Tailings storage facility design report

Tailings Storage Facility Design Report

OLYMPIC DAM EXPANSION PROJECT

bhpbilliton

resourcing the future

CONTENTS

1   INTRODUCTION

1.1   PURPOSE

The purpose of this document is to provide a basis of design for the proposed Olympic Dam Expansion Tailings Storage Facility as part of the required documentation behind the Environmental Impact Statement approval documentation. It also forms the basis of the Selection Phase Design package for tailings management.

1.2   SCOPE

The scope of this document is to illustrate the work carried out to define the preferred option for the storage of new and existing processing plant tailings. In accordance with the EIS requirements, the document describes the associated risk impacts and how they are mitigated or controlled. This is not a detailed design document but does describe the plan sufficiently enough such that it is evident that the design is practical and manages all risks appropriately. Further work will be carried out in the subsequent project design stages to refine the solutions proposed.

1.3   RESPONSIBILITIES

It is the responsibility of all accountable Project staff to ensure that the requirements of this document are met.

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2   EXECUTIVE SUMMARY

BHP Billiton proposes to expand the existing Olympic Dam operation, including all associated infrastructure. Large quantities of tailings (approximately 70 million tonnes per annum) will be stored in an above-ground tailings storage facility (TSF).

This report describes the design of the proposed tailings storage facilities in support of the Environmental Impact Statement (EIS) and the commitments made therein associated with tailings management. The acceptability of the risk levels has been evaluated initially through internal multi-disciplinary risk assessments including specialist external peer reviewers, and regulatory and public engagement. The design will be tested further through additional risk evaluations and through the EIS process. The items identified from the external reviews to date of this and earlier reports have been addressed in the current design.

The intention of this report is to describe the alternatives investigated for storing tailings in the context of potential hazards and impacts both during operation and after closure. The report also provides preliminary design information for the selected disposal and storage method.

The preferred system comprises a multiple cell ring dyke type storage facility, similar to the existing but utilising the large quantities of competent and durable mine rock extracted from the open pit to construct the perimeter walls, other structural elements, and protective covers. The utilisation of mine rock as the construction material in the preferred option realises its value through effectively managing or assisting with the management of identified risk issues.

Alternative storage methods such as co-disposal, central discharge (similar to BHP Billiton's successful Mt Keith Nickel operation) and high density or "paste" thickening of the tailings were found to be unsuitable in this application. These technologies do not improve the ability to manage the potential risk issues and are not practical at the large tonnages envisaged.

Using rockfill as the construction medium rather than tailings provides some significant advantages and benefits in managing tailings associated risks. Radioactive exposure, radon emission, dust generation and erosion can all be effectively managed using the non-reactive, non-radioactive competent and durable rock which will be mined in exposing the orebody. Rockfill also provides an opportunity to minimise the disturbance footprint by constructing higher (but stable and safe) embankments. The central decant rockfill filter walls also allow better control and positioning of the pond over the central liner, minimising seepage as well as providing a stable structure to support avian control measures such as bird netting which is aimed to eliminate bird access to the central decant pond.

The proposed rock-fill centre-line raised TSF is the best alternative for managing tailings within the geological, meteorological and seismic setting at Olympic Dam in which the TSF will operate and eventually be closed.

A risk-based approach ensures that the design of the preferred solution is in compliance with the recommendations of international best practice and standards, and ensures that potential and perceived health, safety, environment and community (HSEC) risks are adequately addressed through control measures designed to eliminate, mitigate, or manage the risks.

As required by the Joint Australian and South Australian Terms of Reference, "Guidelines for an Environmental Impact Statement on the proposed expansion of the Olympic Dam operations at Roxby Downs" (2005), the existing tailings storage facilities are discussed in some detail. The reconciliation of the successful operation of the existing system against predicted behaviour, outcomes and impacts, provides strong support for the basis for the expansion design.

Continual research during the past 10 years operating the existing facility have allowed improvements to water balance controls, which minimise seepage from the TSF. Several have been successfully implemented and tested during construction of the existing TSF Cell 4, illustrating the improved knowledge and design capabilities that have become available since the original cells were built. Design improvements to effectively manage surface water and seepage include:

1. Detailed geotechnical and geophysical investigations of the foundations to identify and design appropriate treatments against high leakage and/or preferential seepage paths.

2. Increasing the tails disposals slurry solids concentration by weight (w/w) from 45 to 55% in the expansion to reduce the free water available for seepage.

3. Thin layer deposition to maximise evaporation through sun-drying and desiccation which reduces the seepage potential. Thin layer deposition also reduces seepage because each fully consolidated layer becomes an effective barrier to vertical seepage.

4. A cell start-up plan to minimise water ponding on bare ground. Until the original ground surface is covered with an effective low permeability tailings liner/barrier, water is stored and evaporated in the bunded/lined central decant area.

5. A central decant rock flow-through filter wall to control the size and position of the decant pond.

6. Underdrainage in the central area to promote consolidation of the tailings into a low permeability liner/barrier under the central pond.

7. A drainage barrier system within and under the perimeter embankment to prevent seepage through the embankment.

8. A surge or balance pond to manage seasonal and storm surges, and a reticulation system to redistribute water over dry tailings beaches when spare evaporative capacity is available in hotter months, to minimise the quantity of water stored in the surge and evaporation ponds.

9. Process improvements; notably an increase in flotation tails thickening underflow pulp density enable more acidic tailings return liquor to be used back in the plant.

Modelling of stability, seepage, groundwater and geochemical analyses have been carried out using data obtained from field and laboratory investigations carried out for this and earlier studies. These analyses confirm that the proposed design is suitable and manages potential risks to an acceptable level both during operation, as well as in the long term after closure (see Draft EIS Appendices K1, K4 and K6 for details).

Together with the proposed seepage controls, the increased solids concentration assists in notably reducing seepage and in achieving a water balance where no additional evaporation ponds are required. This is important as it reflects an improved water usage efficiency compared with the existing system. Also, as there is a risk of bird mortality associated with disposal of acidic liquor using evaporation ponds, and although the expansion project design contemplates the use of bird-netting as a contingency or risk management option for both the decant and balance ponds, a priority has been set on minimising use of the existing evaporation ponds to minimise the attraction to birds.

The project will continue to monitor the operation and refine the model as necessary. Also additional investigations will be carried out during the detail design phase leading up to implementation and continued into operation and closure.

As per the BHP Billiton Charter, the design has focused primarily on a risk-management approach with risk reduction as a priority over cost. Having designed effective risk controls into the system (prioritised according to the hierarchy of controls – "elimination" through "management"), the Project Team is confident that the proposed design will successfully manage health safety, environment and community risk issues well within acceptable norms. Notwithstanding the risk-based design focus, the design nevertheless also achieves a cost-effective solution in utilising the large quantities of available un-mineralised mine rock as its primary construction material.

3   BACKGROUND

Olympic Dam is a large high grade ore body containing copper, gold, uranium and silver, all of which are recovered to final metal (uranium as uranium oxide U_3O_8).

BHP Billiton proposes to expand the existing Olympic Dam operation, including associated infrastructure. The Olympic Dam Expansion will create a large open pit mining, processing, smelting and refining operation increasing the existing 10 million ore-tonnes per annum to approximately 70 million ore-tonnes per year through a staged approach.

The large quantities of tailings produced will be stored above-ground, with surplus tailings water re-used in the process or disposed by evaporation.

A number of alternative tailings storage methodologies have been studied to ensure the selection of the best available approach to managing potential environmental impacts associated with the operation and closure of the tailings storage facilities.

3.1   DESIGN APPROACH

In the lead up to the selection of the preferred tailings storage option, all available leading practice tailings storage methodologies and technologies were evaluated at a conceptual design level, considering the existing knowledge and lessons learned from more than 20 years tailings management at the site – albeit at significantly lower tonnages (Chapter 4).

The numbers of available options were then reduced through more detailed consideration of the proposed project scale (very large tailings tonnages) and the specific Olympic Dam geological, environmental and meteorological conditions (Chapter 5). Through this refinement process, inappropriate and/or inadequate solutions were eliminated, allowing a limited number of methodologies to be carried forward to a more detailed (Selection Phase or Pre-Feasibility) study, from which the preferred method was selected.

The preferred alternative (Chapter 6) was then studied in more detail to ensure that the design would manage the identified risk issues, that geotechnical structural and risk management control designs are fit for purpose, and that the commitments made in the EIS are practical, defendable and achievable. The selection methodology was based on a ranking system of key parameters; notably the HSEC and economic risks.

Leading practice tailings disposal and storage design requires risk-based analysis to be applied to leading practice (proven) tailings disposal methods. In this way, a tailings management system can be developed which effectively manages potential safety, health, environmental and community impacts to levels acceptable to stakeholders.

The basic steps include:

1.   Cleary defining the geological and meteorological setting in which the storage facility will be located and operated. This is particularly important in defining background conditions, potential impacts and loading possible conditions.

2.   Clearly defining the design criteria and operating parameters within which the facility will be expected to operate throughout its life (including the very long period after closure). These parameters include the materials to be stored and the construction materials.

3.   Identifying the potential issues (health, safety, environment and community (HSEC)) associated with tailings storage (including construction, operation and monitoring) in this environment – during operation and after closure. The accepted definition for the purpose of risk management in this report is a target of "zero harm", which in the context of tailings management is "no unacceptable impact" to health, environmental, safety or the community.

4. Appraising leading practice tailings disposal methods (proven and possibly new innovative solutions) which may be applicable to the project scale; that is fit for purpose and the geological and meteorological environment.

5. Developing conceptual design solutions considering leading practice storage methodologies, similar disposal facilities and lessons learned.

6. Demonstrating that the proposed engineering design, construction, operating, management and monitoring programs will manage the potential risks throughout the facility life-cycle. In particular, the proposed systems should be tested against lessons learned through prior operational experience at this site, and relevant scenarios which have occurred elsewhere.

7. Demonstrating that operation, closure and rehabilitation of the proposed facilities to acceptable levels can be achieved.

8. Confirming that this will achieve sustainable outcomes for stakeholders.

3.2   DESIGN STANDARDS

The design was conducted in consideration of the following as minimum design standards and the following guidelines:

- BHP Billiton Tailings Management Plan (BHP Billiton, 2007)

- ANCOLD (1999) – Guidelines on Tailings Dam Design Construction and Operations.

- ICOLD (1996) –A guide to tailings dams and impoundments: design, construction, use and rehabilitation (ICOLD Bulletin106).

- Guideline for Tailings Management, Department of Industry, Tourism and Resources, February 2007(DITR, 2007).

- Draft EPA/PIRSA Guideline - Tailings and Tailings Storage Facilities. EPA (2007).

- Canadian Dam Association Dam Safety Guidelines. CDA; 2007

3.3   ENVIRONMENTAL IMPACT STATEMENT – TERMS OF REFERENCE

The tailings storage assessment and design has also been carried out in consideration of the jointly issued Australian Government "Guidelines for an Environmental Impact Statement on the proposed expansion of the Olympic Dam operations at Roxby Downs" (the "Guidelines") which set out the terms of reference for the EIS. The EIS is required to describe the existing operations and the proposed expanded operations (including alternatives considered), so that interested individuals and groups may gain an understanding of the environment which could be affected, the impacts that may occur, and the measures to be taken to mitigate potentially adverse impacts.

4   EXISTING TAILINGS RETENTION FACILITIES

The EIS Guidelines requires a description of the existing tailings storage facilities. This section describes the existing system within the context of the proposed new tailings and water storage facilities. The information has been compiled from data and information from the 1997 EIS, the design report for the most recent new cell TSF4 (Coffey Metago, 1998) the 2004 operating seepage and stability check (Knight Piésold, 2004), and the preliminary investigations carried out for this expansion study (Coffey Metago, 1998). The various components and performance of the existing Olympic Dam tailings retention system (TRS) – including pumping systems, tailings storage facility (TSF)) and evaporation ponds (EP), and the regional geology and the geology of the Olympic Dam area are described in the 1997 Olympic Dam Expansion Environmental Impact Statement (Chapter 3.2). The regional hydrogeology and the effect that the operation has had on groundwater levels in the area are described in the 1997 EIS in section 4.6.

4.1   TAILINGS STORAGE FACILITY (TSF)

The process tailings are pumped in a slurry to the TSF at a solids concentration around 45 to 48% (ratio of mass of solids to total mass of solids and water) and distributed to four tailings storage cells (Figure 4.1 and Table 4.1). The cells are raised by the upstream construction method (Figure 4.2), each cell having pumped decant facilities that transfer decanted liquor (rainfall runoff and supernatant liquor) to the evaporation ponds.

The tailings storage facility stores approximately 8.2 Mtpa tailings resulting from processing about 8.6 Mtpa ore, with 0.4 Mtpa used in mine backfilling.
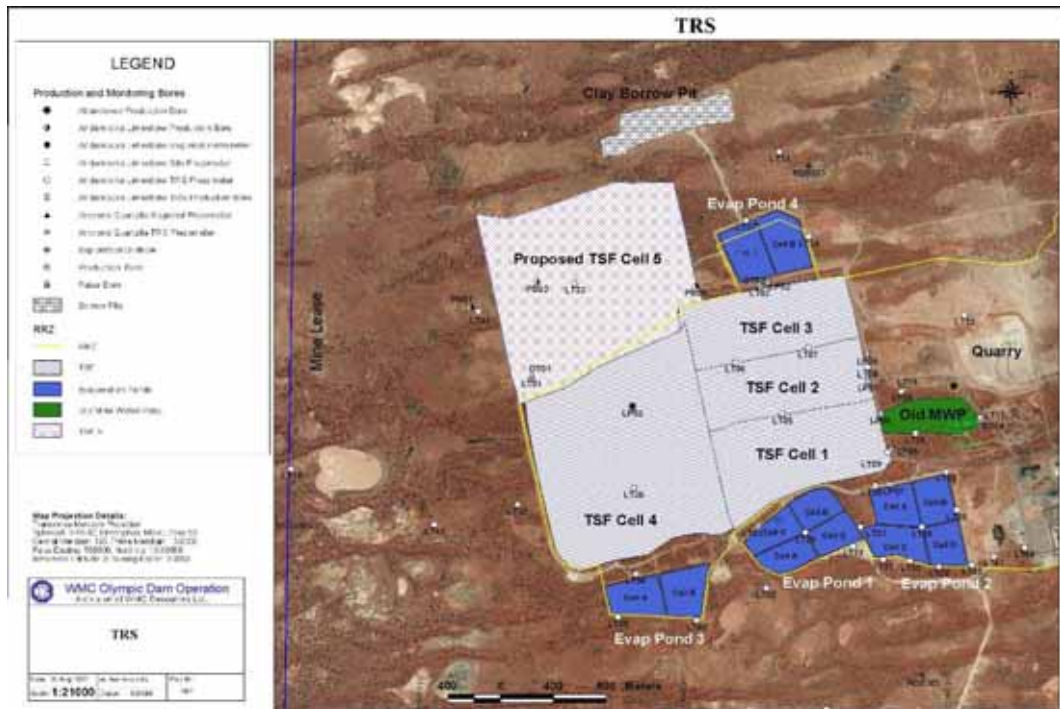
Figure 4.1 Plan view of existing Tailings Retention System

