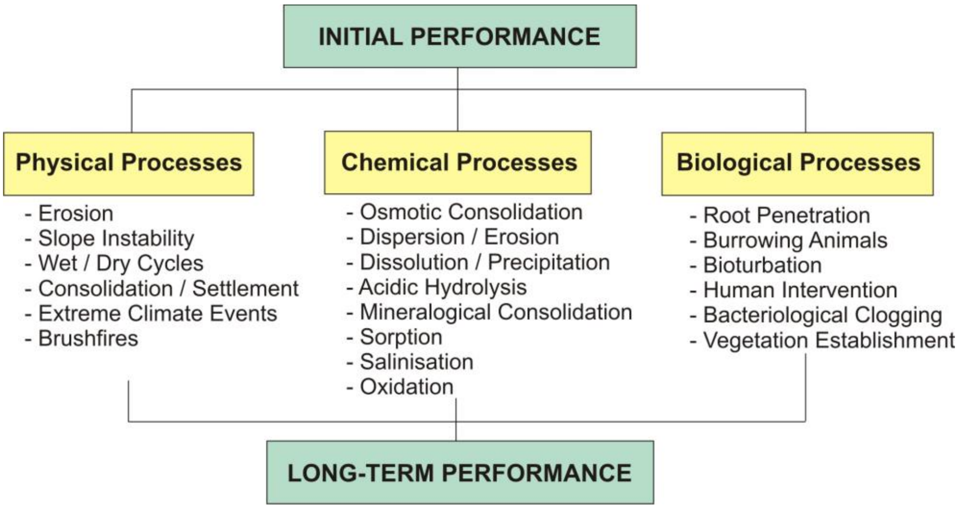

Figure 6.1 Processes that could impact the sustainable performance of mine waste cover systems (adapted from INAP, 2003).

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.

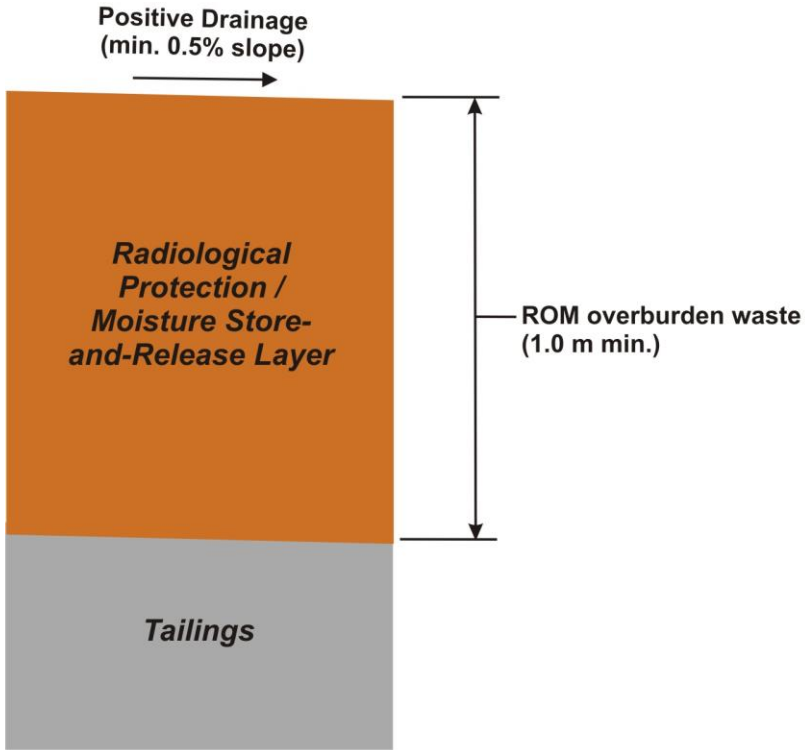

Figure 6.2 Preferred closure cover system design for the ODP TSF.

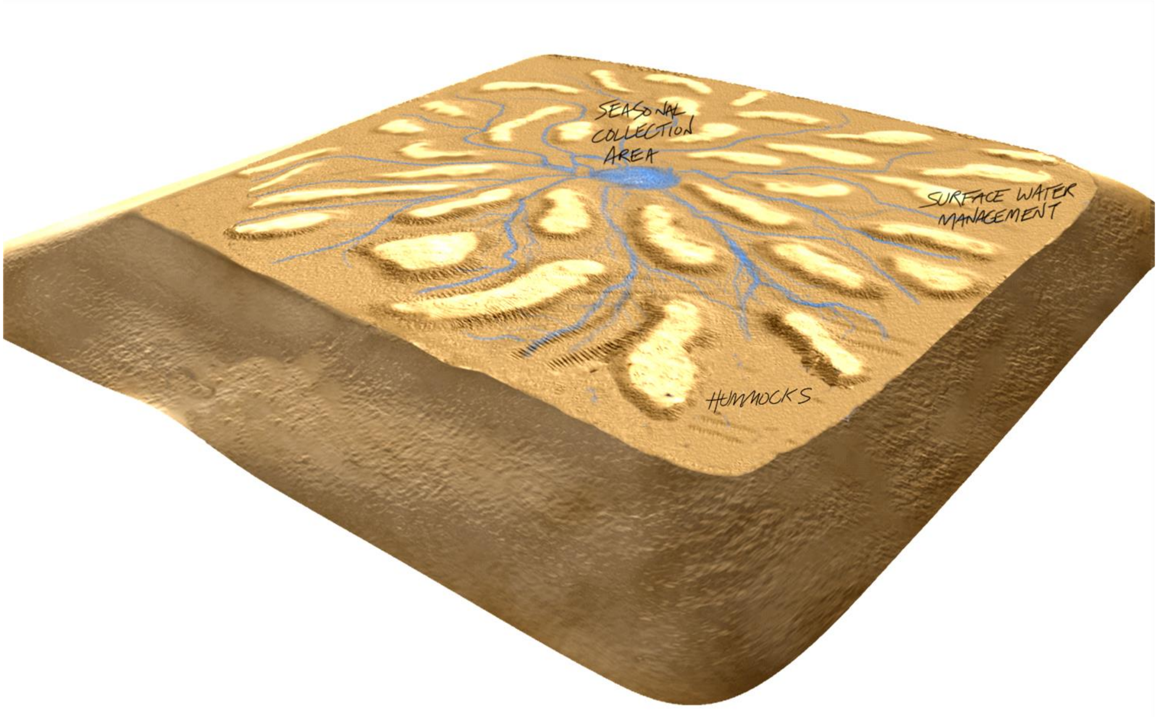

Figure 6.3 Preferred closure landform design for the ODP TSF.

**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.

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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:

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resourcing the future

Prepared by:

O'Kane Consultants Pty Ltd
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February 2013

TABLE OF CONTENTS

Table of Contents .... **A-ii**

List of Tables .... **A-iii**

List of Figures .... **A-iii**

A1 INTRODUCTION **1**
- A1.1 Objectives and Approach 1
- A1.2 Report Organisation 1

A2 DESCRIPTION OF NUMERICAL MODELS **2**

A3 MODEL INPUTS **3**
- A3.1 Material Properties 3
- A3.2 Upper Boundary Conditions 4
  - A3.2.1 Climate 4
  - A3.2.2 Vegetation 6
- A3.3 Lower Boundary Conditions 6
- A3.4 Geometry 6
- A3.5 Initial Conditions 7

A4 MODEL RESULTS **8**
- A4.1 1D Soil-Plant-Atmosphere Numerical Modelling 8
- A4.2 2D Quasi-Soil-Plant-Atmosphere Numerical Modelling 9
- A4.3 Seepage Modelling 10
- A4.4 Model Limitations 12

A5 SUMMARY AND PRELIMINARY RECOMMENDATIONS **14**

A6 REFERENCES **15**

APPENDIX A-1: DEVELOPMENT OF MATERIAL PROPERTIES **2**
- A-1.1 Particle Size Distribution 2
- A-1.2 Moisture Retention Curve 3
- A-1.3 Hydraulic Conductivity Function 3
- A-1.4 Thermal Conductivity Function 4
- A-1.5 Volumetric Specific Heat Function 4

APPENDIX A-2: DEVELOPMENT OF A CLIMATE DATABASE **2**
- A-2.1 Maximum and Minimum Temperature 2
- A-2.2 Rainfall 3
  - A-2.2.1 Amount 3
  - A-2.2.2 Duration 4
- A-2.3 Maximum and Minimum Relative Humidity 5
- A-2.4 Wind Speed 5
- A-2.5 Net Radiation 5
  - A-2.5.1 Atmospheric Radiation 5
  - A-2.5.2 Solar and Shortwave Radiation 6
  - A-2.5.3 Relative Shortwave Radiation 7
  - B.5.4 Net Shortwave Radiation and Albedo 7
  - A-2.5.5 Net Longwave Radiation 7

LIST OF TABLES

Table A3.1 Summary of material inputs. 3

Table A3.2 Summary of average climate parameters for the 100-year ODP climate database. 4

Table A4.1 Predicted average annual water balance components for the modelled cover system alternatives. 8

Table A4.2 Input parameters evaluated with the 2D-quasi SPA models. 9

LIST OF FIGURES

Figure A3.1 AE:PE ratio function used to modify surface flux boundary of quasi-SPA models. 5

Figure A3.2 Geometry used to simulate a) SPA, b) quasi-SPA, and c) seepage models. 7

Figure A4.1 Pond depths simulated during year of largest rainfall event with and without preferential flow paths considered. 10

Figure A4.2 Change in basal flux rate with time for four seepage models. 11

Figure A4.3 Final basal flux rates across base of TSF for two seepage scenarios. 12

Figure A-1.1 Range and average PSD curves for overbuden waste rock and tailings materials. 2

Figure A-1.2 MRCs estimated for overburden waste rock and tailings materials. 3

Figure A-1.3 K-functions estimated for overburden waste rock and tailings materials. 4

Figure A-2.1 Average maximum and minimum daily temperatures. 3

Figure A-2.2 Distribution of annual rainfall amounts for the 100-year climate database. 4

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.

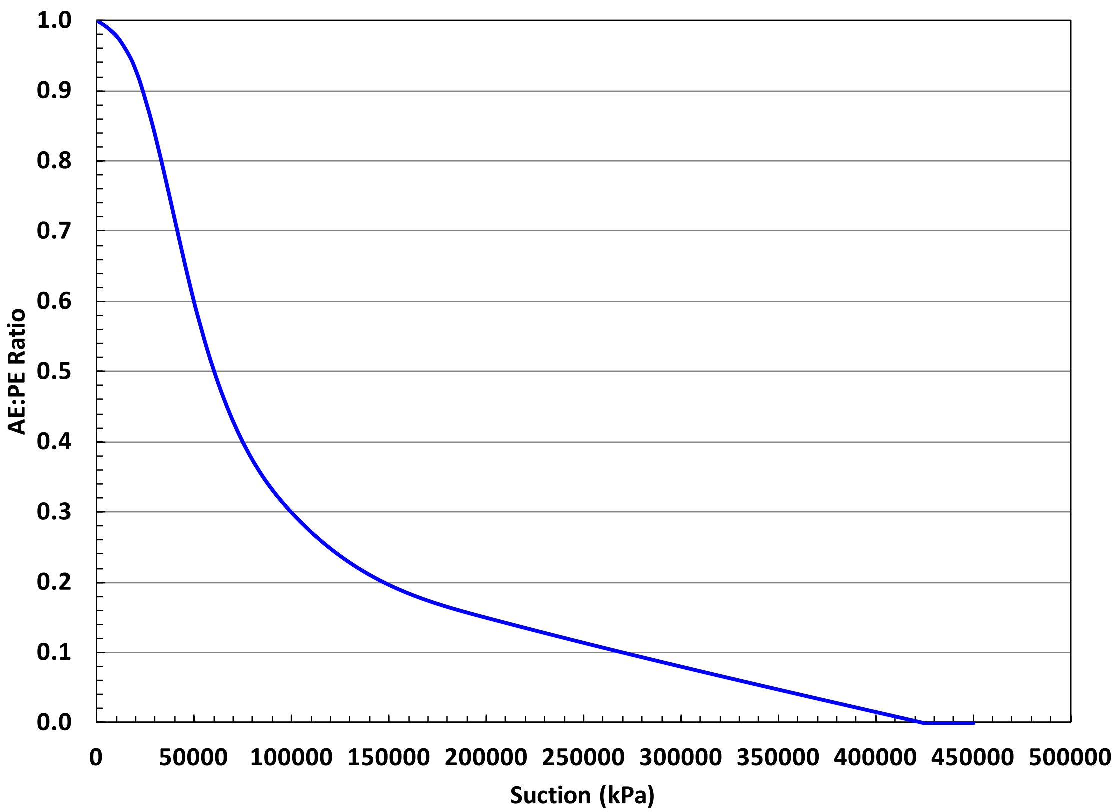

Figure A3.1 AE:PE ratio function used to modify surface flux boundary of quasi-SPA models.

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).