Table 4.1 Existing Tailings Storage Facilities – history and footprint

TSF Cell No.	Footprint (ha)	Commissioning date
Cell 1	79	1988
Cell 2	58	1991
Cell 3	65	1991
Cell 4	193	1999
Cell 5	up to 400	Proposed (2011)
Total	588 minimum	
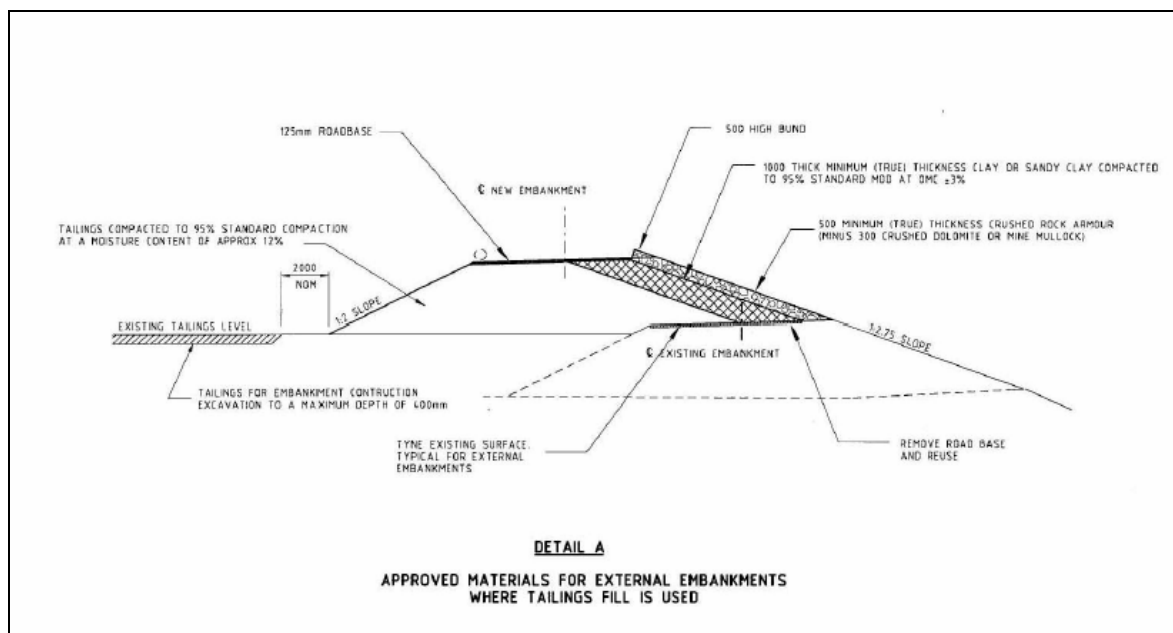
Figure 4.2 Upstream embankment raise construction using tailings

The tailings retention system occupies a combined area of about 550 Ha. As shown in Figure 4.3, a further minimum of 200 ha of tailings storage and 50Ha (20Ha in 2008) of water storage/evaporation capacity, are planned for construction as part of the current approved operation. TSF 5 will be sized to replace cells 1-3 and is projected to be required by mid-2011.
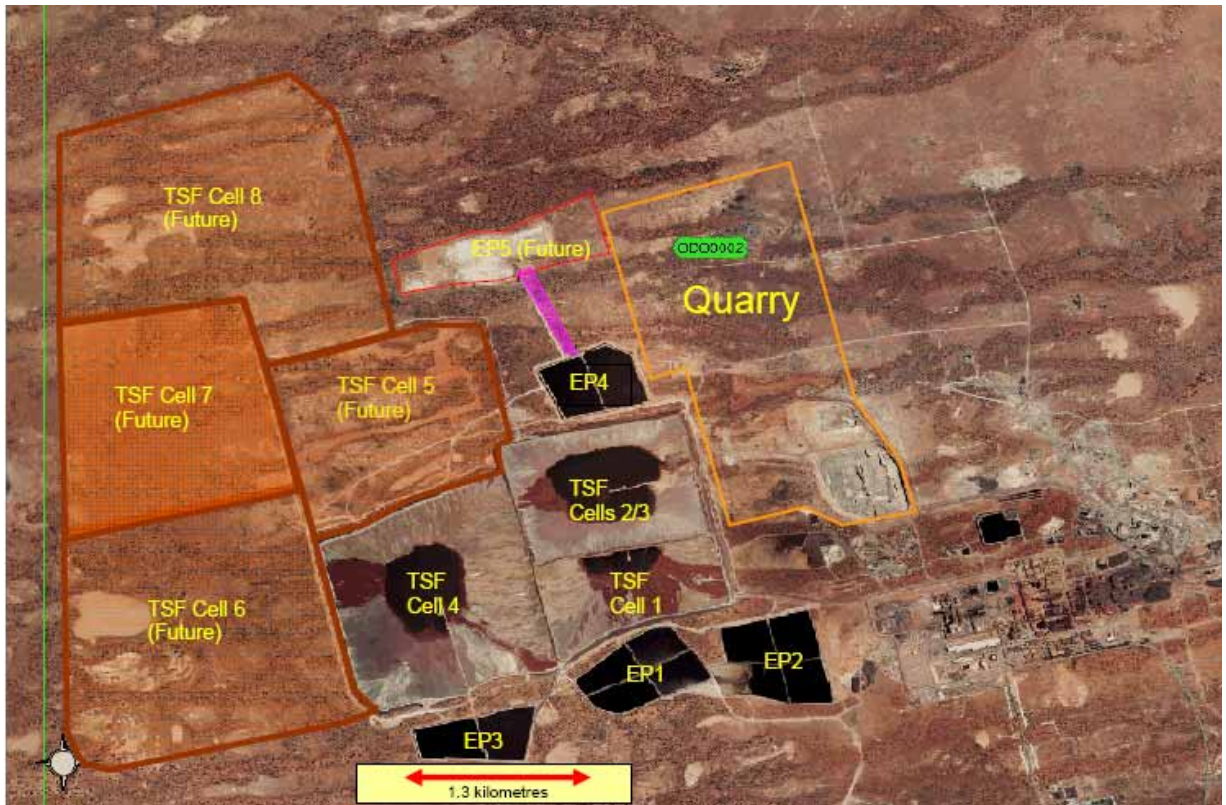
Figure 4.3 Plan for existing TRS

Key design details of the existing cells are:

1. A final embankment height of 30m

2. Outer embankment slopes are constructed at about 2.75:1 (horizontal to vertical).

3. The embankment is zoned:

    a. Compacted tailings core for stability.

    b. Upstream slope oxide cover zone (1000 mm) attenuating radon, and

    c. Upstream slope rock armour (500 mm) as erosion protection.

4. Beach slope angles are less than 1 % overall, with steeper slopes adjacent to the embankment points of deposition, and flatter slopes near the supernatant pond areas.

5. A specific start-up schedule was used in Cell 4 to ensure that an effective tailings floor lining is provided as early as possible, with minimal standing water on bare ground (Figure 4.).
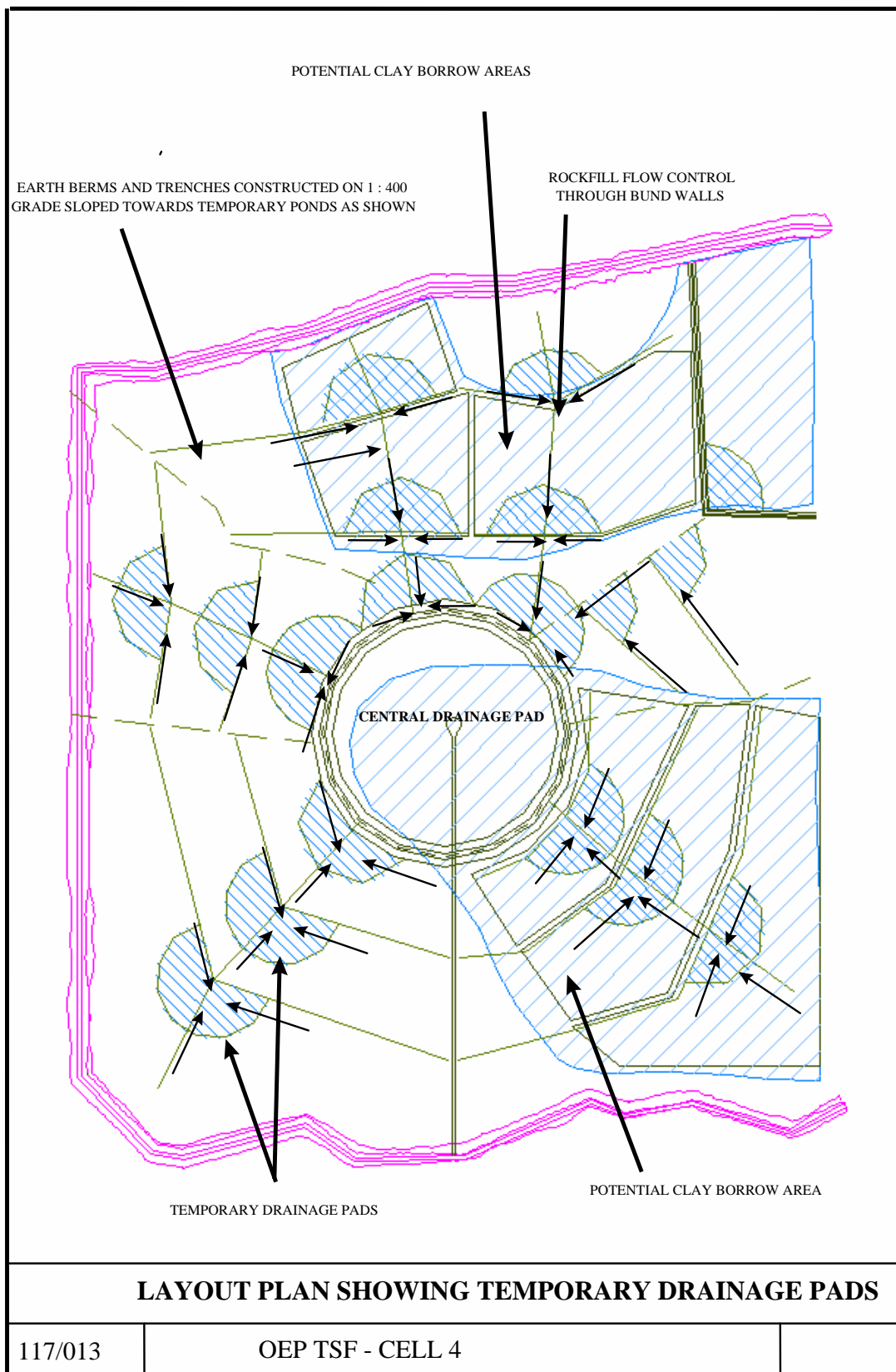
Figure 4.4 Start-up plan for floor covering

4.2   EVAPORATION PONDS

Surplus acidic water (rainfall runoff, supernatant liquor) from the tailings cells, together with excess acidic liquor from the slimes thickener, are disposed in a series of evaporation ponds.

At a disposal rate of around 8.2 million tonnes of ore per annum (Mtpa), approximately 12.5 gigaliters per annum (Glpa) (which equates to 12,500,000 m^3) process water are consumed, with approximately 1.5 Glpa disposed through evaporation from 136Ha of evaporation cells (see Table 4.2).

Table 4.2 Existing Evaporation Ponds – area, depth and history

Evaporation Pond (Minimum Freeboard 1.0m)	Area (Ha)	Average Water Depth	Constructed
EP1a, EP1b, EP1c and EP1d	32	2 m	1995
EP2a, EP2b, EP2c, EP2d	38	2 m	1994/1995
EP3a, EP3b	22	1 m	1998
EP4a & EP4b	24	3.2 m	1999
EP5	20	5.0	To be constructed in 2008
Total	136		

The evaporation ponds are lined with a composite clay/high density polyethylene (HDPE) liner comprising a 500 mm thick compacted clay layer, overlain by a 1.5 mm thick HDPE liner. The ponds are reticulated allowing inter-pond transfer of liquor to maximise evaporation.

4.3   ASSOCIATED INFASTRUCTURE

4.3.1   PIPE CORRIDORS AND PIPELINES

Pipe Corridors are provided for tailings and liquor pipelines transporting tailings and water to the tailings storage facilities and the evaporation ponds. The pipe corridors are constructed with bunds to contain any tailings or liquor spills. There are three tailings pipelines between the metallurgical plant and the tailings storage facility and two principal liquor pipelines between the evaporation ponds and the metallurgical plant.

Additional pipelines provide flushing water to the tailings distribution pipelines around the TSF perimeter, decant from the TSF cells to the evaporation ponds, bleed from the evaporation ponds back to the metallurgical plant, and water transfer between evaporation ponds.