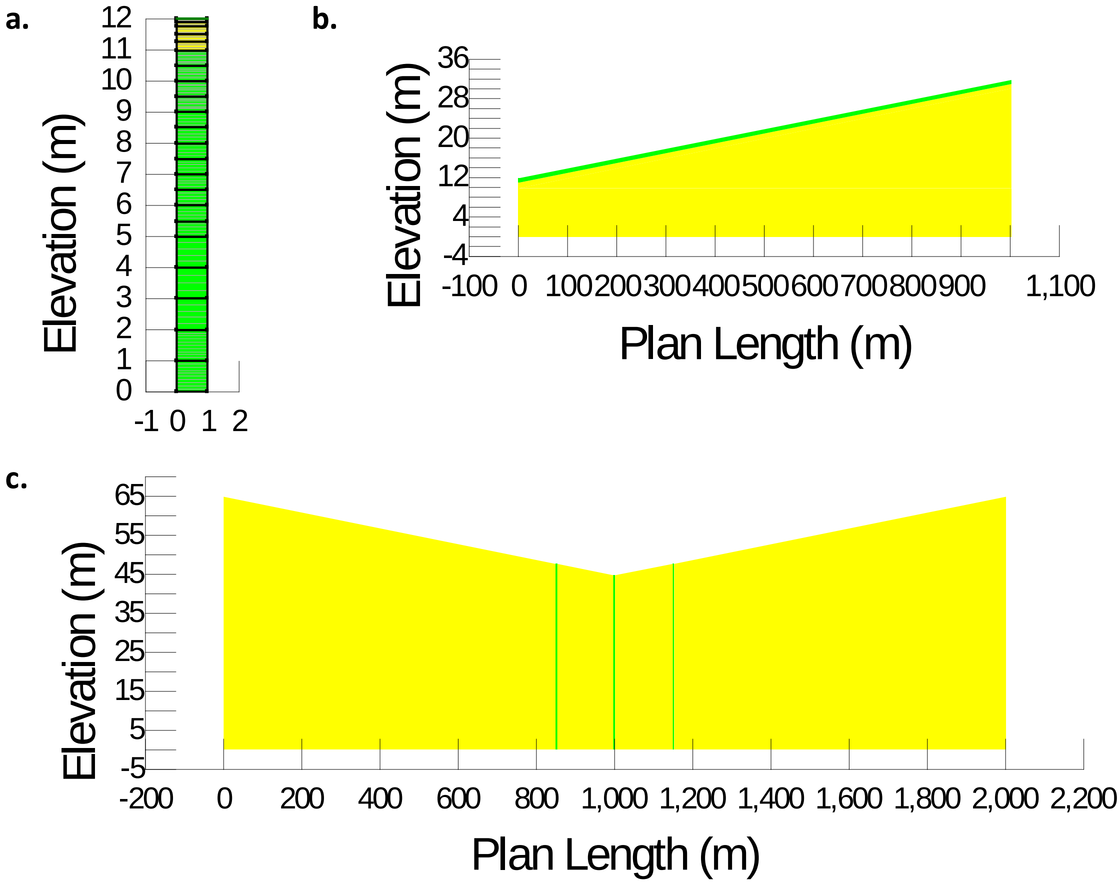

Figure A3.2 Geometry used to simulate a) SPA, b) quasi-SPA, and c) seepage models.

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	**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 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.

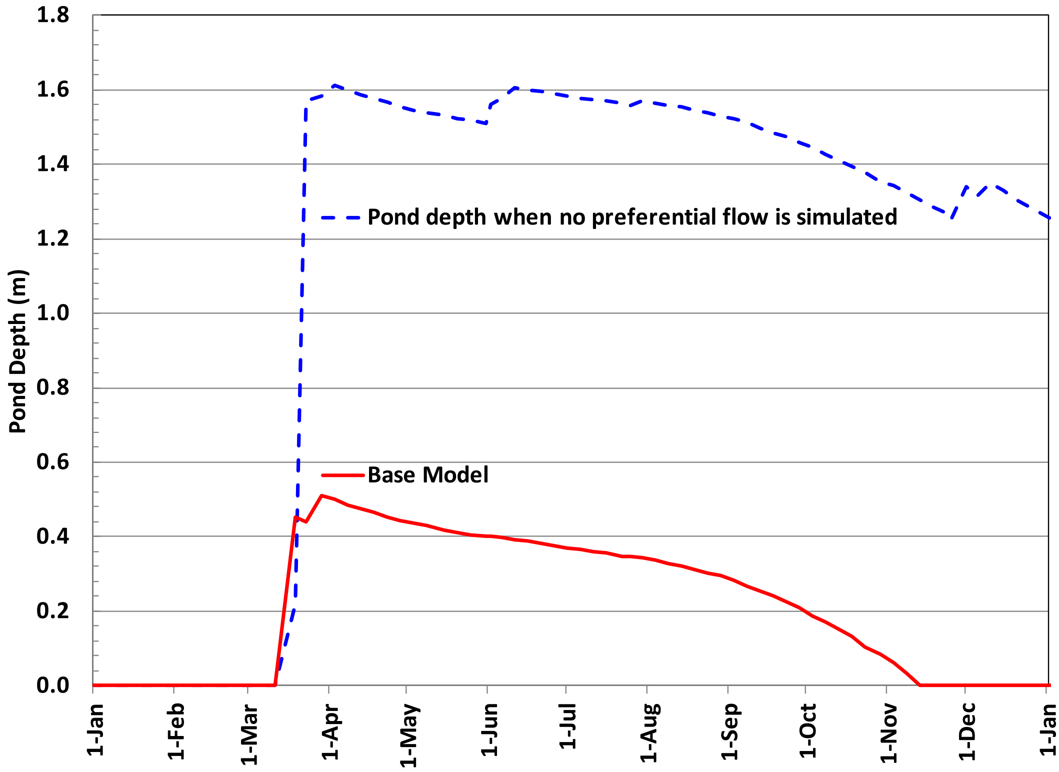

Figure A4.1 Pond depths simulated during year of largest rainfall event with and without preferential flow paths considered.

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).

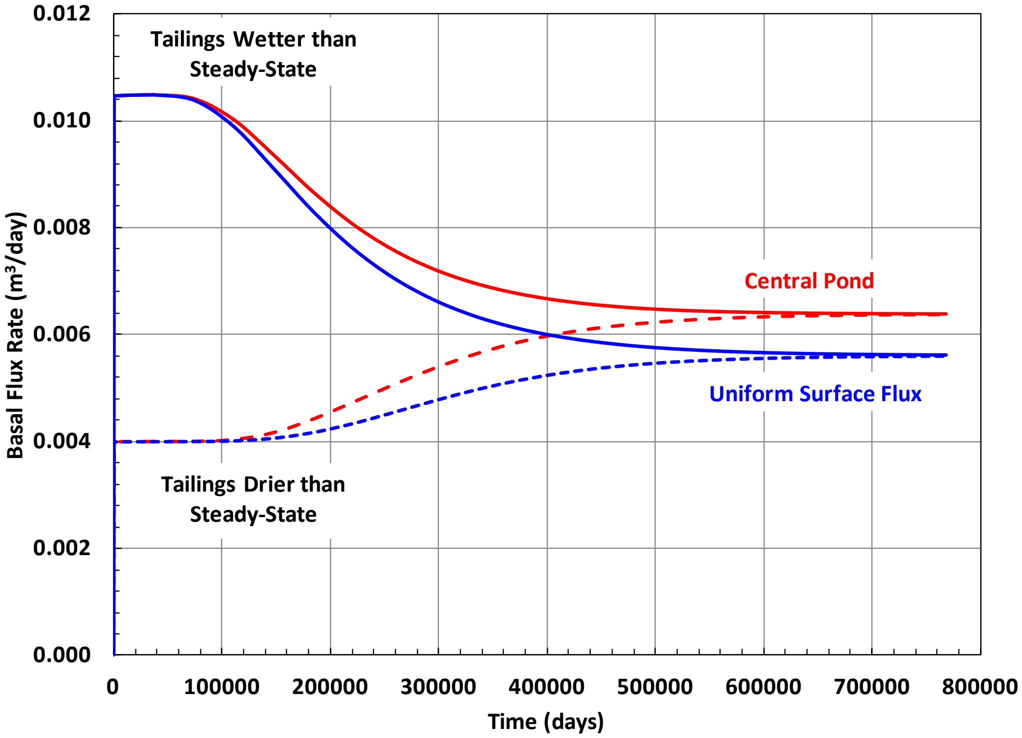

Figure A4.2 Change in basal flux rate with time for four seepage models.

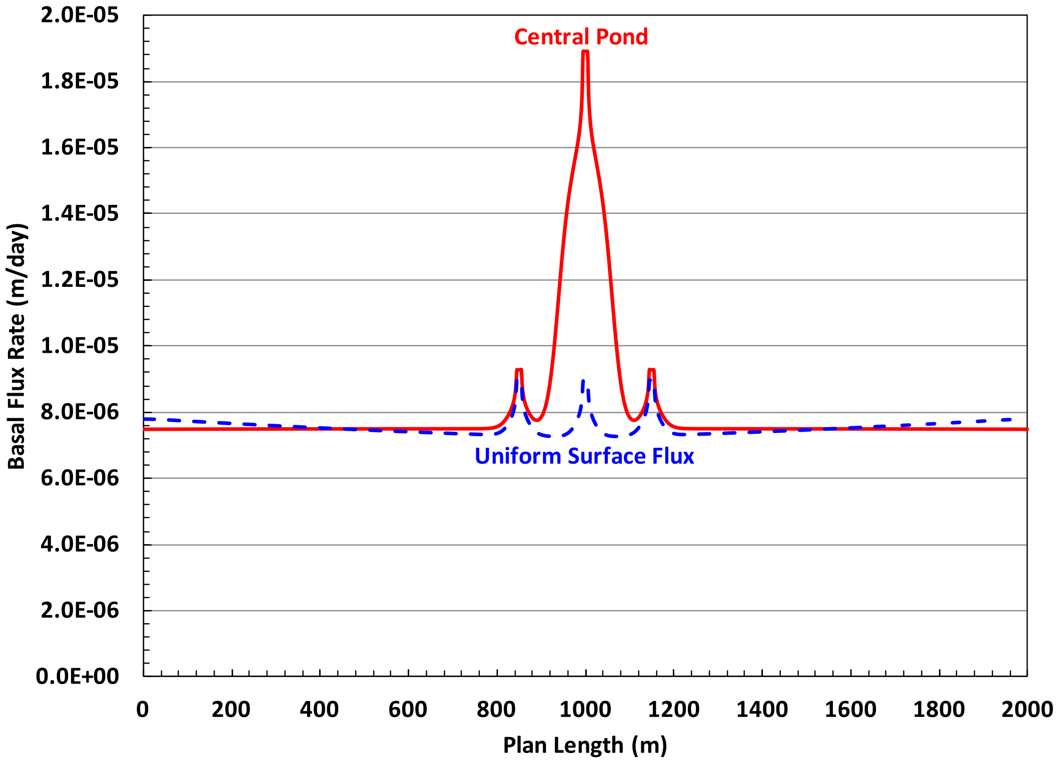

Figure A4.3 Final basal flux rates across base of TSF for two seepage scenarios.

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).

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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.

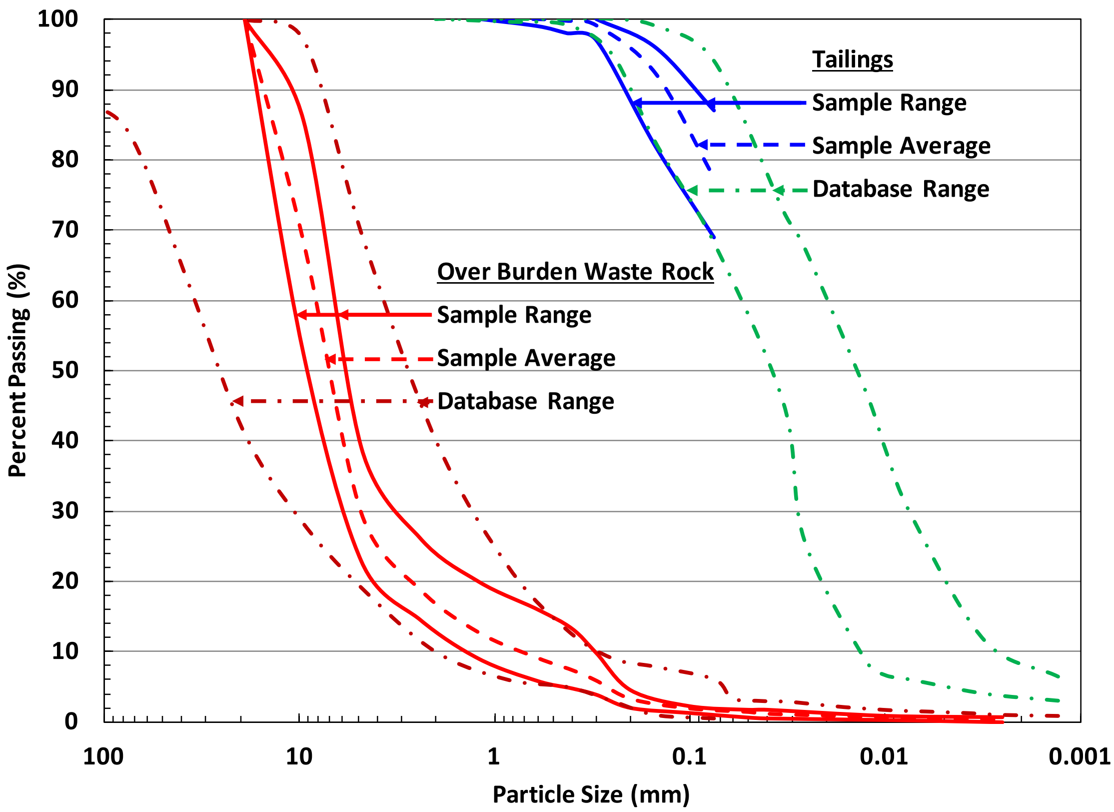

Figure A-1.1 Range and average PSD curves for overbuden waste rock and tailings materials.

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.