4.3.2   GROUNDWATER MONITORING BORES

Groundwater monitoring bores are situated locally around the TRS (red and green dots in Figure 4.5) and regionally (Figure 4.6) to monitor groundwater levels and quality. The monitoring results are described in the Olympic Dam Annual Environmental Report. Additional monitoring bores have been installed as part of ongoing EIS and ODX investigations during the preparation of this report.
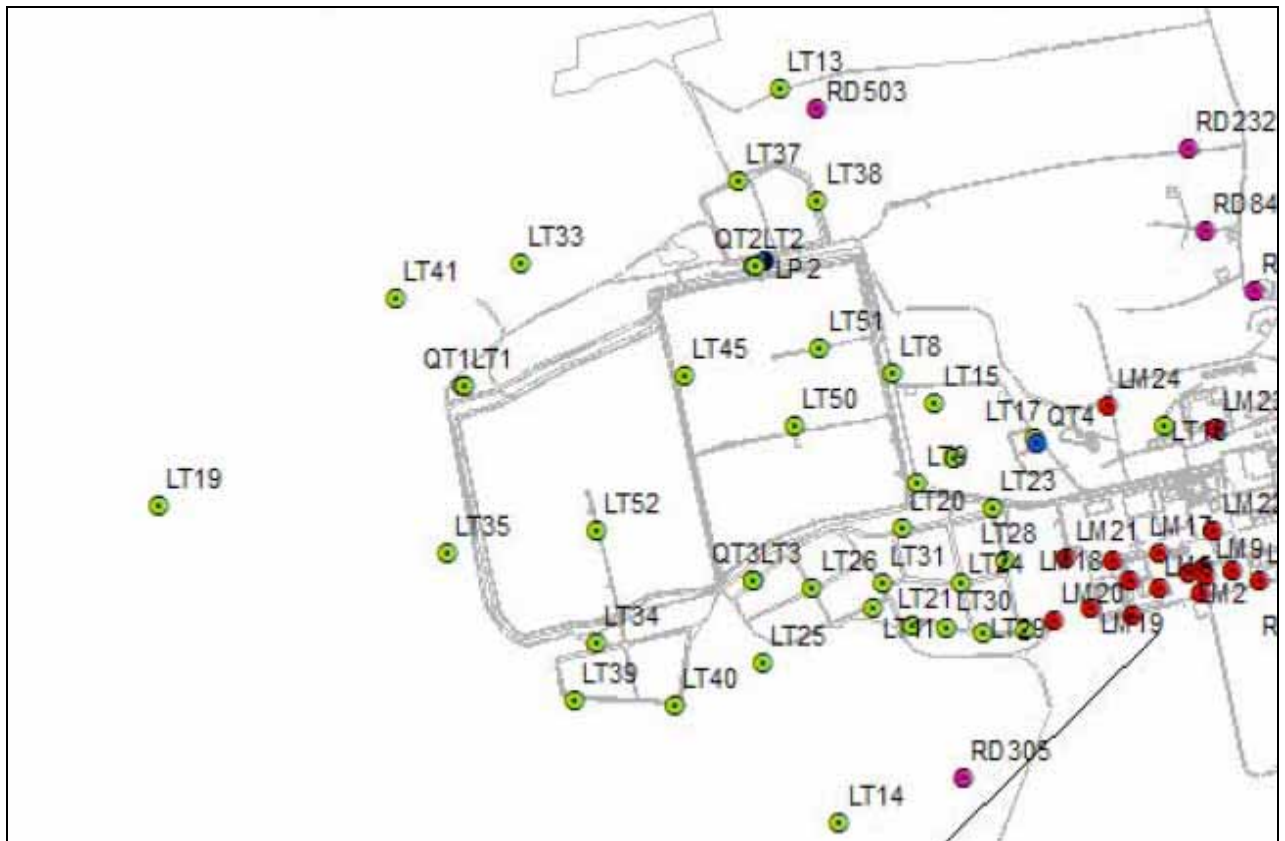
Figure 4.5 TRS Monitoring Bores
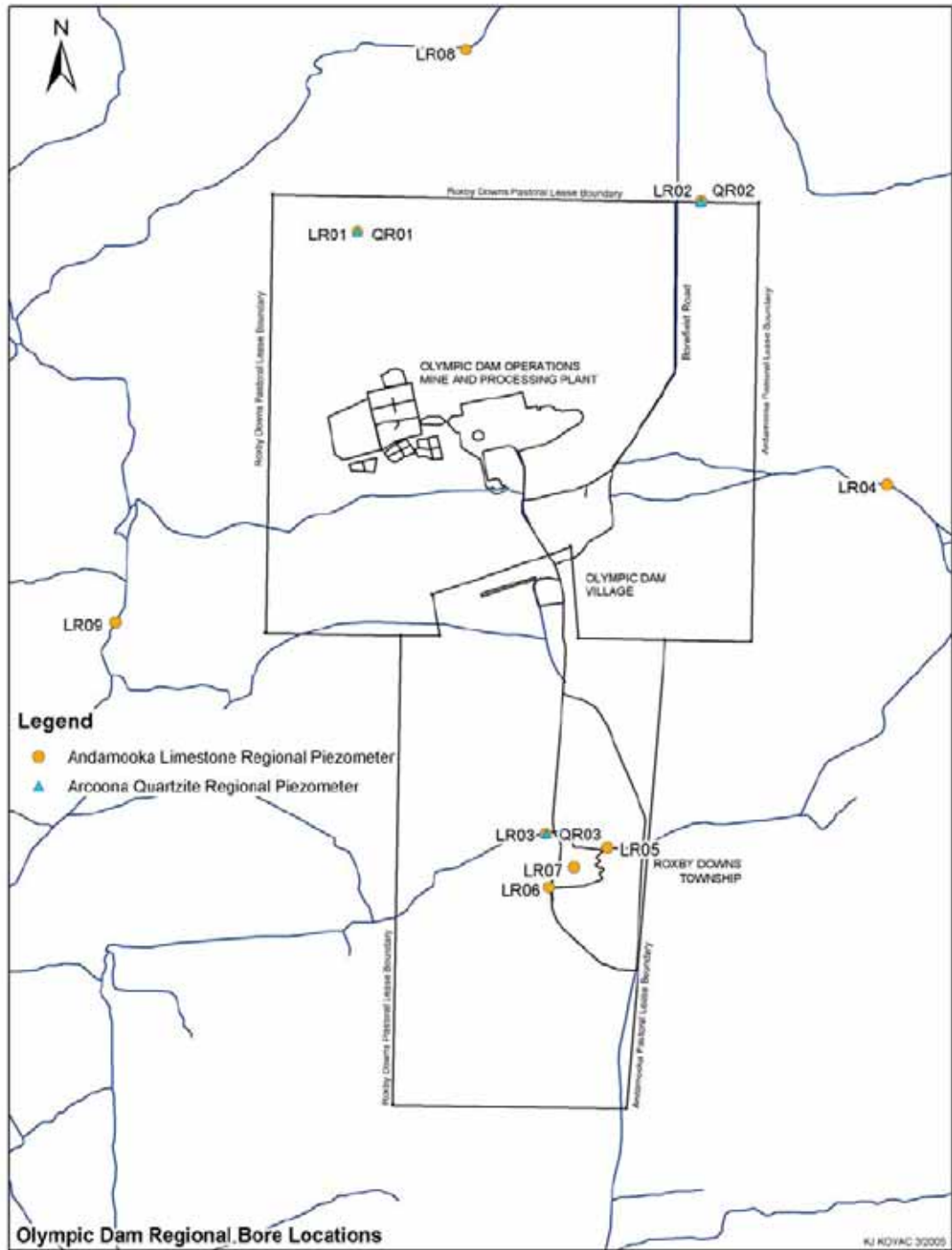
Figure 4.6 Regional Monitoring Bores

4.3.3   GROUNDWATER PRODUCTION BORE

A groundwater production bore LP2 located north of TSF Cell 3 is used to extract groundwater from the Andamooka Limestone aquifer. The water is pumped via pipeline to the process or is used for dust suppression and construction requirements and supplements the main water supply that comes from the current supply borefields located in the Great Artesian Basin.

4.4   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 draw down 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 4 to 5 m. The swale areas between the dunes are generally underlain by calcareous soils and Andamooka Limestone, which outcrops or sub-crops at some locations. Gypsiferous clays can be found between the calcareous soils and limestone over parts of the area.

Geotechnical investigations indicate that there are two distinct sub-surface profiles present within the footprint of the proposed TSF, but it should be noted that the sediments vary widely in form and type. The majority of the area is generally underlain by calcareous sandy clay/clayey sand of varying depth. Beneath this, in some areas, are gypsiferous clays underlain by weathered calcrete and limestone of the Andamooka Limestone group, and occasional bands of weathered sandstone. In other areas, shallow depths of topsoil and calcareous clays underlie variably weathered Andamooka Limestone with some outcropping of the calcrete/limestone being evident.

4.5   SURFACE HYDROLOGY

The surface hydrology in the vicinity of the TRS is characterised by a mosaic of small catchments, which may range in area from 10 to 300ha. The boundaries are generally defined by the east/west trending sand dunes. There are no defined lateral stormwater flow drainages 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 % of annual rainfall which is ~ 170 mm pa.

There are no flow features of any significance within the area of the mine, and location of the TRS does not interrupt any supply flows. Surface water sheet flow is redirected around surface storages, and released into the environment as a sheet flow that mimics the natural flows in the area.

4.6   SURFACE WATER RESOURCES

The flat-lying dune field which controls surface water hydrology extends to at least 15 km from the TRS. 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 northwest of the TRS and on the north side of Lake Torrens. The spring is saline (60 mg/L TDS) and sustained by groundwater flow (Draft EIS Appendix K1, REM, 2008)

4.7   GROUNDWATER CONDITIONS

The hydrogeology of the area is described in detail in Chapter 12 and Appendix K1 of the Draft EIS. The area of the TRS is underlain by a thin cover of Quaternary to Tertiary sediments over Cambrian Andamooka Limestone (Figure 4.7). The Andamooka Limestone is known to be karstic in places, with features such as dolines observed at the surface in a number of locations. The limestone unit is variably weathered within the upper 2 to 30m below ground level.

Underlying the Andamooka Limestone is the Arcoona Quartzite formation, a sequence of fractured and variably indurated sandstones and quartzites with numerous shale interbeds near the top of the formation. The upper section of the Arcoona Quartzite is considered to be less permeable than the basal section. 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.

Groundwater throughout the Stuart Shelf is generally saline (from 25,000 to >200,000 mg/L TDS). A few small useable stock supplies are obtained from shallow bores (<30m deep) which skim brackish water from localised areas of enhanced rainfall recharge. At Olympic Dam, saline groundwater is extracted in part from the Andamooka Limestone under the TRS indicating 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, extending up to 10km from the mine to the north and east and less than 5km from the mine to the southwest.

4.8   DATA FOR THE EXISTING FACILITY

4.8.1   CHARACTERISATION OF TAILINGS AND CONSTRUCTION MATERIALS

Table 4.3 lists the engineering properties of the tailings which can be described as "clayey silty interbedded sandy layers" (Knight Piésold, 2004 & EGi, 2007). Table 4.4 lists the measured shear strengths of the tailings and the various foundation and construction materials associated with the tailings storage facility.

Table 4.3 Engineering properties of Olympic Dam Tailings

Parameter	Description	Design Value
Permeability	Vertical k_v Horizontal k_h Ratio of k_h/k_v	1×10^{-8} - 5×10^{-8} m/s 1.0×10^{-7} - 5×10^{-7} m/s 5 – 10
Compaction	Maximum dry density Optimum moisture content	2.2 to 2.4 t/m^3 10.5 to 13 %
Particle Size Distribution	Sand Fraction Silt Fraction Clay Fraction	Sand : 3 - 20% Silt : 63 to 80% Clay : 13 - 22%

Plasticity	All tailings	Low plasticity & low swell potential
Consolidation and Settlement	Coefficient of consolidation	c_V = 10 - 50 m^2/year m_v = 2 x10^{-4} – 9 x10^{-5} m^2/kN C_c = 0.05 - 0.11
Density	Particle specific gravity (SG) Dry Density	3.0 - 3.5 t/m^3 1.80 t/m^3
Shear Strength	Undrained Drained	s_u = 11 kPa; ϕ_u = 29^0 c' = 0 kPa; ϕ' = 33 – 38^0
Soil Suction	Mixed Tailings	Moisture content = 4.70%, suction = 25kPa Moisture content = 3.54%, suction = 100kPa

Table 4.4 Measured shear strength parameters (Knight Piésold 2004)

Material	c' (kPa)	ϕ' (degrees)	γ_{moist} (kN/m3)	γ_{sat} (kN/m3)
Deposited Tailings	0	22 – 25[0]	17 – 18[0]	20 – 21[0]
Compacted Tailings Fill	0	32	18	21
Compacted Clayey Fill	5	34	18	21
Compacted General Fill	0	34	18	21
Crushed Rock	0	40	19	20
Sand Dunes (clayey sand-foundation)	5	34	19	20
Limestone Foundation	20	45	20	21

4.8.2   TAILINGS CHEMICAL PROPERTIES

The mineral extraction and beneficiation involves a number of grinding, flotation, leaching and thickening processes which produce copper concentrate, uranium filter cake and gold and silver.

Tailings from the uranium extraction process are produced at the metallurgical plant as underflow from the Counter Current Decantation (CCD) thickeners. The Olympic Dam tailings solids particles have a specific gravity around 3.2-3.6 and a typical chemical composition as shown in Table 4.5. This data has been derived from more recent test work and analyses compiled from the past 10 years.

Geochemical test work indicates that time-dependent chemical changes occur in the stored tailings:

1. As, B, K, Mo, P, Pb, Sn and Se are either absorbed or precipitated and removed from solution as the tailings age in the storage facility.

2. Gypsum and K-jarosite precipitation on the exposed tailings surface occurs through reaction between the tailings solids and liquor as the pH increases.

3. The reaction between tailings solids and liquor initially leads to an increase in the concentration of Al, Co, Mn, U and Zn within the liquor.

4. After months of interaction between the tailings and tailings liquor, significantly elevated levels of Ce, Cu, S and U remain in solution.

5. The average radium-226 grade in Olympic Dam tailings is about 7.0 Bq/g and the standard deviation is 1.7 Bq/g. (Kinhill, 1997). Based on an ore grade of 500ppm U, it is estimated that the radon emanation rate will be approximately 0.5 Bq/m^2/s. (Jamnicky 1986 & Akber et al 2001)

Table 4.5 Chemical constituents of existing tailings solids

Constituent	Weight (%) or ppm
Aluminium	4.34%
Arsenic	30 to 150 ppm
Barium	0.6%
Calcium	1.5%
Copper	0.08%
Fluorine	1.0%
Uranium	65 to 274 ppm
Uranium - 238	1.3 Bq/g
Iron	29.6%
Lead	40 to 120 ppm
Lead - 210	5.3 Bq/g
Magnesium	0.22%
Manganese	80 to 170 ppm
Potassium	2.6%
Polonium – 210	6.4 Bq/g
Ra – 226	5.8 Bq/g
Sodium	0.21%
Thorium - 230	4.5 Bq/g
Zinc	30 to 80 ppm

Other mining wastes are co-disposed with the tailings in locations suitable for total encapsulation including:

1. Waste heat boiler dust.
2. Electric furnace slag (Cu < 1%).
3. Recovered materials from process spills.
4. Evaporation pond slimes (dredged).
5. Materials from the original pilot plant (as per the approved Radiation Management Plan for Pilot Plant decommissioning).
6. Sediment from the old mine water evaporation pond.
7. Vanadium pentoxide.
8. Waste sulphur.
9. Miscellaneous hazardous substance

Ultimately, the geochemical and radionuclide properties in the final (upper) 1 to 2 m layer of tailings that will be deposited immediately before closure (final year) will determine surface emissions in the long term and the closure cover required to limit these emissions to within acceptable levels.

4.8.3   PROCESS LIQUOR PROPERTIES

The process liquor is typically acidic (pH of 1.7), with a typical measured chemical composition as tabulated in Table 4.6.