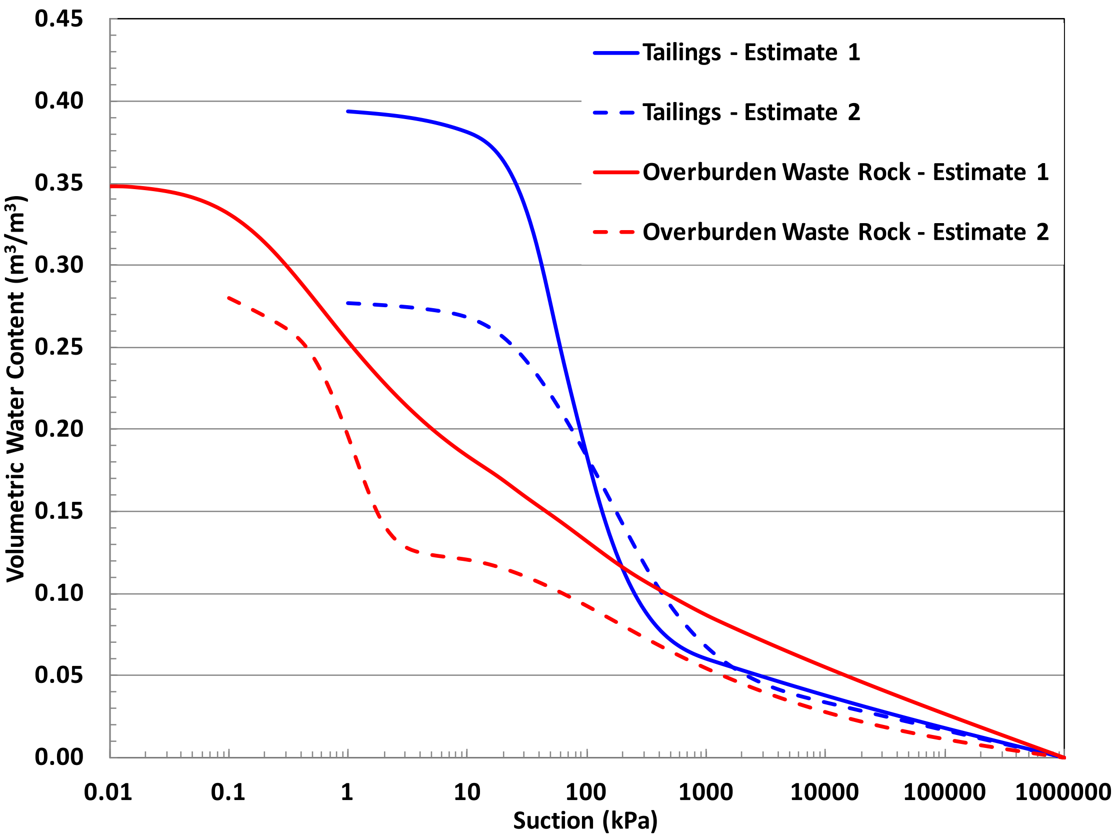

Figure A-1.2 MRCs estimated for overburden waste rock and tailings materials.

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.

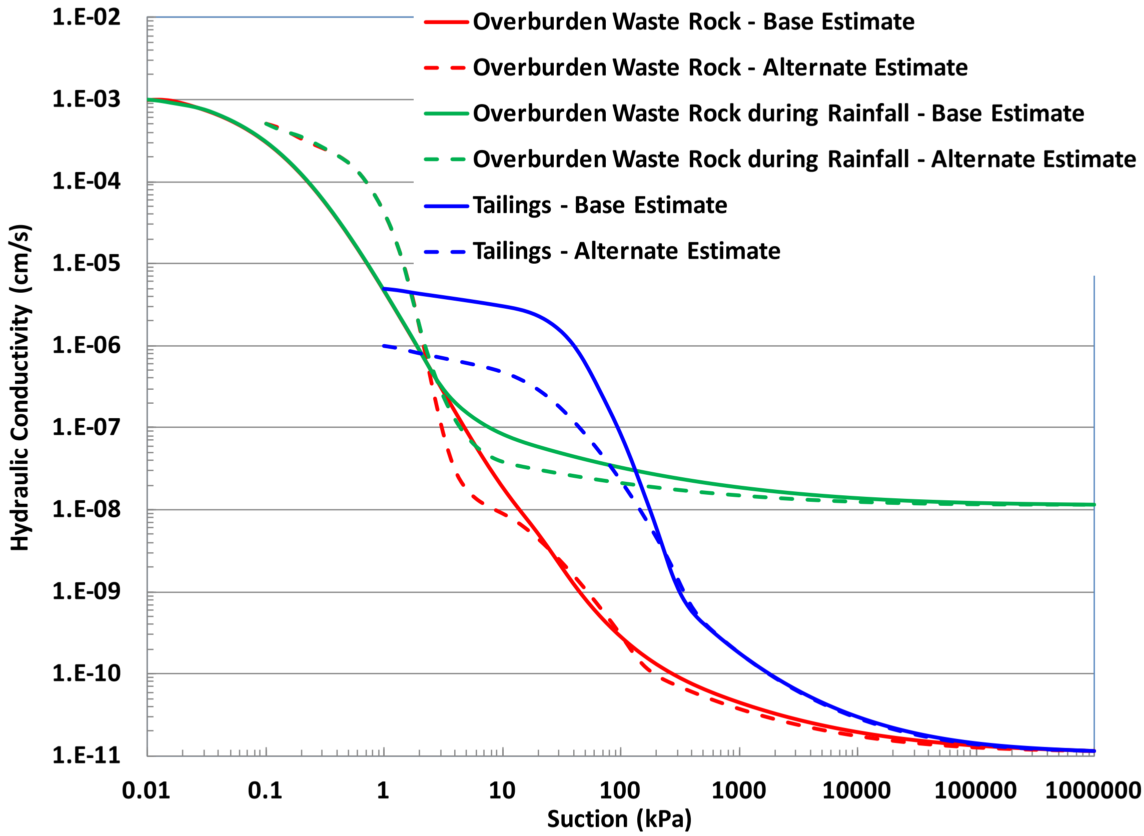

Figure A-1.3 K-functions estimated for overburden waste rock and tailings materials.

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.

$$T_{max} = 6.29034932112222\times10^{-13}t^6 - 6.64771042081076\times10^{-10}t^5 + 2.40495700712341\times10^{-7}t^4 - 3.08476517288658\times10^{-5}t^3 + 3.43705407233941\times10^{-5}t^2 + 0.0129064876779807t + 35.8 \quad [A\text{-}2\text{-}1]$$

$$T_{min} = 3.00384421220948\times10^{-13}t^6 - 3.19744466136065\times10^{-10}t^5 + 1.08334773397554\times10^{-7}t^4 - 8.57905967521777\times10^{-6}t^3 - 1.27794046106722\times10^{-3}t^2 + 0.0697927089087784t + 19.5 \quad [A\text{-}2\text{-}2]$$

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).

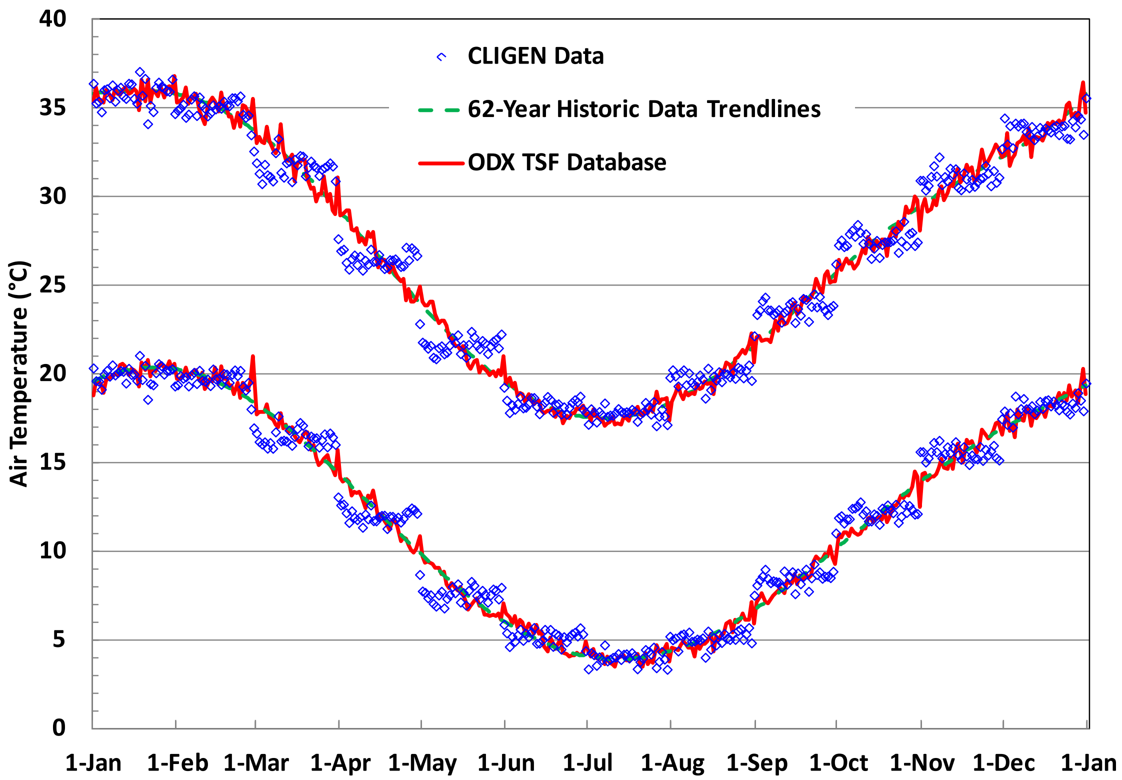

Figure A-2.1 Average maximum and minimum daily temperatures.

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.

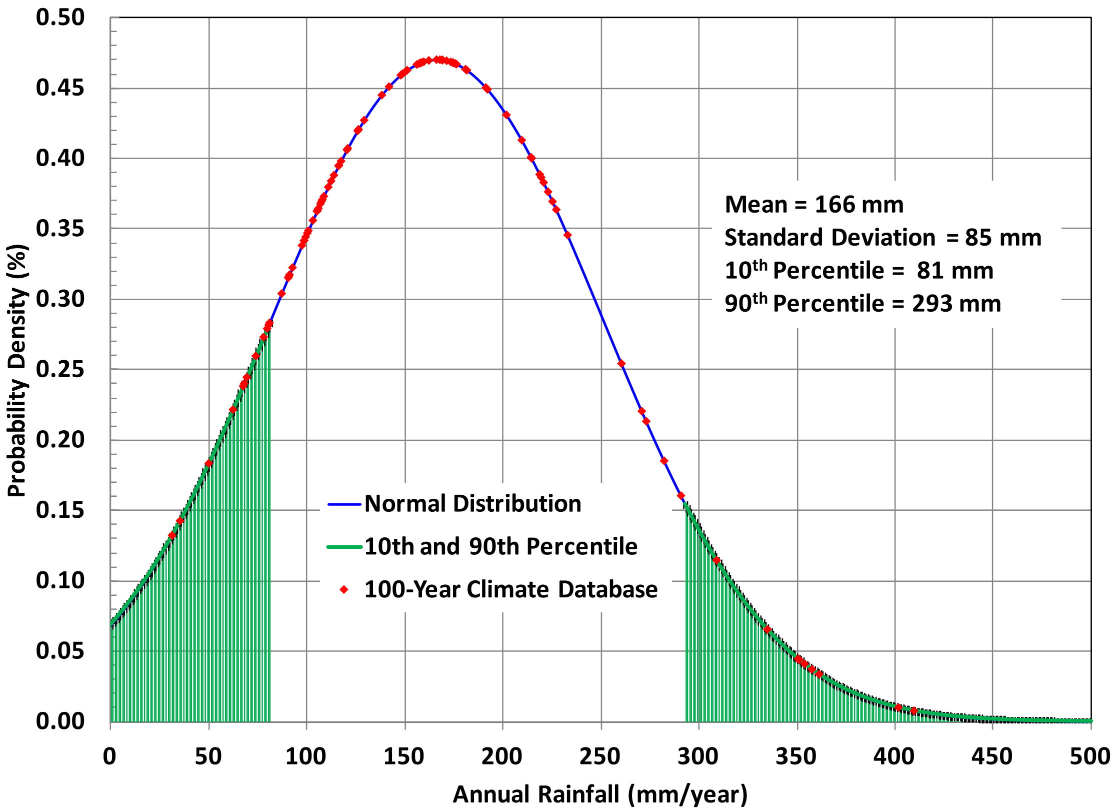

Figure A-2.2 Distribution of annual rainfall amounts for the 100-year climate database.

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:

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

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:

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

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:

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Integrated Geotechnical Engineering Services
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May 2013

TABLE OF CONTENTS

Table of Contents ..... **B-ii**

List of Tables ..... **B-iii**

List of Figures ..... **B-iii**

B1 INTRODUCTION **1**

B1.1 Objective and Approach 1

B1.2 Organisation of Appendix 1

B2 DETERMINATION OF TAILINGS SETTLEMENT AND RATE OF CONSOLIDATION **2**

B2.1 Consolidation Analysis Scenarios 2

B2.2 Method for Calculating Settlement 3

B2.3 Method for Calculating Rate of Consolidation 4

B2.4 Parameters Used for Consolidation Analyses 5

B3 RESULTS OF CONSOLIDATION ANALYSES **6**

B4 IMPLICATIONS OF TAILINGS SETTLEMENT ON COVER DESIGN **8**

B4.1 Proposed Cover Design Field Trial 8

B4.2 Tailings Storage Facility Cells 8

B4.3 Limitations of Tailings Consolidation Analysis and Recommendations 8

B5 REFERENCES **10**

LIST OF TABLES

Table B2.1 Scenarios analysed for tailings consolidation settlement for ODP tailings facilities. 3

Table B2.2 Tailings parameters used for consolidation analyses. 5

Table B3.1 Settlement and rates of consolidation for various tailings consolidation scenarios. 6

LIST OF FIGURES

Figure B2.1 Tailings consolidation analysis base scenerios for the ODP TSF. 2

Figure B3.1 Tailings settlement for Scenarios #3, #8 and #13 for various tailings following 40 years of tailings deposition. 7

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.