Table 4.6 Process liquor chemistry

Constituent	Concentration
Aluminium	9,100 mg/L
Calcium	1,000 mg/L
Chloride	5,500 mg/L
Copper	2,000 mg/L
Cyanide	Not detectable
Iron	40,000 mg/L
Fluoride	2,000 to 5,000mg/L
Lead-210	150 Bq/l - 250 Bq/L
Lead	6 mg/L
Polonium-210	30 to 100 Bq/L
Magnesium	500 to 5,000 mg/L
Potassium	350 to 6,000 mg/L
Radium 226	3 to 10 Bq/L
Silica	2,000 mg/L
Sodium	5,000 to 24,000 mg/L
Sulphate	135,000 mg/L
Sulphuric Acid	11,900 mg/L
Thorium-230	1,200 to 2,400 Bq/L
Thorium	17 mg/L
Uranium-238	250 to 1,200 Bq/l
U_3O_8	130 mg/L
Free Acidity	8,000 to 15,000mg/l

As a consequence of uranium in the ore body, the tailings contain approximately 70-80% of the radioactivity associated with the original ore. The majority of the radioactivity in the ore is from the U-

238 decay series. It should be noted that the reagents such as those used for flotation and thickening are broken down by the action of pumps and the acidic nature of the slurry. These residual compounds remain as part of the tailings solids.

Recent investigations have confirmed that time-dependent in-situ geochemical reactions between the tailings solids and the pore fluid result in an increase in pH - from less than 2 at the time of discharge to about pH 3 within a month (Draft EIS Appendix K4, SRK, 2008). The same investigations also indicate that in the long term, the pH may increase to between 3.5 and 5.

4.9   RISK MANAGEMENT

The existing operation at Olympic Dam manages the risks associated with the TRS through a Tailings Management System developed in accordance with the BHP Billiton Tailings Management Guideline and its associated key references. As defined in Chapter 26 of the Draft EIS, key project risks required further attention with the aim of reducing the level of risk to the principle 'as low as reasonably practicable' (ALARP). The risks mentioned in the following section apply equally to the existing TRS as well as the proposed expanded system.

4.9.1   TAILINGS MANAGEMENT PLAN

For the existing operation, the Olympic Dam Tailings Management Plan, details the processes and procedures by which the tailings retention system is design, operated, monitored, documented and reported.

BHP Billiton have been actively involved as industry partners in promoting tailings risk management and were primary contributor to the compilation of the MCMPR/MCA Strategic Framework for Tailings Management (MCMPR / MCA, 2003) and the DITR Tailings Management Booklet (DITR, 2007).

4.9.2   MONITORING

Monitoring is conducted in accordance with a TSF monitoring plan to assess the performance of the facilities and the effectiveness of the hazard management controls. Monitoring data is critical for effective risk management as it triggers mitigatory actions and provides important information for future designs. Monitoring may also trigger regulatory reporting.

Specific monitoring activities are discussed in more detail in section 4.11.

4.9.3   REPORTING

The existing system is audited annually and reported to the regulators (BHP Billiton Environmental Management and Monitoring Report; 2007). The recent performance of the systems has illustrated the following:

1. All structural aspects of the tailings system are performing in accordance with the design. In-situ geotechnical testing and water level piezometers indicate that design assumptions are appropriate, and adequate consolidation of the tailings is being achieved.

2. Radiation levels, dust and exposure of operations personnel are well within recommended safe doses.

3. The operational freeboard of all elements of the system (tailings cells and evaporation ponds) is maintained at all times resulting in a very low risk of overtopping or embankment failure during the probable maximum flood (PMF) storm event.

4. The slope armour is successful in minimising erosion on embankment slopes.

4.10   RISK MANAGEMENT - HAZARD IDENTIFICATION

While it is possible to manage HSEC risks during operation, leading practice design attempts to eliminate or significantly mitigate potential issues through leading practice design (using ALARA). In order to do this, the possible causes or originators of potential HSEC impacts are to be identified. In the case of the expansion, most of these are readily identifiable from the existing operation, with some additional issues associated with the sheer scale of the project.

Through risk assessments and discussions with stakeholders, the key hazards associated with the potential impacts posed by the existing tailings storage facilities to personnel, flora, fauna and the community, both during operation and after closure, have been identified. These include:

1. Instability and failure of embankments retaining potentially liquefiable tailings which can lead to unacceptable safety and environmental impacts.

2. Seepage of process liquor into the groundwater, potentially impacting usable water resources. The seepage may contain process residue radioactive metals or reactants released through the leaching of oxidised materials.

3. Acidic water stored in open ponds which can result in fauna mortality

4. Tailings and/or tailings liquor releases into the environment either as a result of failure of disposal lines, failure of an embankment, or overtopping of water or tailings embankments.

5. The radioactivity of the stored tailings. Personnel can be exposed to radioactive material, for example during construction activities, either through direct exposure or radon emissions or through inhalation of radioactive windblown dust.

6. Dust generated from exposed tailings surface, which can result in the impacts noted above as well as affecting air quality in and around the mine and neighbouring environs.

7. Erosion of tailings slopes or tailings covers by surface water runoff. This can impact the environment through changing soil and/or water quality, potentially cause embankment instability, or expose covered tailings to the atmosphere.

4.10.1   MANAGEMENT OF HAZARDS

The potential consequences associated with the key hazards are managed through a risk-based design, operating, monitoring and management process which seeks to ensure that HSEC risks are kept within acceptably low levels. The process includes:

1. Design and construction in compliance with the highest international standards – ANCOLD and ICOLD including construction supervision.

2. Risk-based design review processes incorporating a "lessons learnt" approach to identify hazards and minimise potential impacts.

3. Monitoring of lead indicators to confirm that performance trends are and will remain in compliance with the design intent and criteria.

4. Risk-based management system to mitigate or rectify potential out-of-compliance issues prior to a measurable detrimental impact occurring and to ensure that the identified issue will not have an impact either during operation, or for post closure.

This best/leading practice systematic risk-based approach has been successfully applied in the management of a number of BHP Billiton tailings storage facilities over a number of years, and is now the minimum standard applicable to BHP Billiton projects. For more information, refer to:

1. The BHP Billiton Tailings Management Guideline.

2. Guideline for Tailings Management, Department of Industry and Resources, February 2007 (DITR,2007)

3. Other similar Industry guides such as ANCOLD & the Minerals Association of Canada Guide to the Management of Tailings Facilities (MAC, 1998).

4.11   MANAGEMENT SPECIFIC HAZARDS

4.11.1   RADIATION

Ore processing aims to recover most of the uranium. The remaining tailings contains approximately 70 to 80% of the radioactivity of the original ore. This radioactivity is due to the other radionuclides in the uranium decay chain. The key radionuclides in the tailings are Th^{230} and Ra^{226} and both will be in concentrations similar to the original ore. Th^{230} is a long lived radionuclide with a half life of 77,000 years and Ra^{226} has a half life of 1600 years. The Th^{230} will continue to decay to Ra^{226} over time.

Radon (Rn^{222}) formed by the decay of Rn^{226} is an inert gas that emanates into the atmosphere from the surface of the TSF. Rn^{222} is also radioactive and decays to short lived radionuclides and can potentially cause exposure.

It is expected that radon emanation rates will remain the same as experienced today, with radon volumes predicted to increase proportional to the increase in surface area of the tailings storage facility. Exposure to radiation from tailings is managed under the Radiation Waste Management Plan where workers doses are low and well within internationally accepted limits. Past monitoring and modelling of future emissions have been used to predict the doses to workers and members of the public. Radiation doses to both workers and members of the public are expected to remain low and well within internationally accepted limits. (See Draft EIS Chapter 22)

Low levels of dust generation occur in the existing tailings system as the tailings form a crust (see 4.11.2) that prevents dusting. Generation of dust from active tailings storage cells is not expected in the expanded operation for the same reason.

In the longer term, potential exposure from radon emissions and dust will be effectively controlled by covering the exposed tailings with a suitably thick barrier (cover) of inert mine rock. In general, denser material with higher moisture content will provide maximum attenuation.

The design of the cover will ensure that residual Rn^{222} emanation from the surface of the tailings is minimised. The design will aim to ensure that exposures are low enough to be consistent with future land uses and conform to the principles of ALARA.

4.11.2   DUST

The emission of dust from the TSF may occur as a result of two primary pathways; wind erosion of the tailings surface, and dust generated during wall raising activities. Wind-generated erosion of the tailings surface is expected to occur very infrequently during operation, as the tailings surface is wet during deposition cycles. Additionally, the surface crusting of the iron and other salts of the tailings surface may also reduce the potential for loose tailings particles to be dispersed by the wind.

On the existing TSF cells, dust emissions have been monitored over its life and dust levels have been significantly lower than regulatory limits (See Draft EIS Chapter 13).

The change in TSF construction methodology to centreline raises using inert mine rock will reduce dust generation versus the current practice of upstream raises using dried tailings, however dust is still expected to be generated during wall raising activities. This would be managed through the use of appropriate dust suppression methods such as water carts.

4.11.3   SURFACE WATER EROSION

Erosion from surface water can occur during and following infrequent but high intensity rainfall events. It can also occur when a body of water is allowed to pond against a crest – once a breach occurs, the rapidly flowing water is capable of eroding the slope down which it is flowing.

Erosion from flows of surface water represents a high risk to TSF structures during operations when surplus water is retained on the surface and after closure when concentrated flows over embankment crests can be highly destructive. Erosion of embankment slopes, particularly if uncontrolled and concentrated, can result in a release of acidic water, carrying radioactive tailings and metal salts.

Adequate controls are "designed-in" to all existing structures to ensure that their integrity is maintained under repeated runoff erosion effects from the most severe events as well as designing for the long term after closure. Windrows also protect the crests of the TSF embankments, while a rock cover ensures that the downstream face is erosion resistant.

A critical aspect of managing erosion events that can cause wall failure is to manage the surface water on the tailings storage facility. The existing system monitors the size and position of the ponds on a daily basis, always ensuring that there is adequate freeboard to accommodate the probable maximum flood. The design and operation of the existing and proposed facility maintain the pond in the centre of a cell and it is extremely unlikely that a pond could overflow the crests. See section 8.2 to show safety margin.

4.11.4 STABILITY OF TSF EMBANKMENTS

In addition to the potential for embankments and slopes to fail as a result of uncontrolled surface water erosion, slopes can also fail when subjected to earthquake loading. The risk of instability increases as the height of embankment increases, particularly when the stability relies partially on the lower shear strength of potentially liquefiable, under-consolidated tailings that it retains, as in the case of the upstream raised embankments at Olympic Dam.

The ongoing acceptability of the stability of the embankments has been confirmed in a number of performance reviews (Coffey Metago (2007), Knight Piésold (2004) (EGi, 2007) using in-situ data from field investigations and water levels form piezometer monitoring data. Figure 4.8shows the piezometer locations. The proposed facility stability is covered in Chapter 7.

4.11.5 SEEPAGE

Risks associated with seepage are changing groundwater levels (creation of a mound under the TSF), changing a receptor quality and potential contaminants moving offsite. Chapter 9 of this report and Chapter 12 of the Draft EIS further detail the hydrogeology and seepage risks.

Since the South Australian Government Commission of Enquiry in 1995, significant improvements in tailings deposition and water management (start-up process to seal the floor and minimise water ponding on bare ground (seeFigure 4.4), and pond area minimisation) have resulted in a significant reduction in seepage and a slowing in the water level rise rate of the mound in the Andamooka Limestone.

The key controls are:

1. The rate of rise of the tailings surface is limited to a maximum of 2m/year to maximize strength through sun drying, and to minimise free water as a potential source of seepage.

2. Management of the size and location of supernatant ponds through appropriate rotation of deposition points.

3. The correct functioning of the under drainage system, which removed free water above the clay/HDPE liner in the decant area as a source of potential seepage. This ensures that the tailings underlying the pond is as well consolidated as possible, thereby reducing the permeability of the tailings through which the water must flow (effectively the tailings acts as a liner).

Near Surface Seepage

The design of tailings/water retaining embankment and its various seepage control features is based on a typical design scenario, derived from field and laboratory investigations of the various foundation and construction materials. As with all geotechnical investigations, particularly when it comes to the large scale of tailings storage facilities, the typical setting only represents areas of the site which are similar or better. There are areas which will differ, requiring close construction supervision, and operational monitoring and where necessary, mitigation.

The tailings storage facility location (existing and proposed) has some variable permeability due to the variability of the underlying geology, and has the potential for higher-flow near surface features

such as sinkholes to occur. These features are to be identified and treated during construction of the new cells.
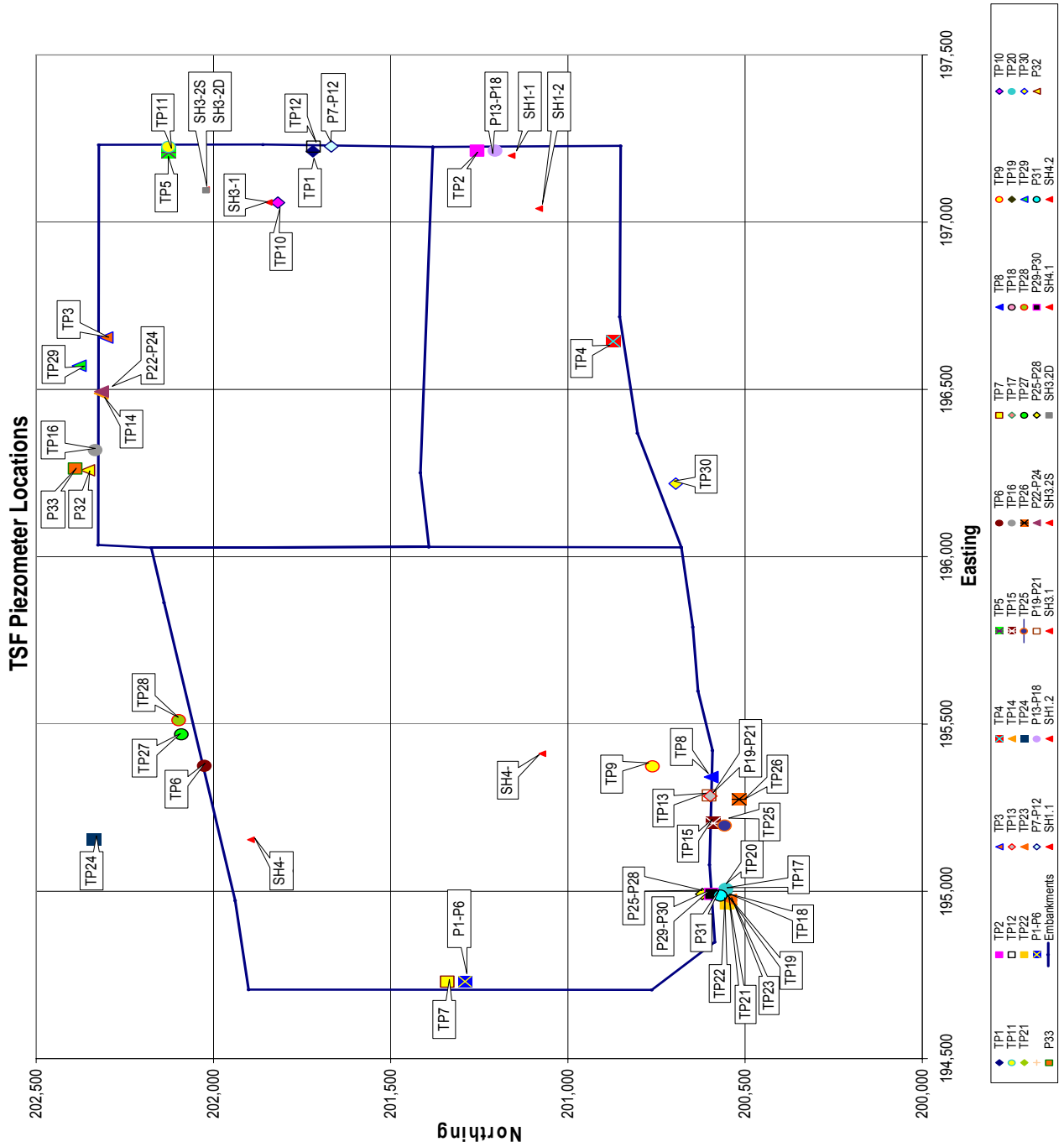
Figure 4.8 TSF Piezometer locations

Monitoring will continue as a matter of course, and if the regular evaluation of seepage indicates changes which cause concern, mitigation measures will be considered and implemented if a significant risk identified.

Development and Control of the Groundwater Mound

The development of a groundwater mound under the existing tailing facility has been modelled and is discussed further in Chapter 9 and in the Draft EIS; Chapter 12 and Appendices K1, K3 and K6. The predicted subsurface seepage and groundwater response is supported by empirical data and the existing TSF.

Figure 4.7 illustrates the geology underlying the tailings storage facility.

Initially, percolation into the foundation passes through the unsaturated zone located between the foundation of the facility and the underlying rock. Partial saturation results in a diffuse path for water travelling through the shallow soil profile and rock due to permeability contrasts.

A partially saturated wetting up front advances downwards through the alluvial sequence and limestone, aided by any preferred seepage paths, and when this water encounters a zone of lower permeability, such as the clayey layers or the underlying Arcoona quartzite, the rock voids become saturated, resulting in the development of a groundwater mound.

Thickness	Unit name	Natural Ground Level
		▽ ~ RL 100
0 - 30m	Silty clayey sands/sediments	
20 - 45m	Andamooka Limestone	Ground water at ~ RL 48
110 – 170m	Arcoona Quartzite (aquitard)	
10 – 25m	Corraberra Sandstone (aquifer)	Water at ~ RL - 80 to -120
100 – 150m	Tregolana Shale	
	Basement Sequence	
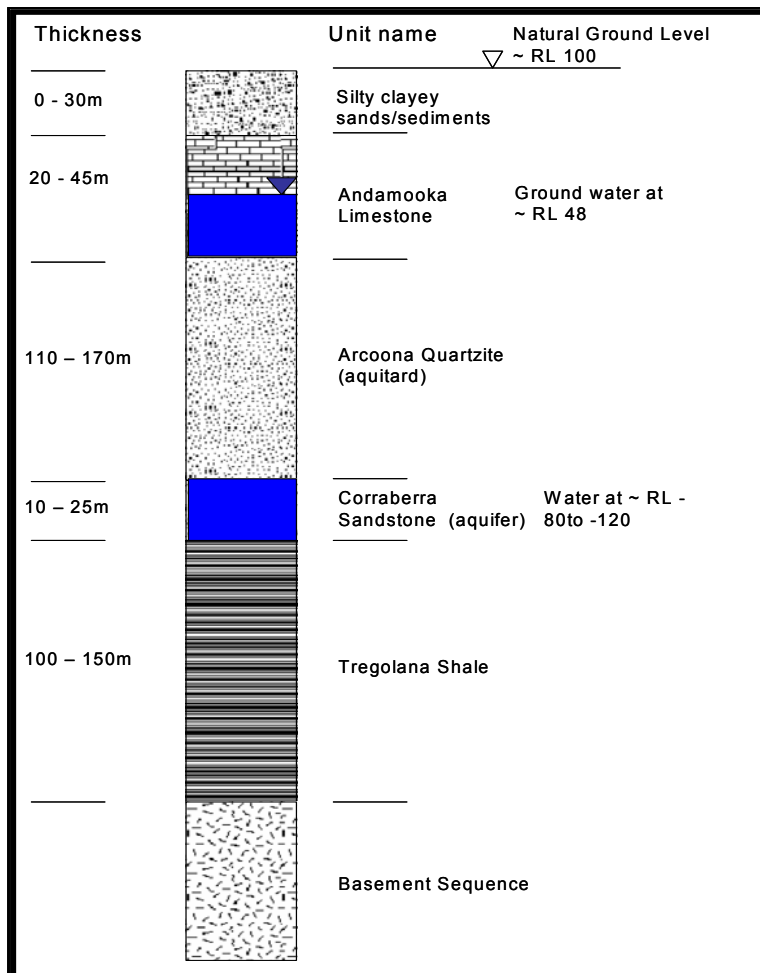
Figure 4.7 Tailings Storage Facilities underlying geology

One of the key performance indicators of the current facility (which is retained for the proposed expansion design) is to protect deep rooted native vegetation by maintaining the Andamooka Limestone groundwater mound below 80m AHD approximately 20m below the ground surface. Monitoring and predictive modelling demonstrate that the groundwater mound is, and will remain, below this level. If monitoring indicates that the ground water level would rise above this level, mitigating controls such as further pumping would be initiated.

Design details were incorporated in the newer Cell 4 when it was commissioned to minimise surface ponding during start-up (seeFigure 4.4) and to construct an effective tailings seal to minimise seepage into the base. Tailings deposition is cycled between cells to maximise evaporation drying, further reducing seepage.

Monitoring of the ground water levels is reported in the Annual Environmental Report (BHP Billiton 2007). Historical monitoring under and around the existing TSF indicates that groundwater levels have risen and the ground water quality altered within a localised mound in the Andamooka Limestone (karstic fractured rock aquifer) directly under the TSF (Figure 4.9), but that the mound height is being successfully controlled through management measures, and that the unsaturated zone below the TSF is being maintained.

The groundwater monitoring data indicates that the mound has stabilised under TSF Cells 1 to 3 in response to measures that have been implemented to minimise seepage from the TSF. Levels under Cell 4 have increased as expected following commissioning in 1999. The groundwater level is currently 17m below the nominated compliance limit of 80m AHD. Ground level is approximately 100m AHD, demonstrating that the groundwater is 37m below ground level.

Monitoring has also shown that there has been a substantial decline in groundwater levels under the former Mine Water Pond since this was decommissioned in 1999. Hydrogeology modelling (Draft EIS, Appendix K1) indicates that the TSF mound will remain within the vicinity of the TSF during operation, but will recede and gradually disperse after closure of the TSF due to a reduction in infiltration and residual seepage.
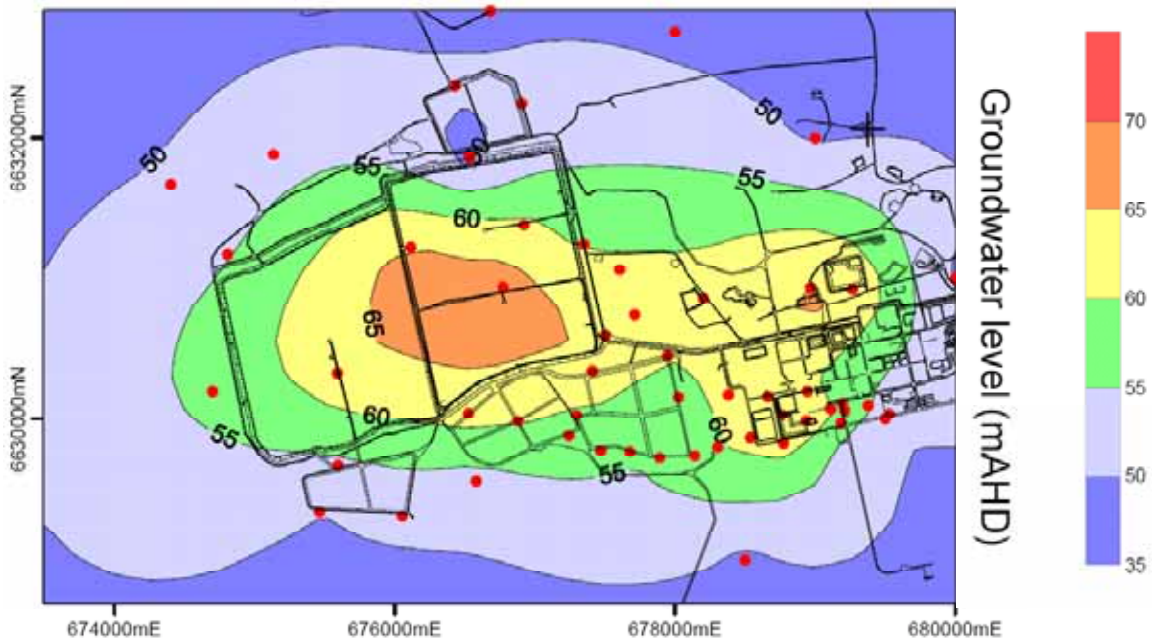
Figure 4.9 Groundwater levels in the Andamooka Limestone – June 2007

Minimising the size of decant ponds is important to managing seepage and hence reducing the groundwater mound beneath the TSF. For the existing system, decant pond area monitoring is a lead monitoring indicator as it should be in any operation. Monitoring data is provided in the Olympic Dam Annual Environmental Report (BHP, 2007). The pond size varies seasonally, and after large storms.

Seepage modelling for the expansion study, using calibrated data from recent modelling (Draft EIS Chapter 12 and Appendix K1) indicate that the seepage losses from the TSF (Cells 1, 2, 3, 4) total between 1 to 3 ML/day depending on the season and the pond size.

Groundwater level and quality monitoring (Draft EIS, Appendix K3) indicates that:

1. The quantity of seepage entering the foundation is relatively small because of the sealing effect of the tailings combined with the permeability contrasts of the underlying alluvial and limestone rock.

2. The calcareous sediments and Andamooka Limestone appear to be effective in neutralising the acidity of the tailings liquor within a localised "mixing" or "attenuation" zone directly under the TSF (EGi, 2007).

3. Higher uranium concentrations in the mixing zone are attributable to seepage from the Mine Water Pond closed in 1999. The higher uranium concentrations observed under the TSF 1, 2 3 and the mine water pond appear to have resulted from large volumetric and high rate of seepage during early tailings deposition through shallow sediments. Similar higher levels of uranium are not observed under Cell 4 which has been operating since 1999.

The existing water quality and level data in the vicinity of the TSF support the groundwater modelling results (Draft EIS, Appendix K6) which predicts that seepage from the TSF is unlikely to have any impact on any regional receptors in the long term (>500 years). The introduction of a permanent open pit only serves to extend the drawdown cone that "captures" solute and ground water from the TSF. In addition, the underlying aquifer is saline being in excess of 30,000 mg/L TDS and this categorises it as not having any beneficial use.

4.11.6 FAUNA ACCESS MITIGATION STRATEGIES

In dry, arid zones, fauna, in particular, migratory birds, are attracted to large open ponds, particularly during dry seasons or droughts.

While stock fencing prevents land based fauna from accessing the contaminated water, migratory and resident birds have been attracted to the existing tailings and evaporation ponds resulting in a number of bird deaths.

The operation continues to investigate methods to address this issue.

No new evaporation ponds will be required for the expansion and the central tailings ponds and balance ponds will be covered to prevent bird access.

4.11.7 SPILLAGE CONTROL MITIGATION

Tailings (or tailings liquor) releases can occur from any of the number of tailings storage cells, evaporation ponds, or the disposal lines transferring tailings to and around the TSF, or transferring water from or between ponds.

Olympic Dam operations maintains a detailed inventory of all lines and flows (Figure 4.10), and monitor the condition and flows in the lines both through visual inspections and alarmed flow meters. Line breaks can be picked up rapidly by leak detection systems, ensuring that environmental releases are minimised. Disposal lines and flanges are contained within bunds and windrows are constructed on embankment crests to minimise the possible release of tailings and water. Freeboards on all facilities are monitored frequently to ensure that an overtopping release does not occur.

These practices ensure that infrequent tailings spills have minimum environmental or health and safety impact.
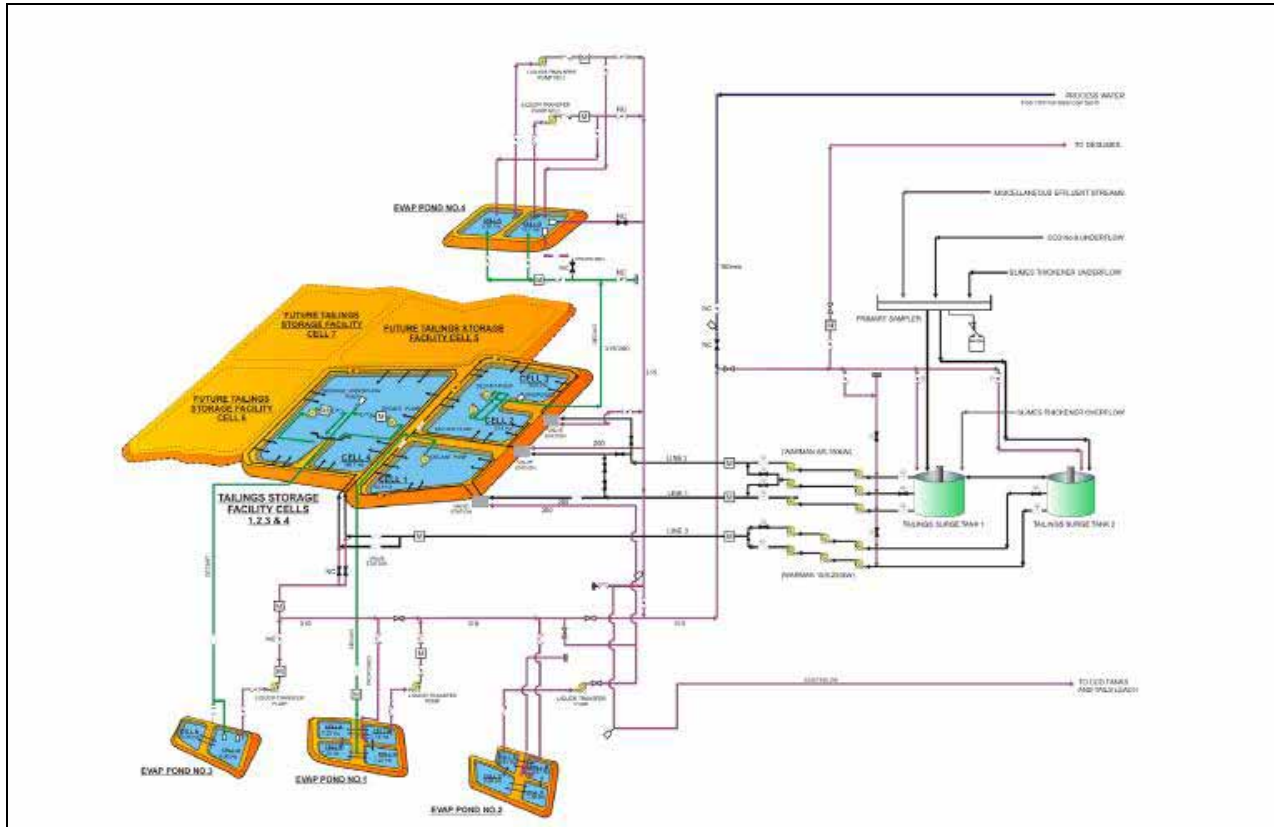
Figure 4.10 Flow diagram for existing Tailings Retention System

4.12   RECONCILIATION – MEASURING PERFORMANCE AGAINST DESIGN

A number of geotechnical investigations have been carried out as a precursor to the expansion study to confirm geotechnical and hydrogeological design assumptions. Clearly such a comparison is valuable for developing the design parameters used for the expansion design.