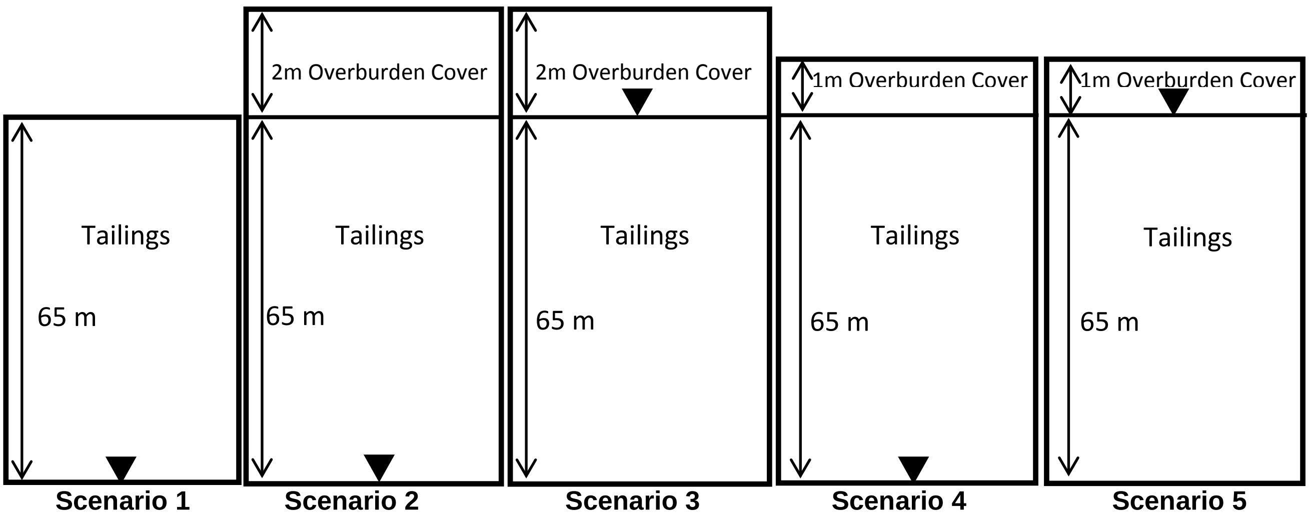

Figure B2.1 Tailings consolidation analysis base scenerios for the ODP TSF.

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).

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

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.

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

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).

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

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.

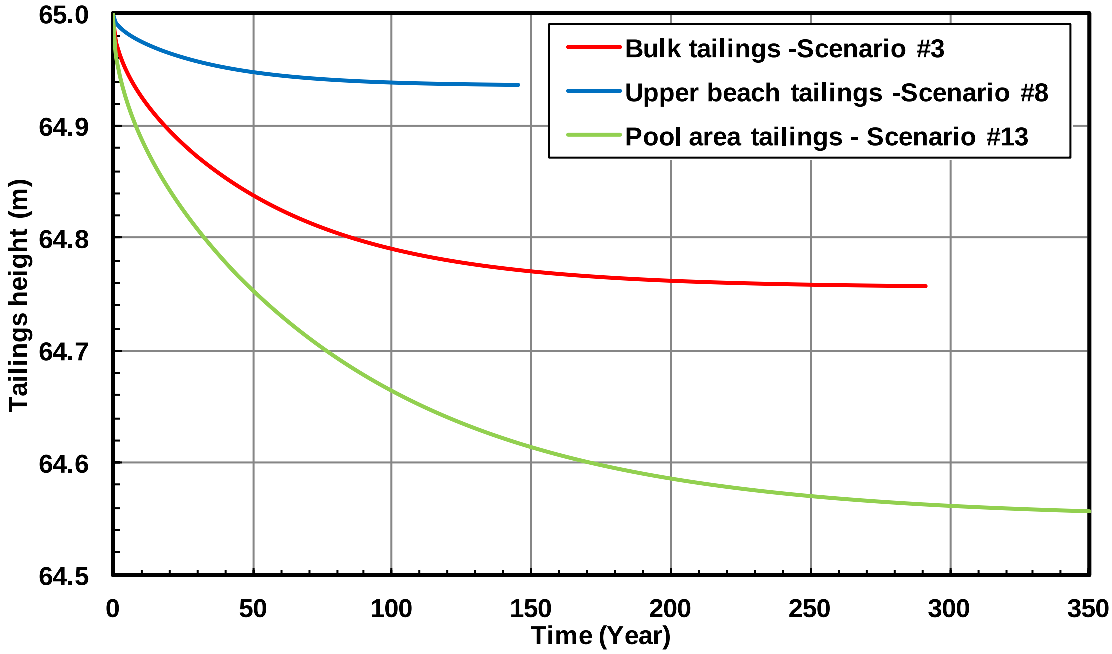

Figure B3.1 Tailings settlement for Scenarios #3, #8 and #13 for various tailings following 40 years of tailings deposition.

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:
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TABLE OF CONTENTS

1. BACKGROUND 1

1.1 PROJECT SCOPE AND MODELLING APPROACH 2

1.2 DATA AVAILABILITY 2

1.3 MODELLING APPROACH 2

2. INPUTS TO SIMULATIONS 3

2.1 SITE OVERVIEW 3

2.2 MATERIAL PARAMETERS 3

3. MODEL OUTPUT 7

4. EROSION PROCESS AND LANDFORM CONSIDERATIONS 9

4.1 FLOW CONCENTRATION 9

4.2 ROCK SIZES AND PLACEMENT 9

4.3 LANDFORM DRAINAGE 10

5. TSF TOP 10

6. FURTHER SIMULATIONS 10

7. REFERENCES 10

APPENDIX 1: THE WEPP MODEL 11

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.

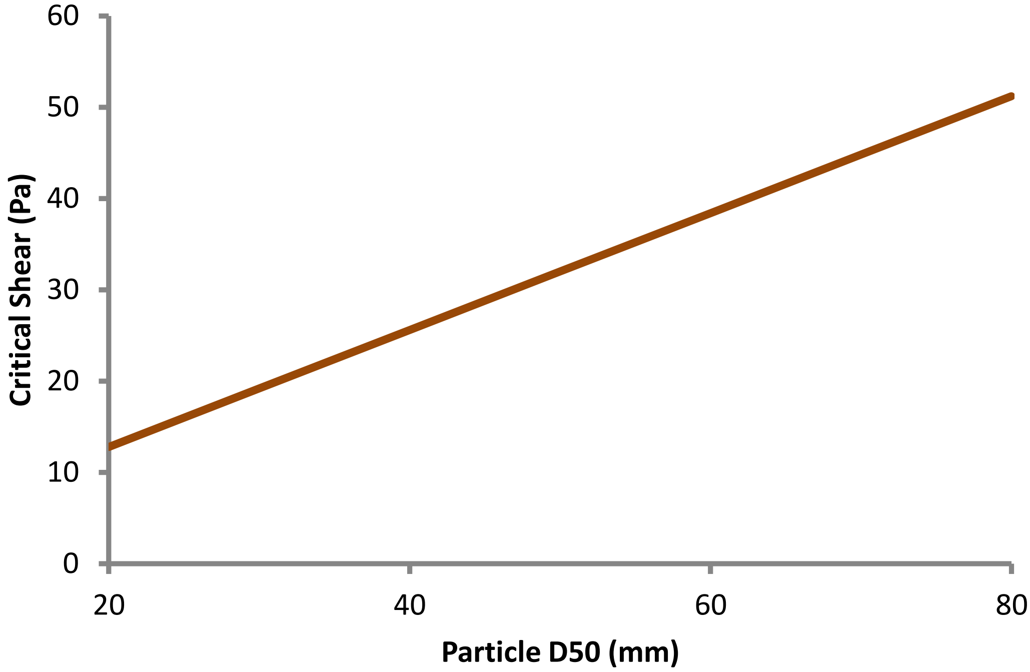


Figure 1: *Critical Shear values calculated for limestone rock of varying particle size.*

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.*

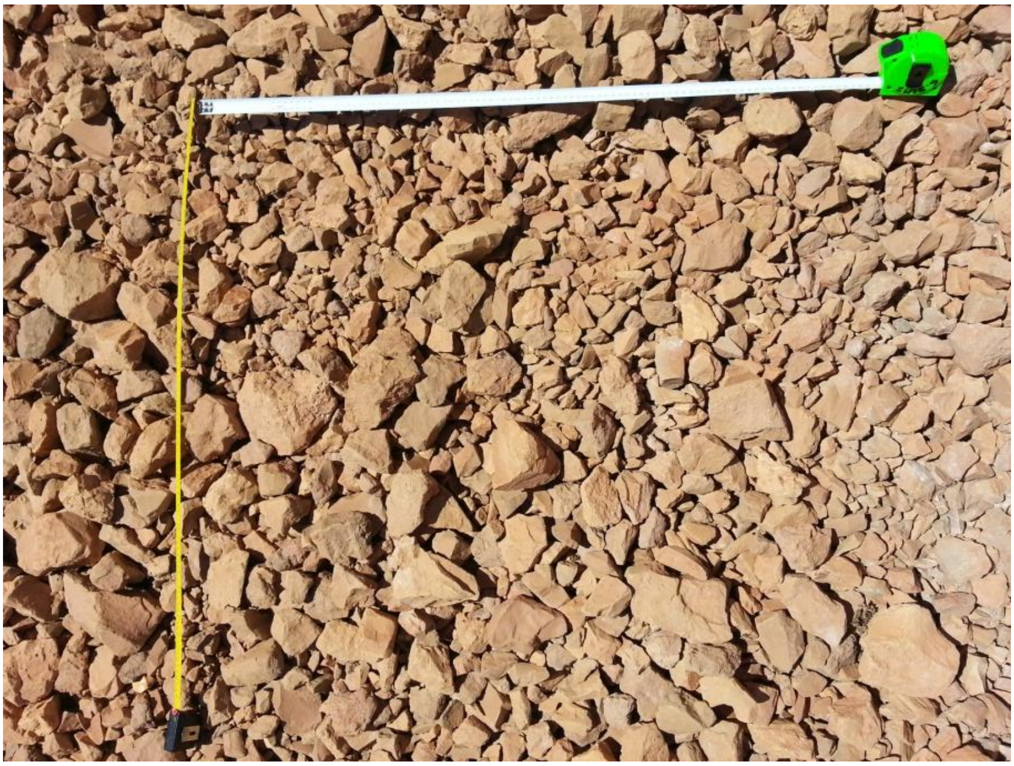


Figure 3: *Cell 1 upper slope batter section with D_{50} of 30.8mm.*

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 $D_{50} \geq$ 60mm.

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 strongly recommended that the data for a 5 m rill spacing be used to guide final slope stabilisation.

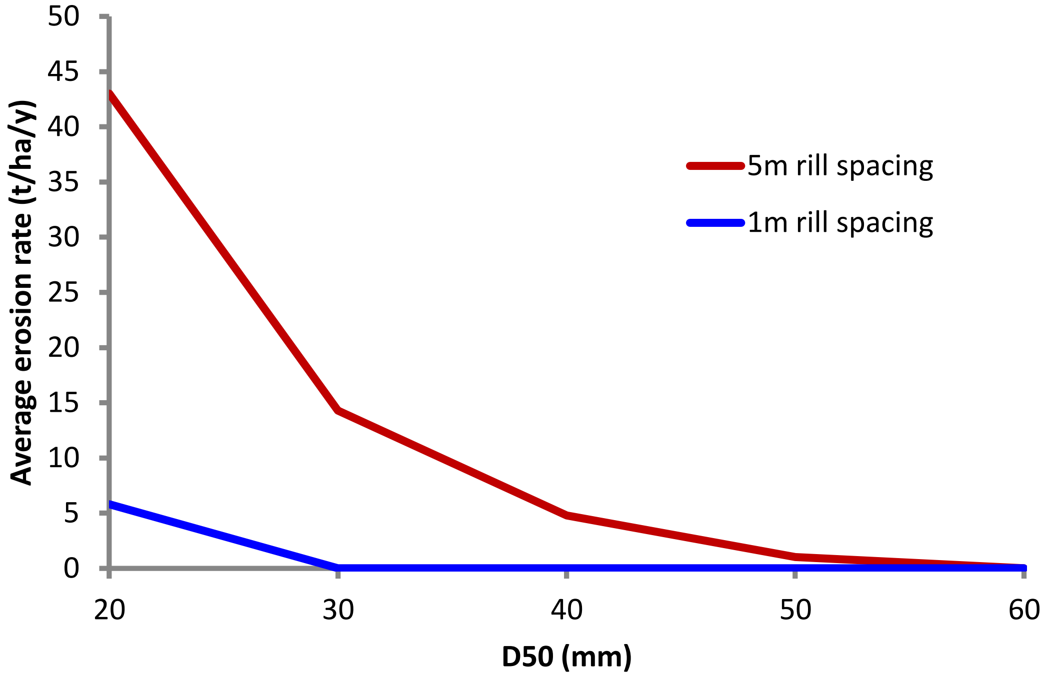


Figure 5: *Predicted impacts of rock D_{50} on average rates of erosion from batters 65m high, 50% gradient.*

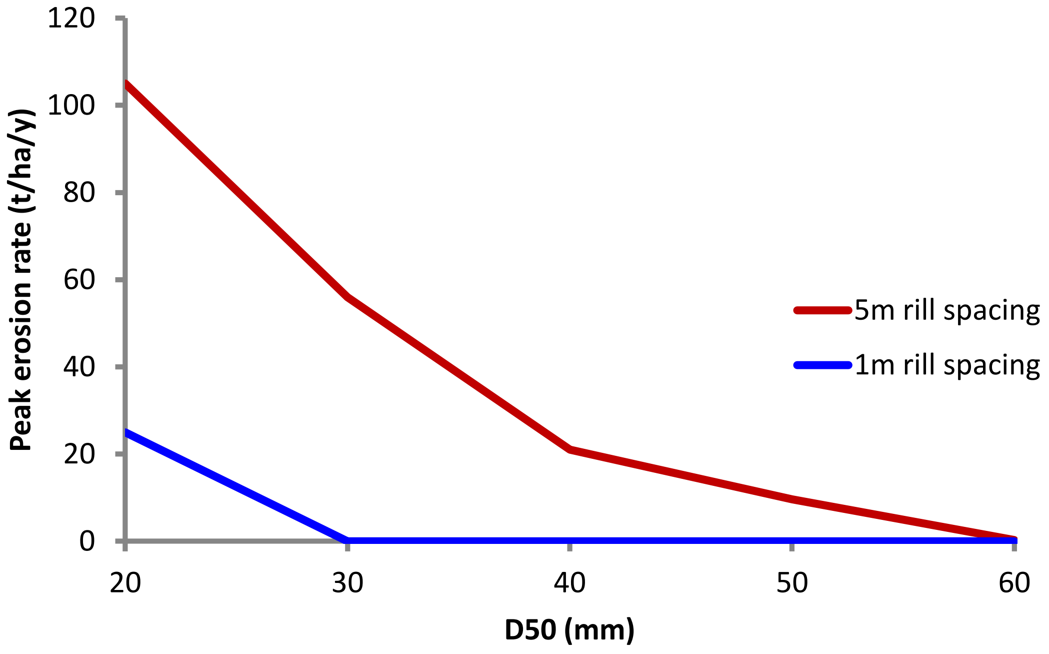


Figure 6: *Predicted impacts of rock D_{50} on peak rates of erosion on batters 65m high, 50% gradient.*

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.

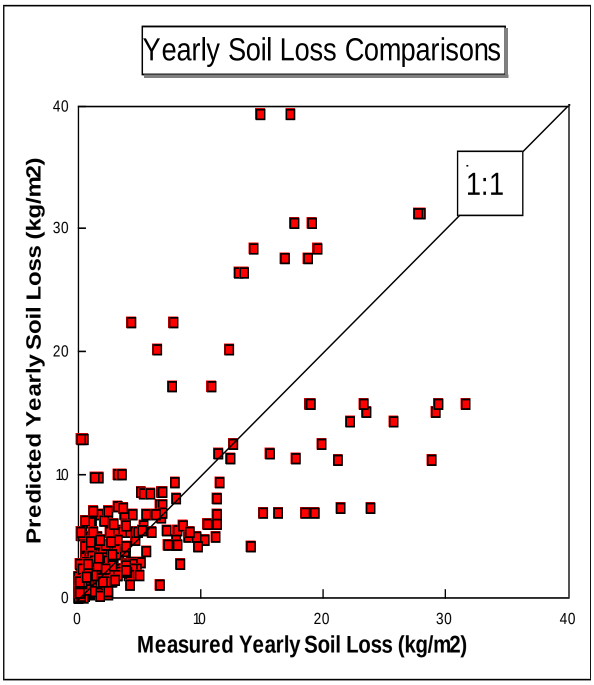
Two methods are used to compute the peak discharge rate depending if the model is run in a continuous or single storm mode and if there are multiple overland flow elements (OFE). A semi-analytical solution of the kinematic wave model is used to compute the runoff hydrograph when the model is run in the 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.



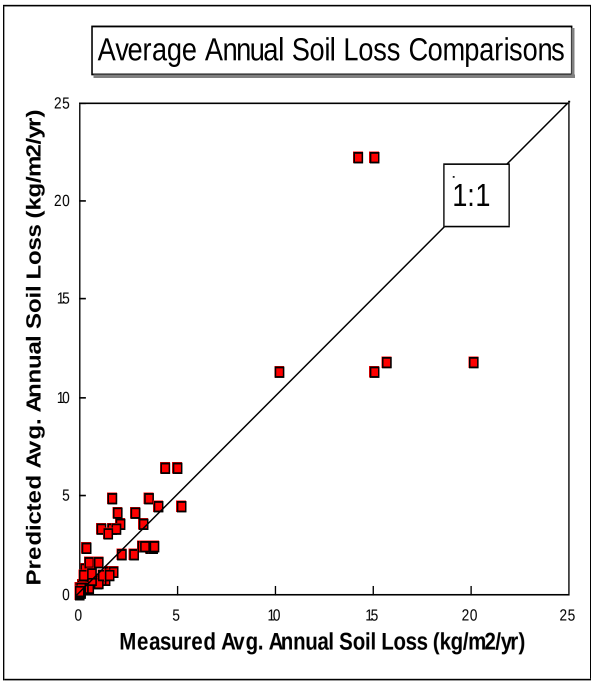


Figure 1-1: *Figures from Nearing and Nicks (1998) showing WEPP model performance against measured data.*

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).

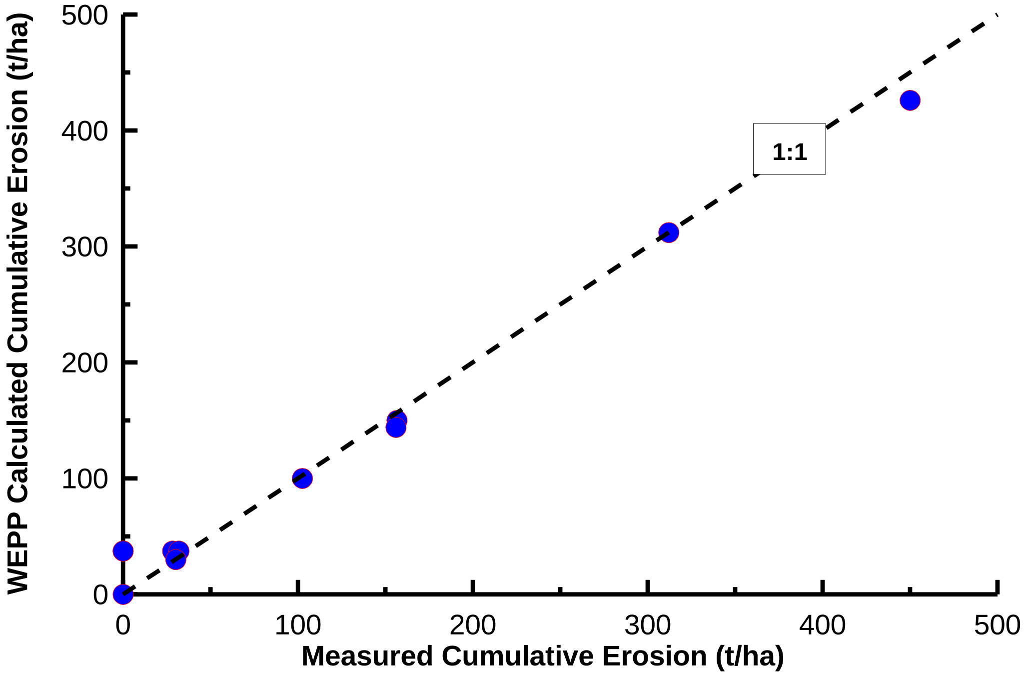


Figure 1-2: *Predicted and observed cumulative erosion rates for 11 batter slope locations in Western Australian mine sites (Howard and Roddy 2012).*

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BHP Billiton Olympic Dam - WEPP simulations for extreme events

21 February 2013

Report prepared for O'Kane Consultants Ltd

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Disclaimer: All care and diligence has been exercised in testing, interpreting data and the development of recommendations presented in this report. The monitoring and testing have been undertaken in a skilled, professional manner, according to accepted practices. Specific circumstances and research findings after the date of publication may influence the accuracy of the data and recommendations within this report.

The simulations reported have relied on rainfall data provided by O'Kane Consultants. Landloch accepts no liability for the accuracy of that data.

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TABLE OF CONTENTS

1. BACKGROUND 1

1.1 PROJECT SCOPE AND MODELLING APPROACH 2

1.2 DATA AVAILABILITY 2

1.3 INITIAL MODELLING APPROACH 2

1.3.1 Landform considered 2

1.3.2 Climate considered 3

1.3.3 Surface modelled 3

1.3.4 Results of initial simulations 3

1.4 CONSIDERATION OF EXTREME EVENTS 5

1.4.1 Concepts 5

1.4.2 Rainfall event considered 5

1.4.3 Surface erodibility characteristics considered 5

1.4.4 Interpretation of erosion predictions 6

2. PREDICTED EROSION FOR 1:10,000 YEAR STORM 6

2.1 CRITICAL SHEAR AND ROCK ARMOUR SIZE 6

2.2 IMPACTS OF BATTER GRADIENT 8

3. REFERENCES 9

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 $D_{50} \geq 60$mm.

[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.

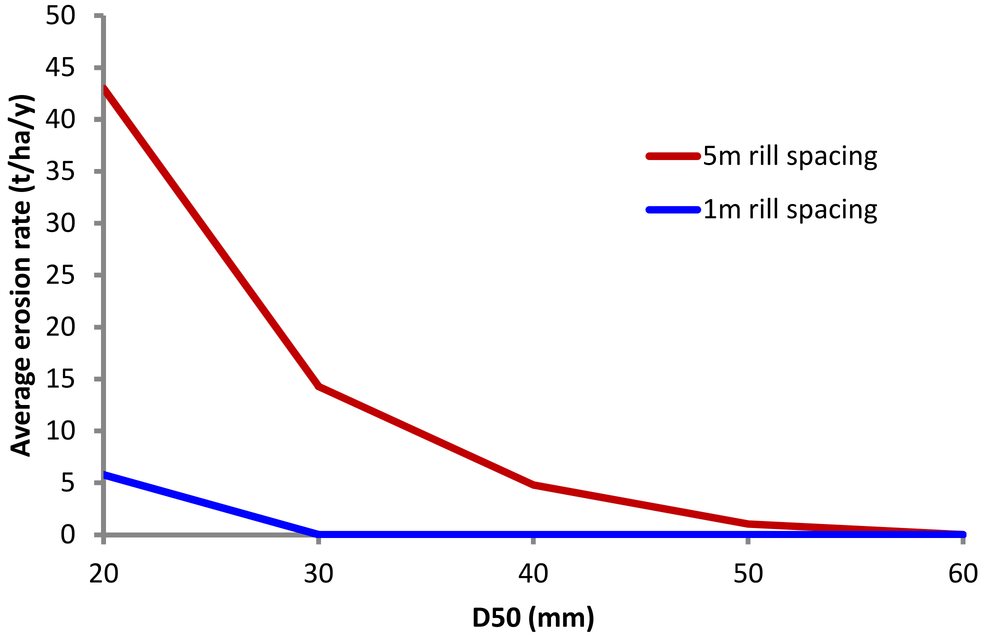

Figure 1: *Predicted impacts of rock D_{50} on* ***average*** *rates of erosion from batters 65m high, 50% gradient.*

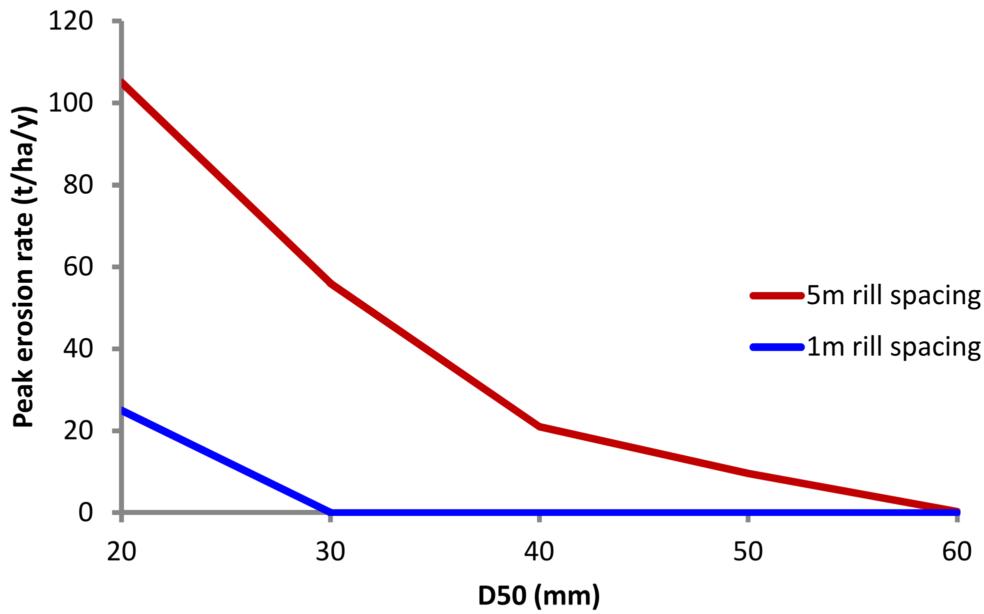

Figure 2: *Predicted impacts of rock D_{50} on* ***peak*** *rates of erosion on batters 65m high, 50% gradient.*

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.)

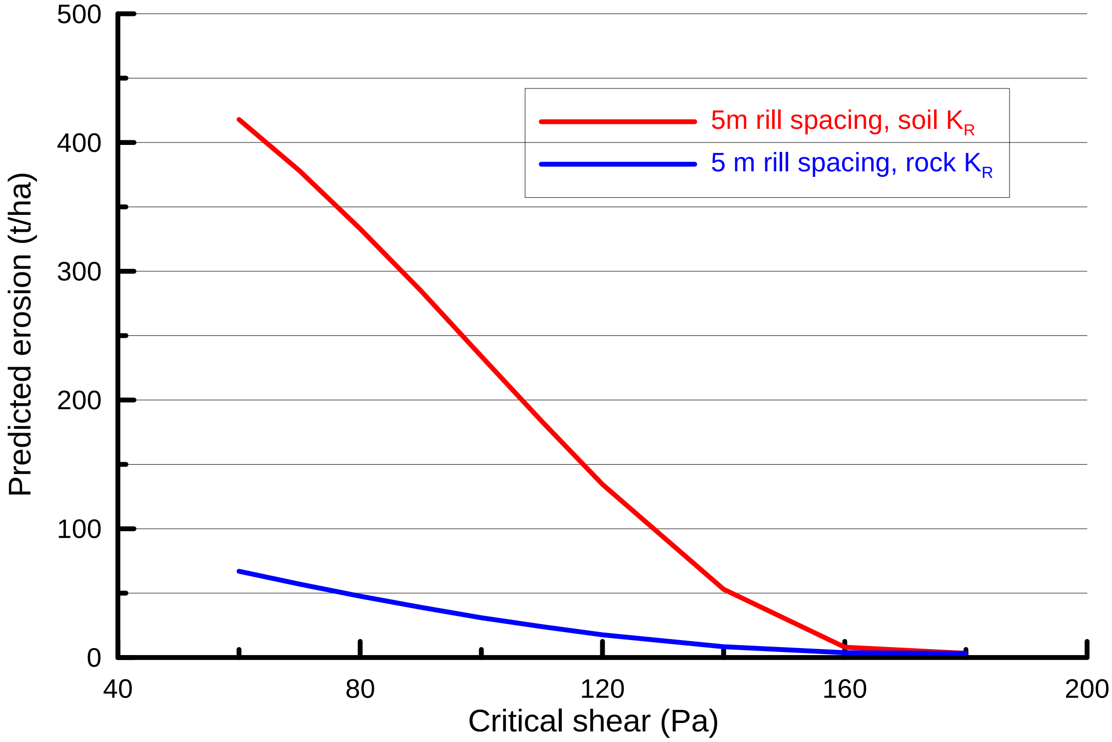

Figure 3: *Predicted impacts of critical shear on erosion predicted for a 1:10,000 year storm, 5 m rill spacing.*