The work included:

1. An investigation of the in-situ properties of the stored tailings to check the strength assumptions.

2. An investigation of the foundation materials underlying the existing TSF to ascertain the extent of seepage (attenuation/neutralisation), and whether the limestone materials have undergone any physio-chemical alteration as a result of seepage from the TSF over the more than 20 year period of operations.

3. A preliminary geotechnical investigation of alternative potential new TSF sites to check whether the founding conditions vary across the site.

4. Groundwater geochemical investigations

4.12.1   IN SITU TAILINGS

A geotechnical investigation into the in-situ tailings was undertaken to confirm the project design parameters. The site investigation included:

1. Ten boreholes in the tailings down to foundation level.

2. In situ strength testing (shear vane) and moisture content sampling/testing at 1.5m intervals.

3. Undisturbed samples for laboratory testing - particle sizes, Atterberg limits, and shear strength (triaxial) testing.

4. Geotechnical logging of each borehole.

4.12.2 EXISTING TSF FOUNDATION

The geotechnical investigation into the foundations included:

1. Drilling four boreholes (extension of TSF boreholes) 20m into the foundation rock.

2. Logging of the foundation core - photograph and geological description of the core.

Core samples were submitted to a laboratory for geochemical testing to ascertain the impact of acidic seepage over the preceding 20 year operations.

4.12.3 INVESTIGATION OF ALTERNATIVE NEW TAILINGS STORAGE SITES

A preliminary geotechnical site investigation of possible TSF locations was undertaken. The fieldwork included:

1. Auger drilling of 21 boreholes (up to 15m deep or refusal) to provide a general description of the foundation profile for each area.

2. Sampling and testing (in situ and laboratory) of a number of materials to provide an overview of the engineering properties of the TSF foundation profile and also considering their possible use as construction materials.

3. Geotechnical logging of each borehole.

4.12.4 GROUND WATER GEOCHEMICAL INVESTIGATIONS

The objectives of the work were to assess the impacts of seepage on the underlying substrate from the existing TSF to assist planning and design of tailings storage for the proposed expansion. Geochemical testing was carried out on samples from four selected holes drilled through the TSF into underlying natural substrate.

4.12.5 RESULTS OF INVESTIGATIONS

Geotechnical Investigations

The visual observations and laboratory and field test results are reported in separate reports (Coffey, 2007a & b). The following conclusions were made:

1. The potential sites for the expansion of the TSF (north, east and west of existing plant site) appear to have similar near surface geotechnical profiles to the existing TSF location and thus all appear equally suitable for the ODX TSF expansion.

2. There is a distinctive interface between the deposited tailings and the foundation. There is no evidence of tailings solids being transported into fractures, indicating positive containment of the tailings.

3. There is no visible evidence of alteration in the foundation rock structure or strength (i.e. the rock beneath the TSF cells is similar to the background rock).

4. The triaxial test results support the angle of friction used by Knight Piésold in their analyses, (i.e. in the 24^0 to 28^0 range).

Geochemical Investigations

The immediate natural substrate below the tailings consists of a sediment unit comprising mainly sands and clays, which overlie Andamooka Limestone. The Andamooka Limestone is dolomitic in this location, with a thickness of approximately 40-50m, and overlies the Arcoona Quartzite, which

has thickness of greater than 200m. The Andamooka Limestone hosts a regional groundwater aquifer, which has mounded below the TSF due to seepage of tailings liquor.

The results from the geochemical investigations showed that seepage from the TSF (and probably largely from the original mine water pond which has been relocated) has to some extent influenced the underlying substrate sediments, the Andamooka Limestone and the Andamooka Limestone aquifer, (see Chapter 9) as the mixing or attenuation zone. This is the zone in which the seepage percolates and their reaction products will be detected.

The extent of the influence appears to be restricted to the region immediately underlying the TSF, with little lateral migration. Results suggest the following geochemical processes are occurring within the TSF and substrate profile (Draft EIS, Appendix K4, SRK 2008):

1. The tailings liquor has a pH of less than 2 when deposited in the TSF. However, geochemical processes within the deposited tailings are able to buffer the acidic liquor, increasing the pH to 3.5 or greater before it leaves the base of the TSF. Ag, As, Ce, Co, Cu, F, S, Th, U and W appear to be readily mobilised from the tailings into the substrate, with some minor migration of Se. Although elements Bi, Fe, Hg, Mo and Sb are elevated in the tailings, they do not appear to have migrated significantly from the tailings.

2. The near surface sediments further neutralise acidic liquor, however a depletion front progresses downwards in the substrate sediments due to neutralisation reactions with the tailings liquor.

3. The excess buffering in the lower part of the sediment unit appears to be effective in neutralising the tailings liquor and attenuating most tailings derived constituents before the seepage reaches the Andamooka Limestone.

4. The Andamooka Limestone further attenuates the more mobile tailings derived constituents (mainly S and U), but preferential flow pathways (structures) and build up of coatings on carbonate mineral surfaces, may reduce the buffering effectiveness of this unit.

5. The TSF has caused mounding of the Andamooka Limestone groundwater aquifer, but only minor effects on the groundwater chemistry. The interactions between the tailings seepage and the substrate units results in low absolute metal and metalloid concentrations in the Andamooka Limestone aquifer below the TSF, but U and Se concentrations are elevated (>2 times) relative to regional background.

6. Bicarbonate concentration is also higher in the Andamooka Limestone aquifer below the TSF relative to regional concentrations. This is due to increased dissolution of carbonates during interaction of the acidic tailings liquor with substrate materials. The high excess buffering in the groundwater is most likely derived from the substrate sediments, which are relatively permeable, providing a high surface area for contact with acid tailings seepage.

Based on the available data, it appears that the buffering in the substrate sediments is controlling acid migration and providing the bulk of attenuation of the tailings liquor constituents.

At this stage of the operating life of the existing TSF, there are no indications that seepage associated products from the TSF will impact downstream resources. Nevertheless, more detailed geochemical investigations and analyses were conducted to further quantify the geochemical reactions in the materials underlying the TSF. The main findings of this study are outlined in the Draft EIS Appendix K4, (SRK 2008).

5 EXPANSION TSF DESIGN

5.1 OPERATING ENVIRONMENT

The geological, hydrological (surface water); hydrogeological (groundwater) settings are described in Chapter 4. This is no different to the current setting.

The seismological setting is described in section 7.2.1 where it applies to the stability analysis.

The meteorological setting is described in section 8.1 where it applies to surface water management.

5.2 OPERATING PARAMETERS

The operational parameters, (i.e. the known parameters to be used in the design) are listed in Table 5.1.

Table 5.1 TSF operating parameters

Parameter	
Production rate tailings (Mtpa)	20-70
Facility operating life (Years)	40
Deposition solids concentration (%)	55
Maximum Rate of Rise (m/annum)	2
Dry density of stored tailings (t/m^3)	1.7
Beach slope (%)	1

5.3 DESIGN ALTERNATIVES

In the early stages of the expansion study, a variety of alternative tailings storage methods were considered within the context of the large scale of this project. A primary consideration was also the change in mining method from underground to open pit, which results in large quantities of un-mineralised mine rock being potentially available for the construction of tailings cells.

In order to make a reasonable comparison of the numerous alternatives, similar methodology types (such as "paddock") were grouped together, and the selection narrowed through a refining process where the potential methods were ranked against a set of risk, design and operating parameters. Rating of the alternatives - against fatal flaws, unacceptable risk profiles, or lower rankings - allowed the majority to be eliminated, with the most appropriate alternatives carried forward to more detailed pre-feasibility assessment. The ranking parameters were:

1. Design – current knowledge adequate to design a safe and cost effective facility?

2. Construction – the construction of the starter and raises is practical, safe and cost effective?

3. Can the facility be integrated in the mine plan to utilise available mine rock materials during construction, operation and at closure?

4. Operation – robust, safe and cost effective to operate and maintain at large throughputs?

5. Flexibility and contingency (e.g. capacity) and capability for back-up systems to ensure safe and continuous operation?

6. HSEC Risk – potential impacts within acceptable HSEC risk limits - seepage, long term stability, geochemical stability, radiation, dust, closure?

7. Water management - improved usage and inventory balance compared to existing system?

8. Closure – improved design to manage potential operational and post-closure risks. Achievable long term (>1000 years) safety, stability and environmental objectives. Manipulate natural physical processes as far as possible to control the natural flux of water across the final engineered barrier system.

9. Community - will stakeholders and interested parties agree that the system is acceptable?

10. Cost - capital and operating costs within reasonable benchmark cost range?

From this assessment, three alternative tailings disposal methods were selected for consideration during the next phase. These were:

1. A ring dyke with paddock disposal system using tailings to construct upstream raises – similar to the existing system.

2. A ring dyke with paddock disposal system using mine rock to construct the walls – similar in shape and location to the existing system, but utilising mine rock from the pit to construct the perimeter walls and other structural elements.

3. A central discharge type system – similar in nature to BHP Billiton's highly successful Mt Keith Nickel operation centralised discharge tailings storage facility (CTDSF).

Several alternatives did not get carried forward. The reasons for eliminating these were:

1. Co-disposal or co-mingling of tailings and mine rock – the objective of this method is to utilise the voids between rock in the rock storage facility (RSF) to store the tailings. The Olympic Dam mine rock does not have an adequate void volume, which results in poor operating efficiencies, poor shear strength (no rock-to-rock contact), and an inability to control supernatant and contained water and seepage. This alternative would be unmanageable at the proposed throughputs.

2. Co-location of tailings and RSF – implies the simultaneous construction of the mine rock and tailings storage facilities in the same location. This system has merits in a smaller open pit operation (around 1 to 5 Mtpa) but is difficult to implement in the expanded case (>70 Mtpa) because of the risks associated with operating a very large mining rock haulage fleet in and around a large area of tailings storage and associated facilities and infrastructure. This is similar to co-disposal and it should be noted that if the operation continues beyond the assessed 40 years, the RSF will cover some of the initial cells and allow easier closure of the remaining cells.

Two aspects are considered in all alternatives:

1. "High density" or "paste" tailings can be applied to all disposal methods. Thickened tailings remove water prior to deposition in the TSF, thus creating a more stable tails composition. This method has been used successfully as sites such as Bulyanhulu Gold Mine in Tanzania, with exhibits a similar semi arid climate to the Oympic Dam Mine (Theriault et al, 2003).

2. An "integrated waste landform" where the tailings storage facility is constructed adjacent to or within the footprint of the RSF. While this option may not be immediately available to this project (because of risks associated with the large rate of mine rock and tailings), if mining were to occur beyond the 40 years, the landforms would merge. The details on how this would best be achieved would be studied further, if and when this aspect became possible.

5.4   FURTHER EVALUATION OF ALTERNATIVES

Conceptual designs, to a level of detail adequate to assess and compare their adequacy with respect to stability, capacity, practicality and risk management capabilities, were developed. These are shown below.

5.4.1   UPSTREAM RAISING USING TAILINGS

The conceptual design cross-section for the upstream raised tailings embankment is shown Figure 5.1.
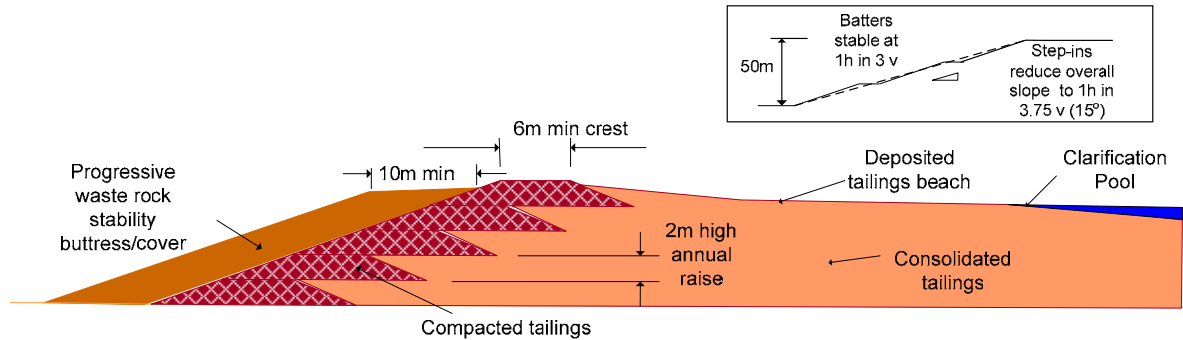
Figure 5.1 Upstream raised tailings embankment - conceptual design cross-section

For a 40m high embankment, because the failure surface occurs in the weaker partially consolidate tailings, it is estimated that in order to achieve better than required factors of safety against slope failure particularly during earthquake conditions (see ANCOLD factors of safety), the overall slope will need to be flattened to around 15^0 and a 10m wide mine rock cover/buttress provided for operating and long term (post-closure) stability.

The 10m wide rock buttress would also reduce the potential for radon, erosion and stability risks. An upstream toe drain would be provided. Intermediate toe drains would probably also be required to keep the phreatic surface suppressed, and to ensure the tailings are consolidated. The advantages and disadvantages of this method are discussed in following sections.

5.4.2   MINE ROCK CENTER LINE RAISE EMBANKMENT
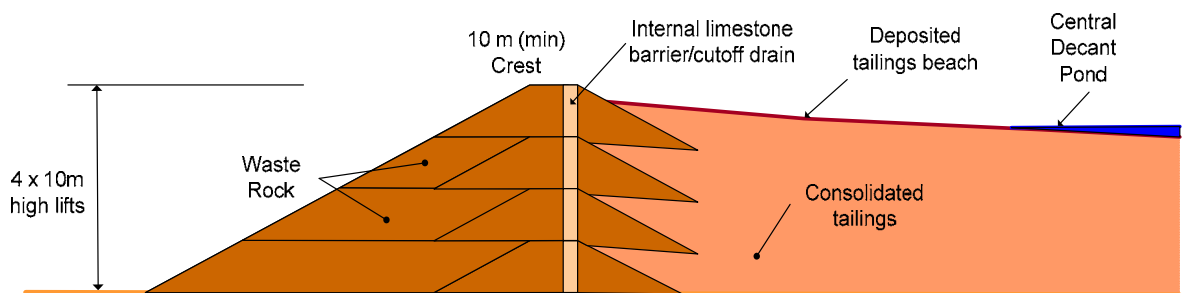
Figure 5.2 Centre line raised rock fill embankment - conceptual design cross-section

The mine rock centre-line alternative makes use of the un-mineralised mine rock from the open pit to achieve a perimeter embankment stable under all loading conditions.

This configuration ensures that the critical failure surface would pass through the rock-fill, which is much stronger than partially consolidated fine tailings. Under a combined saturated/earthquake condition when tailings can liquefy (and lose strength), the rock-fill will not liquefy or lose strength, while effective drainage of the tailings by the rock-fill ensures that the tailings near the embankment is fully consolidated. The embankment would have an internal barrier drain and a basal collector drain with both upstream and downstream collectors (seeFigure 5.2) to meet factors of safety for a the unlikely event of a high pond and to ensure no seepage gets into the environment.

All water collected in these drains would be collected in lined sumps and recycled back to the process, or returned to the TSF. Further discussion of the advantages and disadvantages is discussed in following sections.

5.4.3   CENTRAL DISCHARGE TAILINGS STORAGE FACILITY (CTDSF)

The central discharge type storage facility (Figure 5.3 and Figure 5.4) occupies a larger footprint as the unconstrained tailings beach spreads out to natural ground level at the extents. As in the Mt Keith design, a ring of "outer" risers is necessary to create an efficient (volumetric) plateau shape which can still drain gravitationally outwards. Whilst this system is a practical solution for tailings discharge at Mt Keith, there are a number of reasons why this is not suitable for mining operations involving uranium tailings. The unconstrained spread of tailings beaches increases the potential for seepage on bare ground. Furthermore, the protruding nature of the final plateau landform is prone to windblown dusting. Despite the reduced operating costs associated with this method, a more relevant site specific technique for tailings disposal is required at Olympic Dam.

In the CTDSF system, ponds form at low points between the individual mounds and at the end of the beaches where water is clarified before entering surface drains leading to the water storage area. As the inner ponds are inaccessible, while the outer ponds are transient, (i.e. they move as the facility develops) none can be bird-netted, resulting in a high risk of avian fatalities. The CDTSF cannot contain storm water, which must be immediately taken off the facility into a lined water dam. This would need to be large to accommodate the runoff from the extensive CTDSF footprint (for storage and evaporation capacity), lined, and covered with bird netting. Further discussion of the advantages and disadvantages is discussed in following sections.
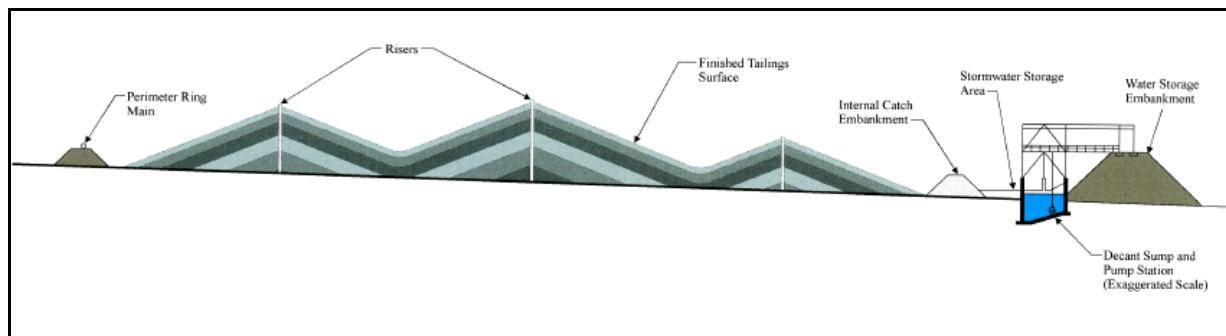
Figure 5.3 Central discharge TSF - conceptual design cross-section (from Mt Keith Nickel Operation Design)
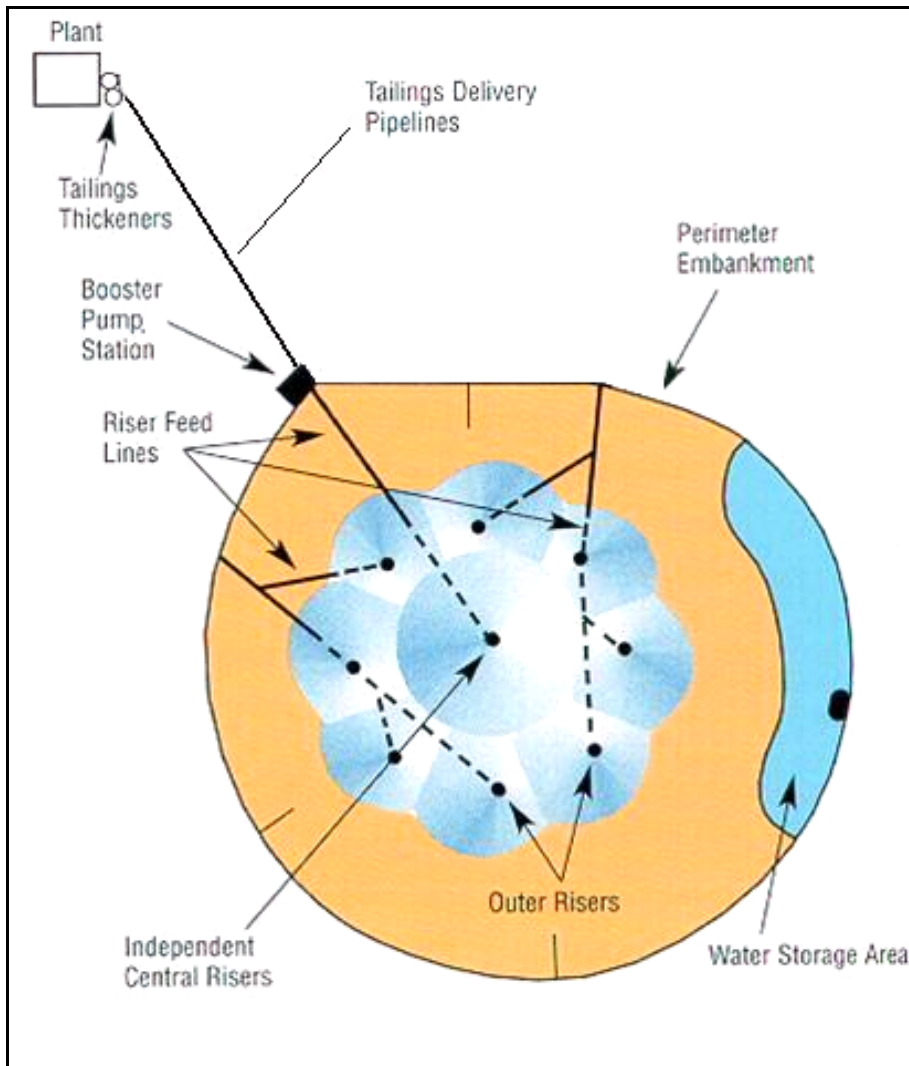
Figure 5.4 Central discharge TSF - conceptual plan

5.4.4   PASTE TAILINGS

The use of paste tailings methods was considered at an early stage in all alternatives, but tended to indicate disadvantages rather than benefits, because of the steeper beach slope and the additional contaminated waste water requiring disposal through evaporation.

1. The beach slope for paste tailings would be around 3 to 5% (3 to 5m drop in 100m) resulting in an edge to centre height difference of some 40 metres in 1,000 metres. This is a very inefficient storage profile as 40m high embankments would provide very little storage capacity, the tailings just reaching the centre at ground level as it reaches the crest of the embankment. Hence to achieve reasonable storage efficiency, the tailings would need to be spread mechanically - probably by stackers supported on permanent raised supports as bulldozers could not safely and practically work the high tailings tonnages deposited at low strengths.

2. Paste tailings removes water from the tailings, to be disposed in evaporation ponds, which would otherwise have been safely evaporated on the beach. If upstream water balance issues could not be resolved to reuse excess liquor, large areas (around 1,000 Ha) of evaporation ponds would be required to evaporate the excess water from paste at around 70%, which would result in a separate water management operation, similar in scale to the tailings disposal, with its own attendant risk issues, such as the risk of increased bird deaths.

Nevertheless, it was recognised that thickening the tailings slurry to an optimum solids concentration which allowed efficient storage, maximises safe excess, unusable water disposal through sun-drying evaporation, and thus minimises seepage, was a critical criteria for the success of the system, and hence the target concentration was set at 52 - 55% compared to the current target around 45 to 47%.

The ability to send a "denser" slurry to the TSF is achieved through increasing the slurry density that crosses from the Concentrator to the Hydromet plant. At a throughput of 70Mtpa, an increase in the flotation tailings solids concentration to the targeted 70% w/w, compared to the business-as-usual 65% (consistent with the existing operation), through the use of higher efficiency thickeners would result in a decrease in water demand from the coastal desalination plant of around 9.5 ML/d (approximately 3.45 GL per annum).

5.4.5   PRELIMINARY SIZING OF ALTERNATIVES

The footprints required for the three alternatives were estimated for comparative purposes using a maximum rate of rise of 2m/year, 70Mtpa throughput and a dry density (stored tailings) of 1.7tonnes/m^3.

As an example, the minimum area required for rockfill centreline is:

A_{min} = 70x10^6 t/y $\div$ 1.7 t/m3 $\div$ 1.6m/y $\div$ 1x10^4 m/Ha = 2,060Ha

Therefore, based on 10Mtpa cells, 7 cells are required with cell area of 2,060Ha/7 = 294Ha each. The centerline wall widths are (294 *10,000)$^{1/2}$ =1715m per side.

The comparison is done to determine total common minimum area requirements. In the refined design (see Chapter 6), the cells will be bigger to allow for uncertainties in drying rate, beach slope and decant pond size.

The comparison of total footprint size has been based on designing each cell to accommodate 10Mtpa, and using the rate of rise of 1.6m/yr. Final height is method dependent and discussed in each comparison.

Upstream Raised Using Tailings

Upstream raising uses significantly more initial area for a variety of reasons. Each upstream raised cell has a larger footprint than its rockfill counterpart because for stability, the downstream embankment slope for upstream wall is significantly shallower – 15$^°$ (1: 3.75) compared with 25$^°$ (1:2) for centreline rock wall. Also, at each raise the upstream raise cell is losing area as the walls step in over the tails so it has to be sized for a final desired evaporation area. For this comparison, the final evaporation area is assumed to be the same as the centreline method (2,060 Ha) but with the extra cells as noted below.

For 70Mtpa at 10Mtpa per cell, 7 cells are required. However, if only 7 cells are provided at start-up, all 7 cells would need to be raised by maximum of 2m each year, but this would be impossible while simultaneously and continuously depositing tailings at 10Mtpa (per cell). To ensure that each cell is dry enough and can be raised without risk of production interruption (upstream raising requires dry tailings for construction, and is therefore dependent on drying time and weather), each cell would require a duplicate cell which can be operated while its matching cell is being raised.

Therefore the upstream tailings system requires a footprint of 14 cells at start-up and the initial (and final) footprint required would be approximately 5,170 Ha when allowing for pipe and road corridor.

In order to achieve comparable stability to centreline methods using the upstream tailings alternative, it is necessary to incorporate a 10m wide mine rock buttress which also assists in managing erosion and radon exhalation risks. However as will be seen in Chapter 6 and 8, the upstream raised tailings system cannot meet stability requirements under seismic loading above 40m, even when significantly buttressed with a rock cover. HSEC risks (dust and radiation) during construction of the raises (continuous throughout the year and throughout the life of the facility) would also pose a significant challenge. Therefore, once the 40m mark is achieved another set of 14 cells would be required. However, given the actual average rate of rise (for the 14 cells) would be 1m per year, only the 14 cells would be required for the assessed 40 year period.

Centreline Rockfill

The rockfill cells would also need to be taken off-line during final wall raising, but as the raises can be higher (10m raises assumed), this only needs to be done every ~5 years for a 10m raise depending on the throughput. Therefore the same 7 cells are required for 70Mtpa but an additional 8th cell is required for wall raising. Therefore sequencing can be done by staggering the starter heights (to stagger raise start schedule), and by providing a single additional cell which would be operated while each of the other cells is being raised. The rockfill raising is not dependent on the tailings conditions or weather – the embankments can be raised irrespective of the condition of the beach.

The footprint at start-up (Table 5.2) is therefore approximately 2,400 Ha including the rockfill embankment footprint. At an average rate of rise of 1.6m/year for the 8 cells (equivalent to 2m a year for 7), at the 40 year mark (term of this EIS) the cells would reach the assumed height of 65m.

As defined above, the minimum cell requirements but with the wall slope of 1:2 and allowances for pipes and roads, the final footprint is 3,100 Ha at the 40 year mark.

Central Discharge

A maximum centre height of 50m is assumed based on cost effective pumping to this height over the radial (perimeter to centre) distance of around 4.6 km at 55% solids concentration by weight (w/w).

A shallow sloped cone is not an efficient storage shape, and it is assumed that this alternative can be kept competitive by creating a plateau type shape (as done at Mt Keith) using a ring of outer risers. The preliminary calculation of the volume and thus the footprint then assumes a "cylinder" shape over half the height (i.e. average height over the full footprint).

For a 70Mtpa CDTSF at the 40 year mark, the TSF itself would be 6,600 Ha with a further 600 Ha lined water storage area, giving a total of 7,200 Ha.

Table 5.2 Preliminary estimates of footprint (70Mtpa facility)

	Number of Cells Required	Year 0 Footprint (ha)	Year 40 Footprint (ha)
Upstream raising using tailings	14	5,170	5,170
Centre-line mine rock	8	2,400	3,100
Central discharge	1	7,200	7,200

Reducing Footprint Disturbance by Increasing Top height

The expansion base case configuration assumes an annual tailings tonnage of 70 Mtpa with a facility design life of 40 years. It is probable that the life of the mine will extend well beyond this, so expansion of the facility with minimum new disturbance is a desirable objective. Assuming the centre raised cells method and that the geotechnical investigations allow, the cells may continue to possibly as high as 80m. See Chapter 8 for more details.

Theoretically, in all cases, the opportunity exists to reduce the disturbance footprint by increasing the top height but this possibility requires further geotechnical analysis. In reality, this will only be feasible for the rockfill alternative, where the slope heights will be limited only by the stability of the rockfill embankment.

As the RSF height is likely to be 150m in height, there is no reason why the rockfill TSF, correctly designed, could not have a top height of approximately 80m, in which case the disturbance footprint would be significantly less than the other alternatives. The cells under the submission are 2km centreline wall lengths. Therefore it is expected that the total disturbed footprint of the TSF (8 cells + 1 contingent) would be 4,400 Ha at the 40 year mark when including all service corridors and embankment wall heights at 65m. This still compares favourably with 5,170 Ha for upstream methods and 7,200 Ha for a CDTSF.