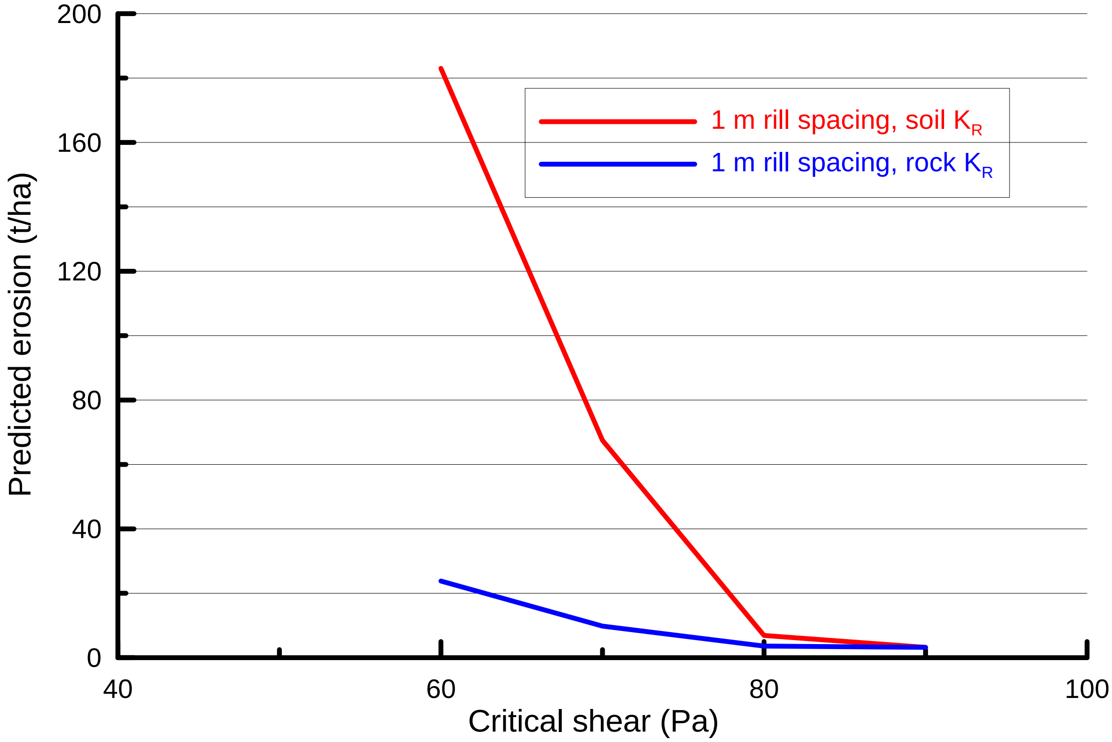

Figure 4: *Predicted impacts of critical shear on erosion predicted for a 1:10,000 year storm, 1 m rill spacing.*

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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.

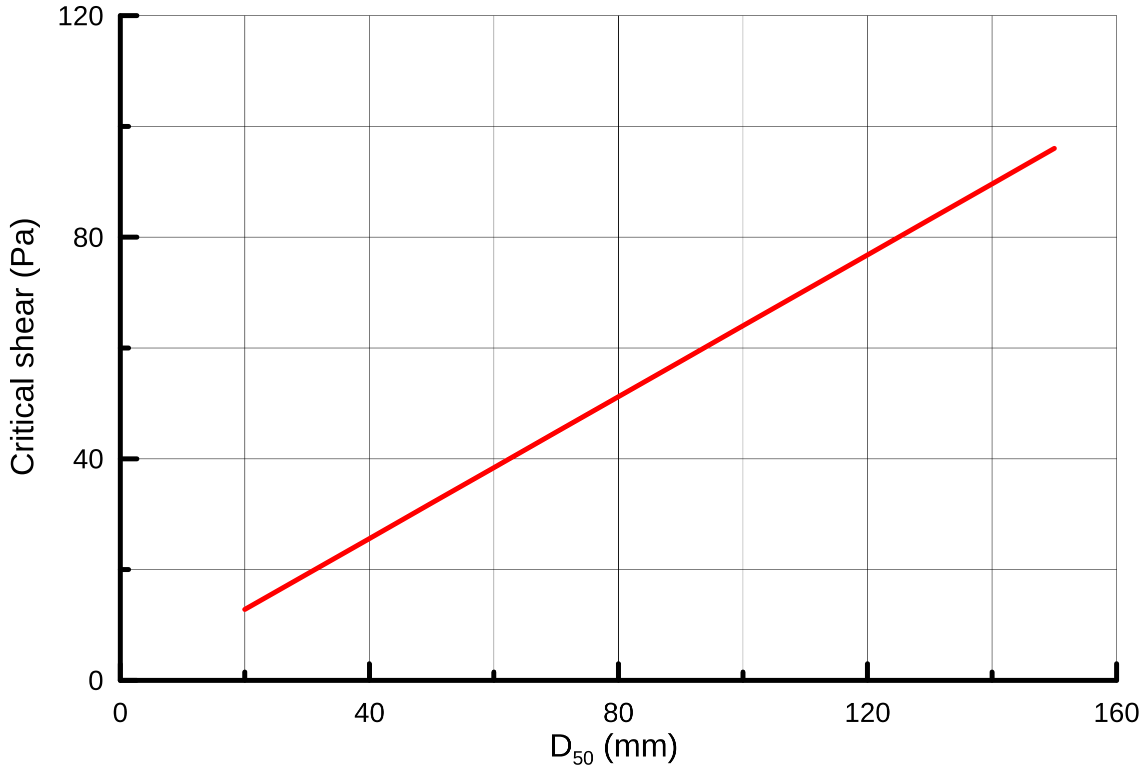

Figure 5: *Relationship between rock D50 and critical shear, for assumed rock specific gravity of 2.45 g/cc.*

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

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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:

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May 2013

TABLE OF CONTENTS

Table of Contents .... **D-ii**

List of Tables .... **D-iii**

List of Figures .... **D-iii**

D1 INTRODUCTION **D-1**

D1.1 Objective and Approach D-1

D1.2 Organisation of Appendix D-1

D2 MODEL DEVELOPMENT **D-2**

D2.1 Model Description and Inputs D-2

D2.2 Material Properties D-2

D2.3 Seismic Load D-3

D2.4 Geometry and Modelling Scenarios D-3

D3 MODELLING RESULTS AND RECOMMENDATIONS **D-4**

D4 REFERENCES **D-9**

LIST OF TABLES

Table D2.1 Summary of shear strength parameters for various materials used in SLOPE/W. 2

Table D2.2 Modelling Scenarios in the stability analyses. 3

Table D3.1 Slope stability analysis results – 65 m high centre-line rockfill embankment. 4

LIST OF FIGURES

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. 5

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. 6

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. 7

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).

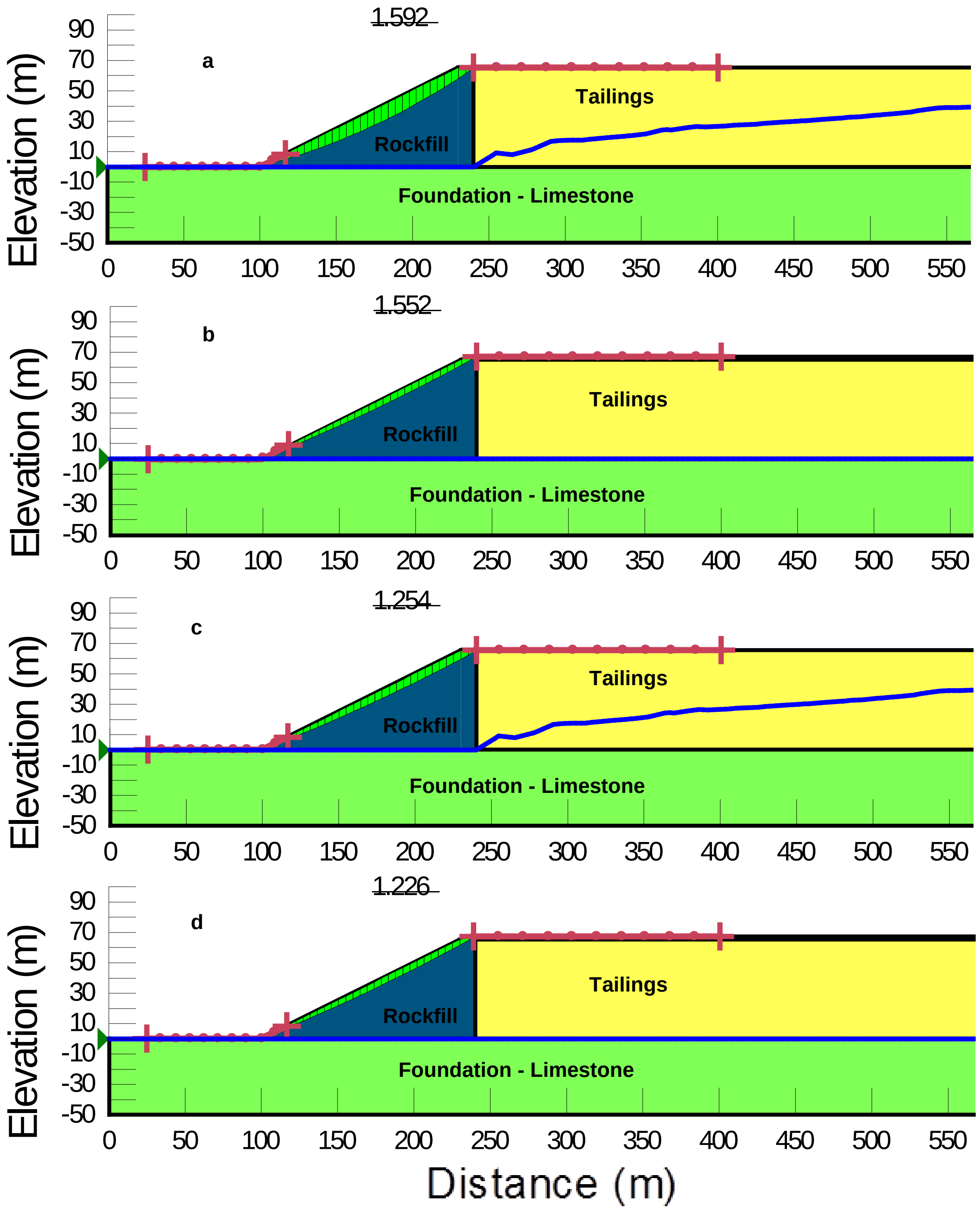


Figure D3.1 Stability analyses for Scenario #3 (Rockfill embankment with 0.4 m thick armoured rock layer overlying thick limestone foundation). a:static loading – operations; b:static loading – post-closure; c:pseudostatic – operations; d:pseudostatic – post-closure.

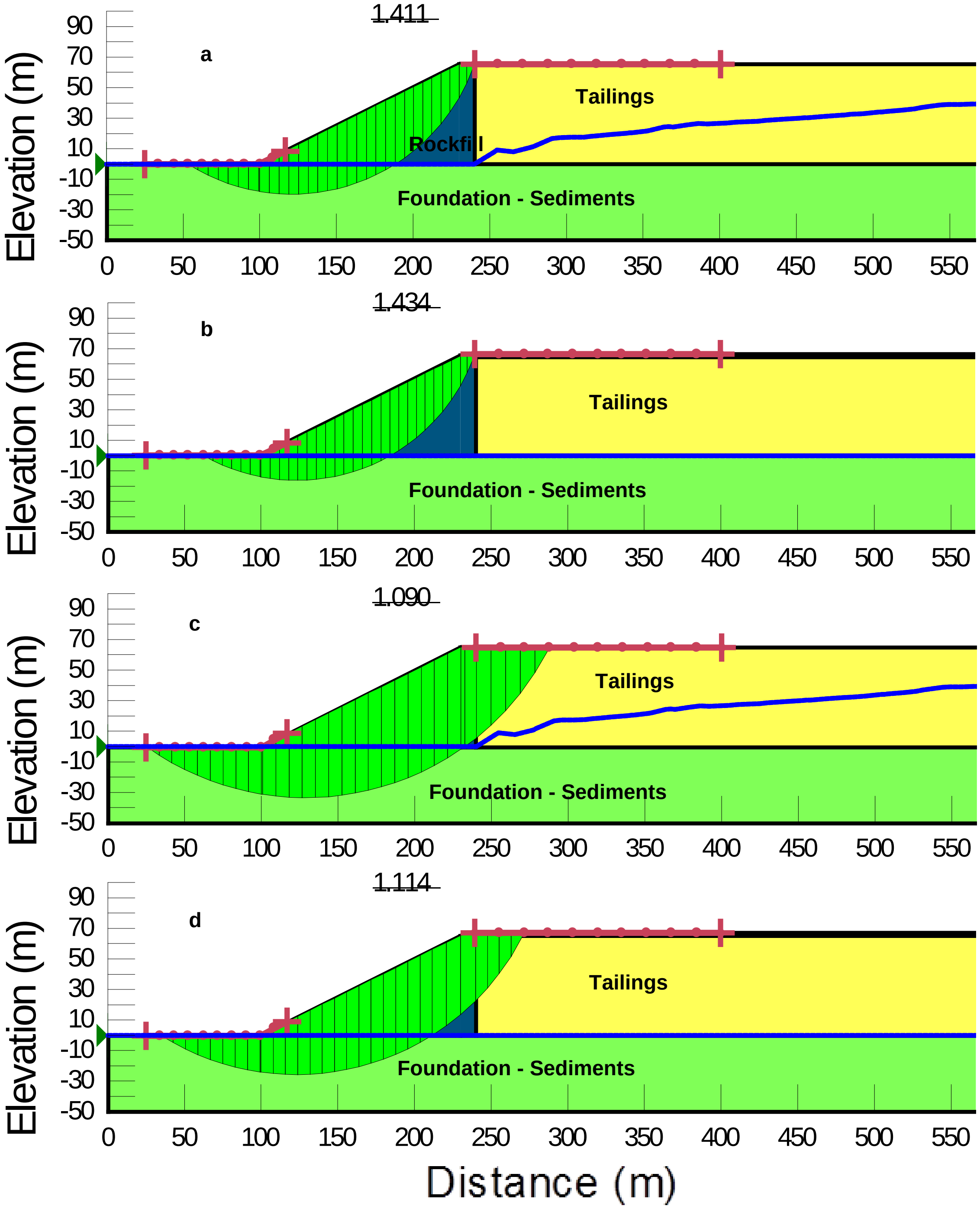


Figure D3.2 Stability analyses for Scenario #4 (Rockfill embankment with 0.4 m thick armoured rock layer overlying thick sediments foundation). a:static loading – operations; b:static loading – post-closure; c:pseudostatic – operations; d:pseudostatic – post-closure.

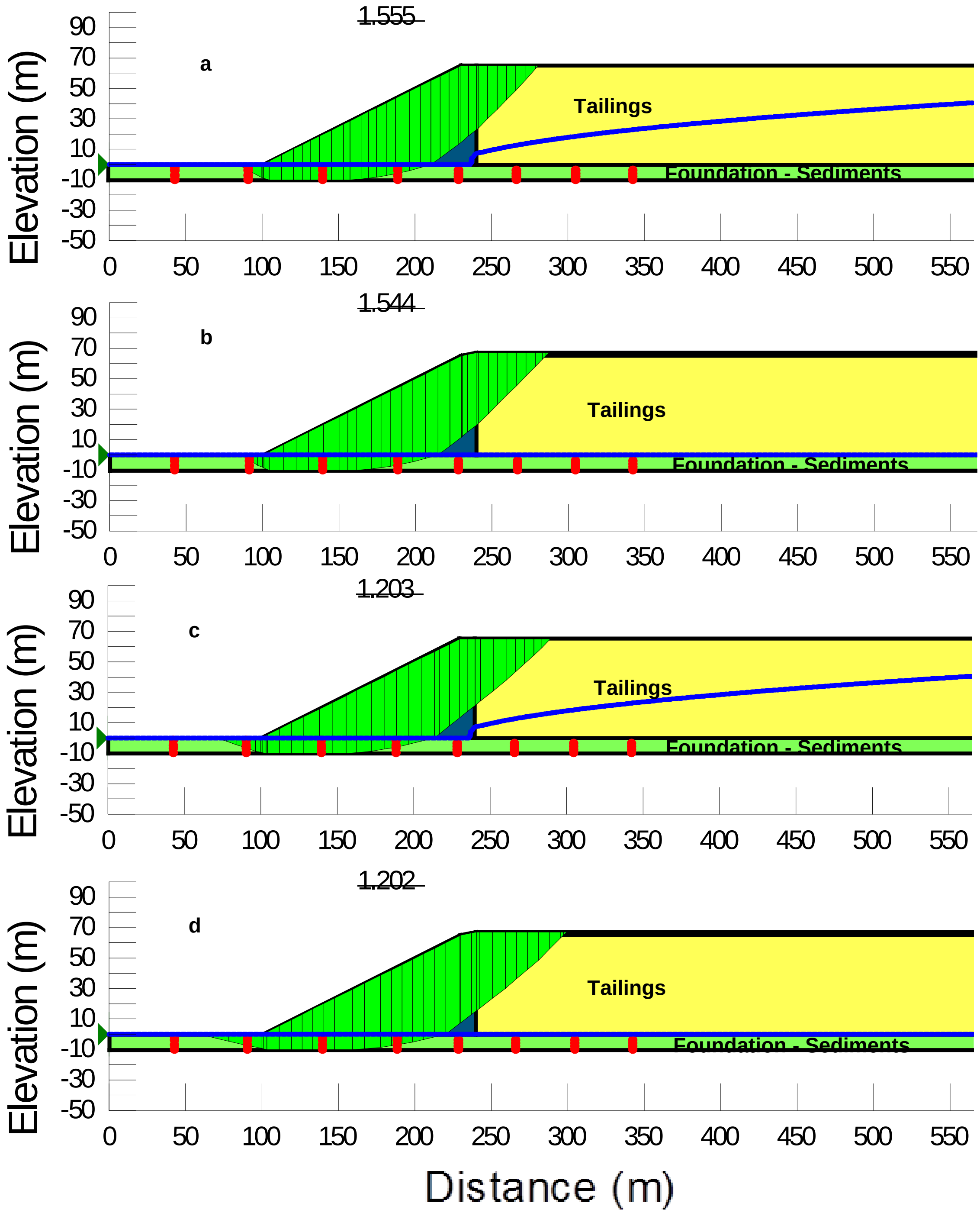


Figure D3.3 Stability analyses for Scenario #5 (Rockfill embankment with 0.4 m thick armoured rock layer overlying thin sediments foundation). a:static loading – operations; b:static loading – post-closure; c:pseudostatic – operations; d:pseudostatic – post-closure.

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						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			
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: 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
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: 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
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

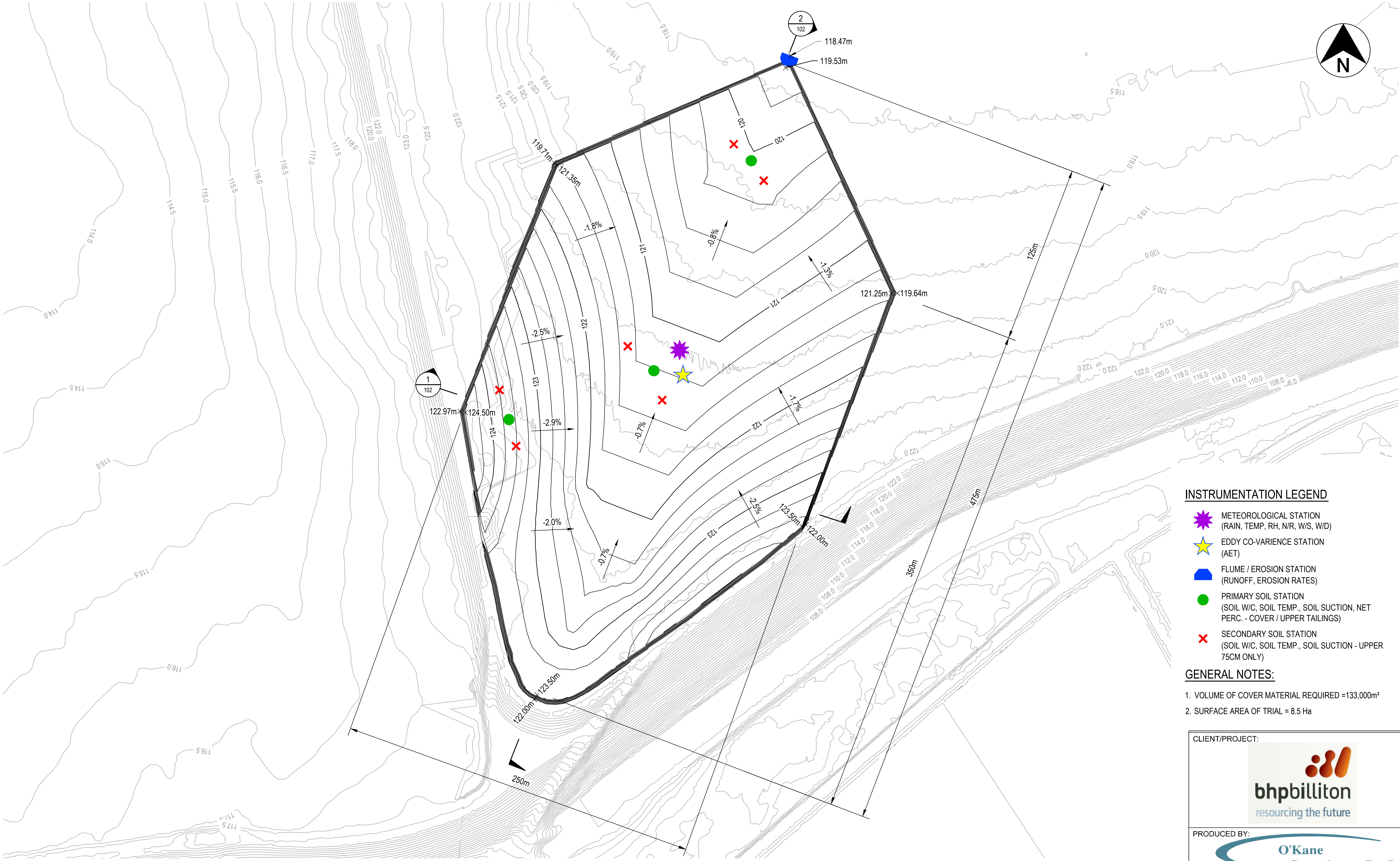
PRODUCED BY:
O'Kane Consultants Pty Ltd.
Integrated Geotechnical Engineering Services
Specialists in Unsaturated Zone Hydrology

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



PROPOSED TSF COVER TRIAL LAYOUT

1:2500

SCALE 1:2500 (25 0 25 50 75 100 125m)

CLIENT/PROJECT: bhpbilliton resourcing the future

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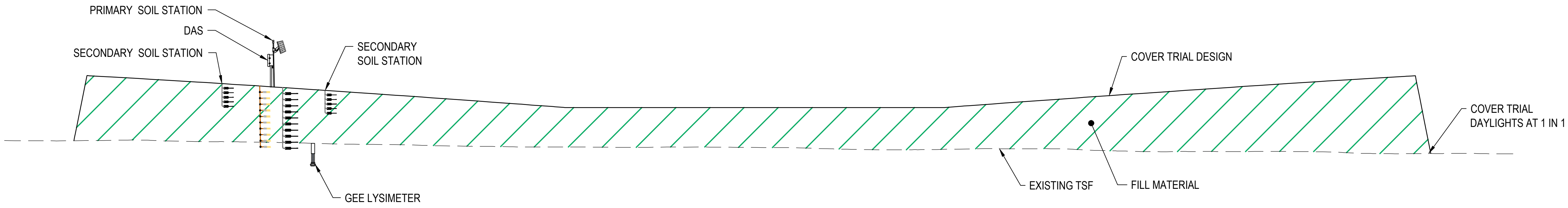
REFERENCE DWG. NO.	DESCRIPTION

REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

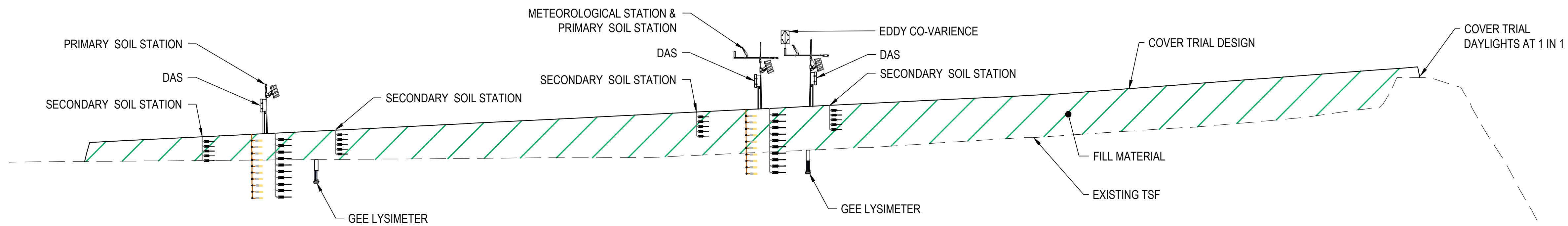
DRN. BY:	S. WALKER	DATE:	31.01.13
APPD. BY:	B. AYRES	DATE:	31.01.13
SCALE:	AS SHOWN	REPORT NUM:	809/5

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.

PROPOSED TSF COVER TRIAL - TYPICAL SECTIONS
NTS

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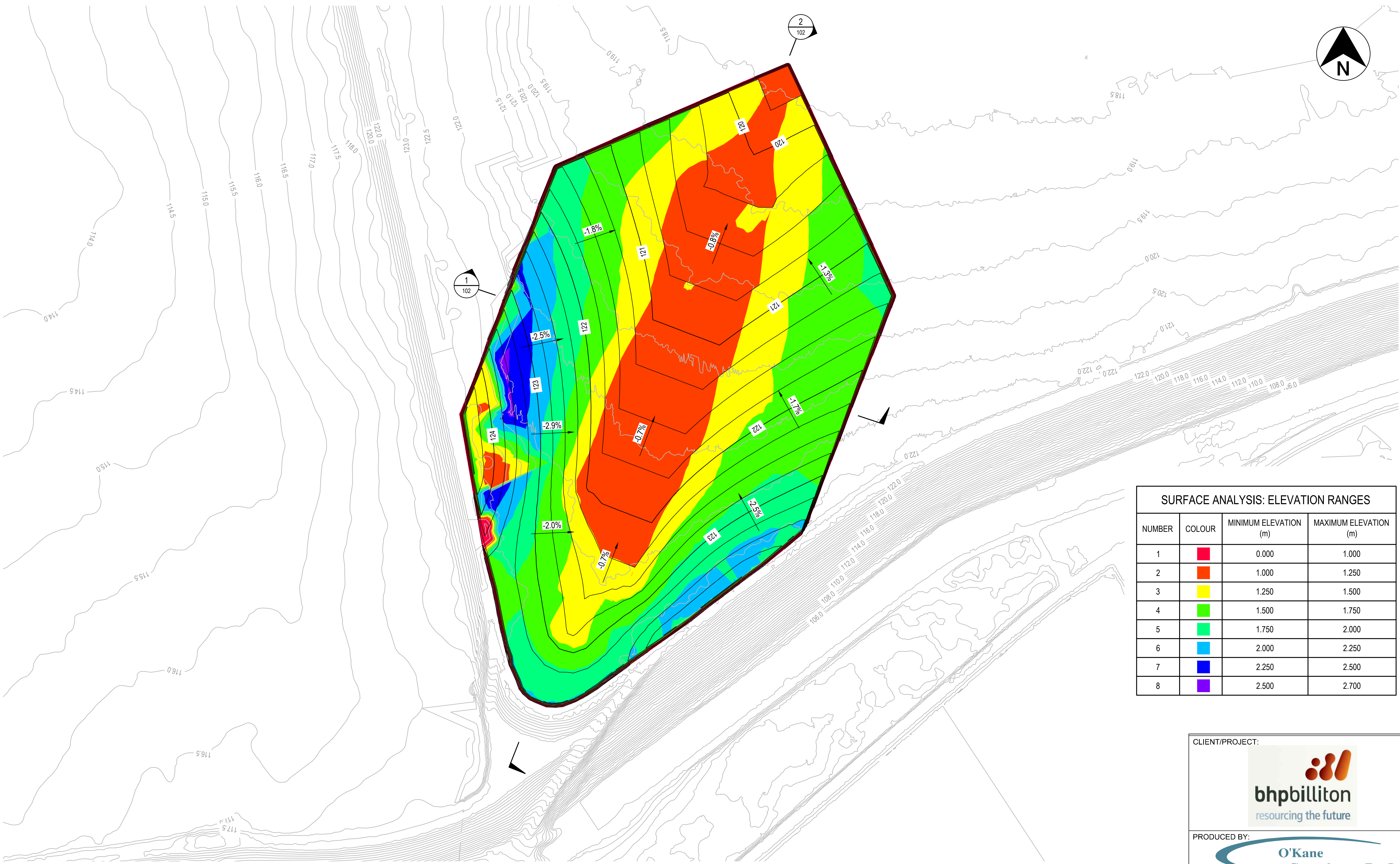
REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

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		0.000	1.000
2		1.000	1.250
3		1.250	1.500
4		1.500	1.750
5		1.750	2.000
6		2.000	2.250
7		2.250	2.500
8		2.500	2.700

CLIENT/PROJECT:

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PROPOSED TSF COVER TRIAL - FILL DEPTHS
1:2500

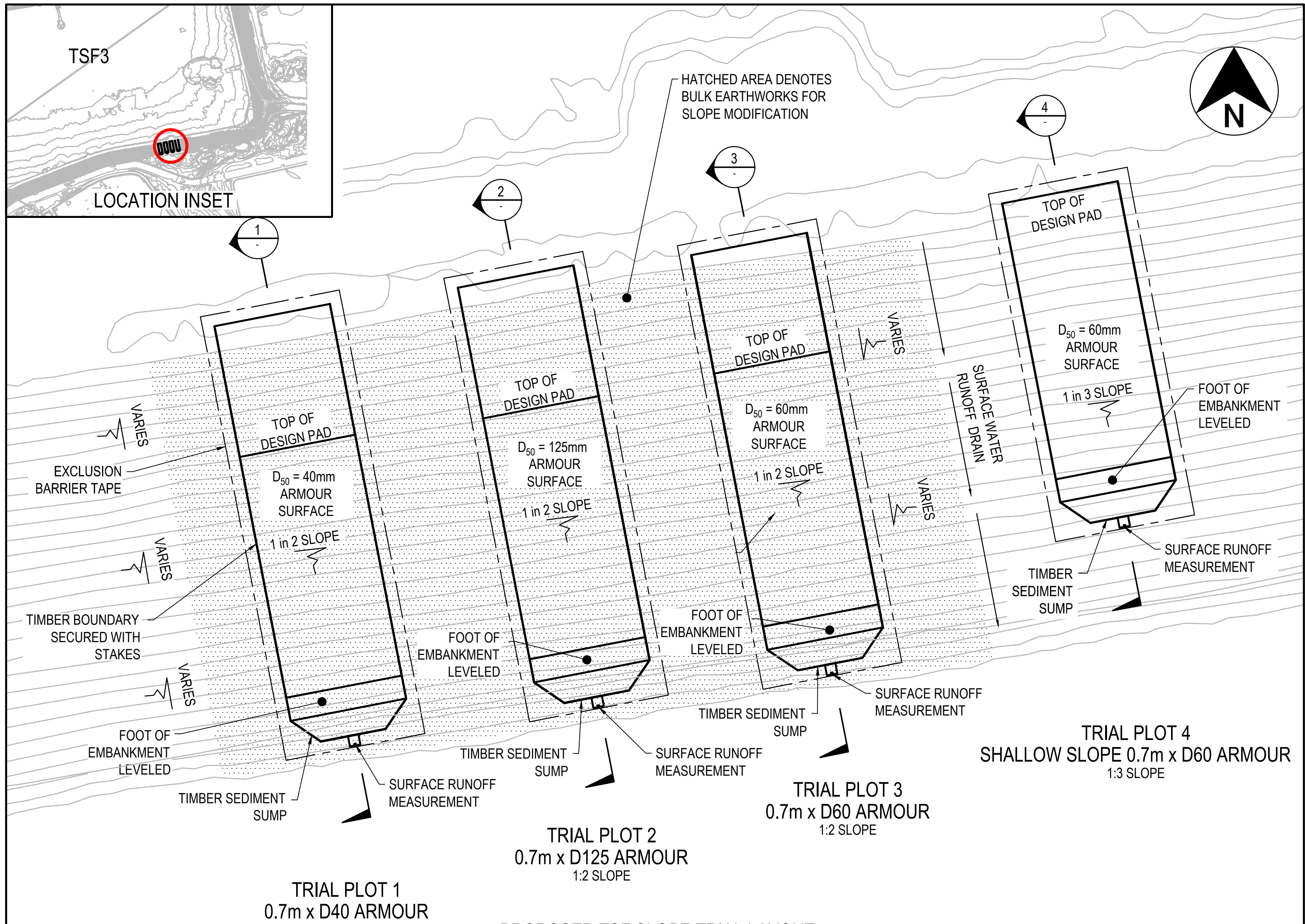
SCALE 1:2500

REFERENCE DWG. NO.	DESCRIPTION	REVISIONS NO.	DESCRIPTION	DRN. BY:	DATE
		0	ISSUED TO CLIENT FOR REVIEW	SMW	31.01.13

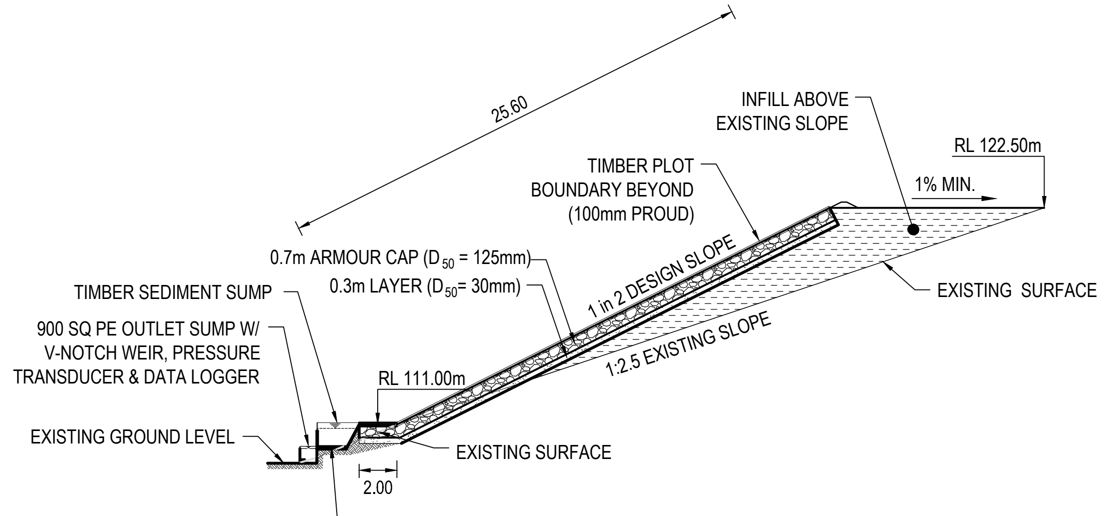
DRN. BY:	S. WALKER	DATE:	31.01.13
APPD. BY:	B. AYRES	DATE:	31.01.13
SCALE:	AS SHOWN	REPORT NUM:	809/5

PROPOSED TSF COVER TRIAL - FILL DEPTHS

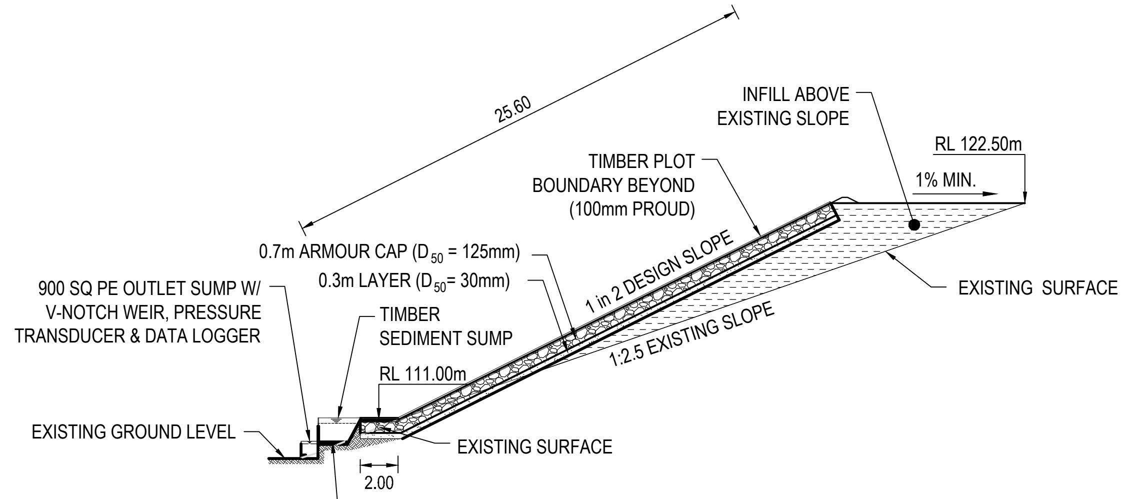
DRG NUM: 809-5-103 Rev: 0



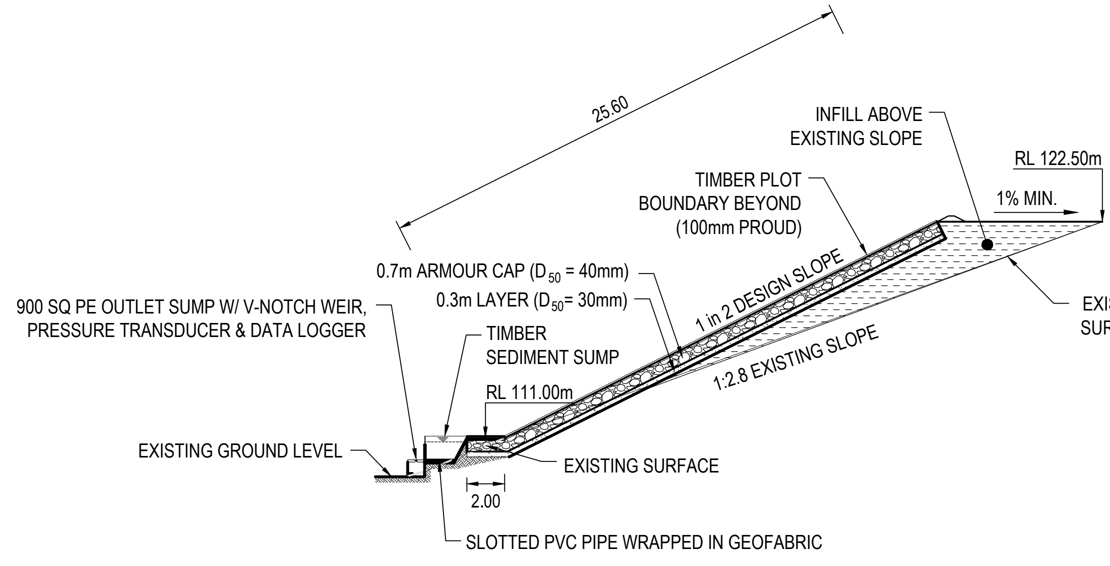
PROPOSED TSF SLOPE TRIAL LAYOUT
1:500



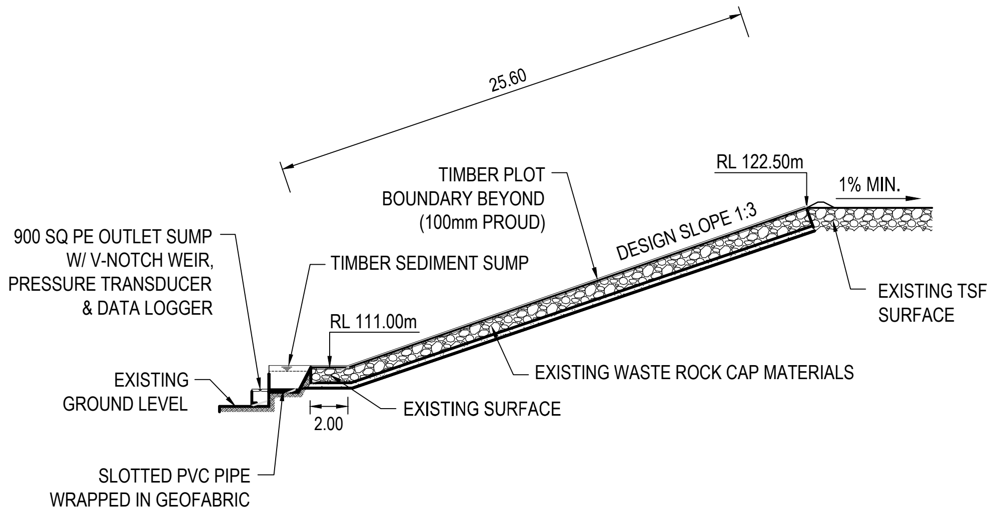
SECTION: PROPOSED TRIAL PLOT 2
1:400



SECTION: PROPOSED TRIAL PLOT 3
1:400



SECTION: PROPOSED TRIAL PLOT 1
1:400



SECTION: PROPOSED TRIAL PLOT 4
1:400

SCALE 1:400
SCALE 1:500

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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