5.5   SELECTION OF PREFERRED ALTERNATIVE

The suitability of the alternatives was evaluated primarily by comparing their ability to manage the key risks listed and discussed in Sections 4.10 and 4.12.

Table 5.3 summarises this evaluation and illustrates clearly that the rockfill alternative is the best method for managing potential health, safety, environment and community risks. The balanced scorecard is a simple ranking of the risk aspects of the alternatives – it is not a proportional methodology, rather an absolute system to obtain a decision. Table 5.4 elaborates further on the rankings.

Given the availability of mine rock, from the open pit, it is also the best alternative for practical construction at the proposed production rates. Even though it may appear more expensive in initial capital and maintenance construction costs, the ranking indicates that the cost will be offset by the reduction in risks associated with the other methods.

The mine rock embankment, being some 100m thick at the toe and 10m at the crest, provides an effective restrictive barrier to radon emanation as well as risk of direct radiation, and effectively manages dust and erosion issues, both during operation (the dumping of rockfill does not disturb the tailings surface) and in the very long term; after closure. At closure, the top surface of the TSF can be covered with a thick rock cover If the mine operation continues past the assessed 40 years then the TSF would become integrated into the rock facility itself as indicated in Section 5.3.

Stability is significantly enhanced by the substantial mass of higher shear strength mine rock which can be designed to provide a stable embankment, independent of the strength of the tailings that it retains, under all loading conditions.

Construction issues can be better managed with rockfill, which is easier to handle and work on during wet weather and which itself provides a stable platform when placed onto existing beaches (rockfill can be placed onto a wet beach to provide stability, whereas upstream raising requires a dry, stable beach). The rockfill embankment also provides a useful design configuration for managing seepage. The constructability hazards are magnified when wall raising starts as surface mobile equipment (SME) will have to work on tops of the walls along side the tailings. This risk will be mitigated through increasing the wall width so that safe operation of SME can be carried out.

The CTDSF alternative is not able to improve on any of the risk management aspects. There are potentially increased risks associated with the greater degree of drying (dust generation), and the total exposure during the full operating life (radon emanation). The CTDSF also requires a significantly larger footprint, and the off-facility water storage is likely to pose an increased risk to fauna, as well as being impractical to maintain (it will be dry and unused for long periods, and hence the liner will be exposed to wind and UV damage).

Expansion Case

The Expansion Case is based on a staged approach starting initially with a 20Mtpa expansion and then ramping up over the following years to a maximum of 60 Mtpa of new ore throughput. Tailings production to the expanded TSF would include the existing facility at 12Mtpa production. Total tailings is less product tonnage, mass loses to solution and the material sent to mine backfill. The tailings tonnage is therefore nominally 70Mtpa. The preferred alternative is the only practical method at these large tonnages. A total of 8 cells (with an extra contingent cell) would be required at a ~2km centreline and would be numbered consecutively 5 to 13 as a continuation of the current cell numbering.

Table 5.3 Balance Score card of TSF Alternatives.

	Balanced Scorecard Alternatives Ranking Matrix (1 = lowest risk)						
	Alternative	**Economics**	**Health**	**Safety**	**Environment**	**Community**	**Risk Profile**
1	Upstream Raising – as used in present system	2	2	3	3	3	3
2	Integrated Waste Landform paddock system C/L Rock Fill – near mine	1	1	1	1	1	1
3	Waste Landform paddock system – C/L Rock Fill – distant to mine	4	1	1	2	2	2
4	CDTSF	3	1	2	4	4	4

Table 5.4 Risk Ranking of Alternatives

Hazard	Risk Ranking (1 = lowest risk)			Comments on Rankings
	U/S raised Tailings	**C/L Rock-Fill[1]**	**CDTSF**	
Option	**1**	**2/3**	**4**	
Radiation exposure	2	1	3	Rockfill provides 10 to100m thick radon attenuation zone. Personnel not exposed to radiation during construction. Central discharge exposed to atmosphere until closure.
Dust generation	2	1	3	Rockfill provides thick dust protection layer. Upstream tailings generate dust during construction. Central discharge dries out more and is continually exposed to atmosphere as a protruding mound – difficult to control moisture.
Surface water erosion	2	1	2	Thick rockfill provides secure separation layer during and after operation. CTDSF would need to be capped with thick layer at closure, which in itself would be difficult to maintain due to long lateral diversion length (see section 8.1.1.)
Embankment Stability	3	1	1	Rockfill embankment ensures failure surface through strongest material under all circumstances. CTDSF not necessarily stable under earthquake loading. Upstream construction not suitable for high cell walls under earthquake load.
Near Surface Seepage	3	1	1	Rockfill can be used to provide a secure seepage barrier between tailings and the environment. CTDSF would have lined water storage facilities. Tailings would require rockfill buttress and drains to match rockfill option.
Seepage through base to groundwater	3	1	2	Central pond system able to control free water better and "raises" the pond above the tailings as the facility rises providing increased "liner/barrier" thickness. CDTSF can have ponding on bare ground for life of storage – worst case for seepage to groundwater.
Bird & fauna deaths	1	1	1	Rock-fill can control better through central system with rock ring wall, and bird netting over water areas. CDTSF has increased risk after large rain events – need lined and netted storage/disposal area. Will not be cost competitive and brings no advantage.
Tailings release	1	1	1	10 to 100m thick rockfill embankment provides most effective barrier between tailing and the environment for operation and closure
Comparative Risk Rating	**17**	**8**	**14**	

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[1] Note that the C/L Rock Fill risk assessment is for both options 2 & 3 from the Balanced Score card table. Both of these options are similar in terms of the risks ranked and are only different by their respective locations on the site.

5.6   LOCATION

The location of the existing TSF has proved successful in managing potential HSEC impacts including:

1. Visual – the TSFs are distant from public roads and are not visible.

2. Dust – the TSFs are well removed from accommodation areas and dust from surfaces is controlled (cover on side slopes) and monitored.

3. Seepage – the TSFs are located away from usable water resources and sensitive receivers

4. Infrastructure – the TRS does not interfere with the operation or access to any mining or processing infrastructure.

5. Interruption of surface water features – the TSFs do not obstruct significant permanent or seasonal surface flow features.

6. Closure benefits – the TSF is located near the quarry which can be used to source cover materials.

Figure 5.5 shows the proposed location of the TSF expansion adjacent to the existing facility, so that the existing infrastructure can be utilised to minimise land disturbance. It shows the first eight cells (+ one contingent cell) draped onto a photograph of the existing facility. Combining the old and new facilities will also allow the seepage from the existing and expanded facilities to be managed as a single issue as well as for both facilities to be incorporated into a single closure landform.

The groundwater modelling has also identified that the north western location is suitable in ensuring post-closure mound dissipation towards the pit void.

There are no apparent advantages to locating the expansion TSF elsewhere on site, but as discussed in Section 5.3, placing the TSF closer to the RSF would lead to benefits both in terms of improved HSEC and construction risk management as well as costs. However this would need to be balanced against the potential risks associated with the interaction of the mining fleet with the TSF construction activities and longer term mining opportunities.
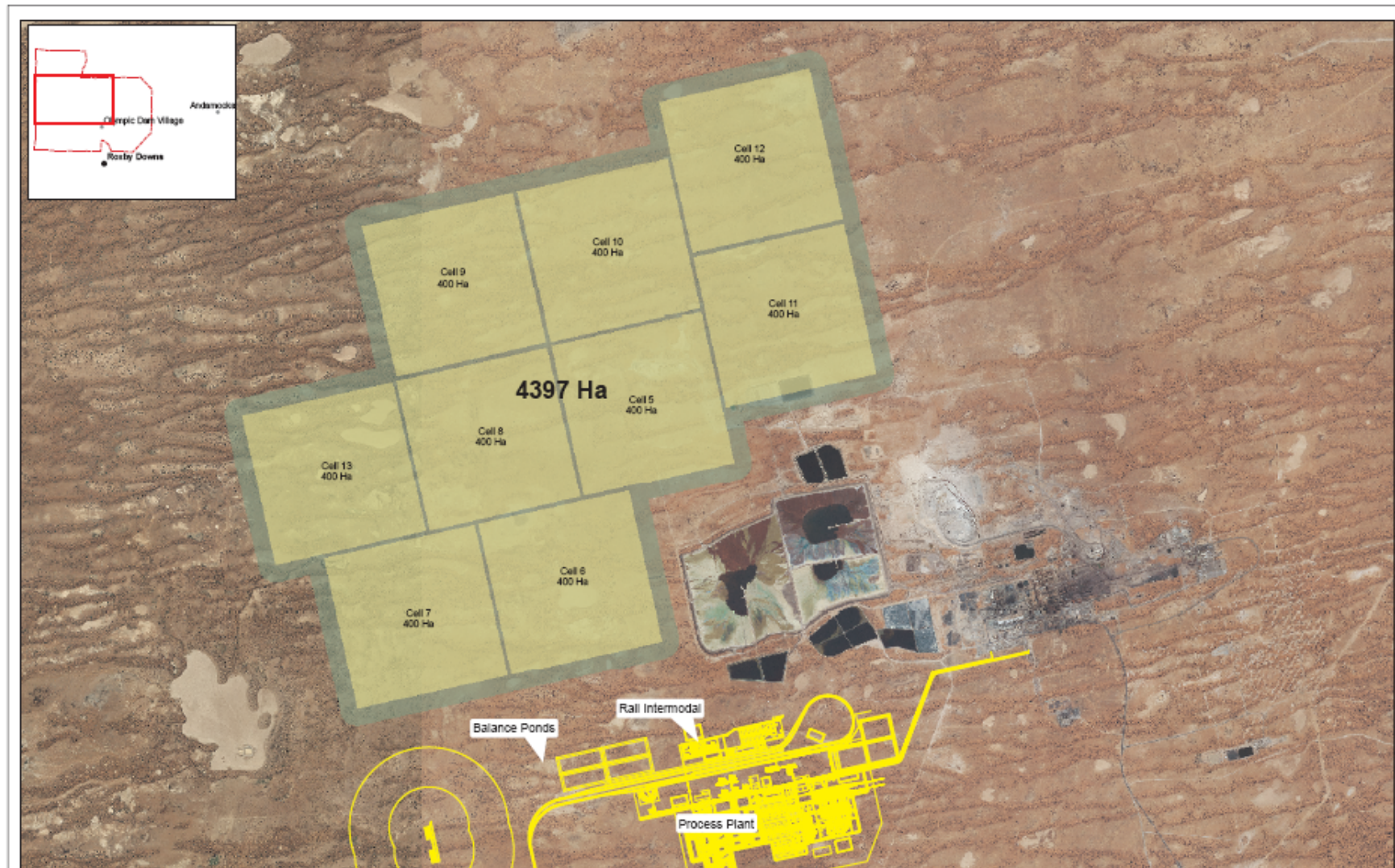
Figure 5.5 Plan showing the location of the expanded TRS

6 REFINEMENT OF THE SELECTED TSF METHOD – DESIGN AND OPERATING CONSIDERATIONS

6.1 SELECTED TSF – CENTRELINE ROCKFILL EMBANKMENT

The proposed design configuration that minimises risk (to ALARP) during operation and for closure is:

1. A ring dyke paddock discharge type system receiving tailings thickened to a target solids concentration of 52 - 55%. The large increase in the slurry solids concentration compared with the existing operation (~45%) significantly reduces environmental risks through reduction in seepage and elimination of off-dam disposal of acidic water in evaporation ponds.

2. Centre-line raising of perimeter embankments constructed using a small proportion of the large quantities of non acid producing mine rock originating from the new open pit development. The use of non-reactive, non-radioactive, and geochemically stable mine rock to build stable and safe tailings cells, which could ultimately be integrated with the rock storage facility to provide a socially responsible, low-risk closure design and assists in reducing health safety and environmental risks.

This configuration is preferred as it provides:

1. Safe and stable perimeter embankments – a design compliant with international best practice design criteria (ICOLD and ANCOLD) under both normal and extreme loading conditions.

2. Acceptably low environmental and health risks – for potential impacts associated with radioactivity, dust, seepage and avian access to acidic liquor.

3. Maximum re-use and recycling of mine materials – mine rock and surplus water.

4. A practical (and low risk) methodology for constructing embankment raises at the high production rates anticipated.

5. The ability to effectively manage design, operational, health, environmental, safety and community (HSEC) issues which arise in other alternatives.

A benchmarking study (Burgess & Paulker, 2008) compared the key risks of the proposed facility to how similar facilities managed these risks. It was shown that the design features defined for a TSF to control the distinctive risks have to be developed for the unique local environmental conditions. With regard to the Olympic Dam expansion case, the risks were found to be manageable to a level that would be considered leading practice.

The following section describes the design of the selected TSF configuration.

6.2 DESIGN PARAMETERS

Table 6.1 summarises key design parameters. These are derived not only from international standards, but also from requirements set out in BHP Billiton's Fatal Risk Control Protocols, which specify minimum safe road running widths for equipment and light vehicles.

These nominal parameters may be refined as the detail design progresses, however a conservative approach to the design is presented and assessed. Therefore future refinements should not alter the impact assessment outcomes materially.

Table 6.1 Centreline raised rockfill TSF design parameters

Design Parameter	Value
Production rate tailings (Mtpa)	30-70 (Staged approach)
Facility operating life (Years)	40
Deposition slurry solids concentration (%)	55
Maximum Rate of Rise (m/annum)	2
Dry density of stored tailings (t/m^3)	1.7
Final height (m)	65 (up to 80 – see section 5.4.5)
Embankment slopes - vertical to horizontal	1:2
Nominal height of starter embankment (average) (m)	10
Nominal raise height (m)	10
Crest width of external walls for pipe & traffic	10
Beach slope (%)	1

6.3   HAZARD RATING AND DESIGN, OPERATING AND REVIEW REQUIREMENTS

The proposed tailings storage facilities are classified "high hazard" dams by virtue of their proposed embankment heights and large annual quantities of tailings to be disposed and safely managed (~70 Mtpa). The hazard presented by a TSF is more truly described as the potential consequences of a failure if it were to occur (ANCOLD, 1999). In this instance, the hazard rating is used as a means of determining the degree of design and care necessary to reduce the risk of failure at a level appropriate to the consequence of failure.

Table 6.2 shows the design and management framework which will be implemented to meet and exceed ANCOLD (1999) requirements for the relevant hazard classification of the Olympic Dam Expansion TSF.

The BHP Billiton requirements exceed the ANCOLD both in the level of detail required, and the requirement for peer review of designs by independent experts.

The geotechnical aspects of this EIS level design have been independently reviewed by Mr Christopher Lane of Coffey International (Coffey. 2007c) whose review comments have been incorporated in the design, or are being followed up for incorporation into the detailed design (e.g. seepage geochemistry quantification).

During the detailed design phase, the proposed design concepts are required to go through a series of constructability, operability and risk assessments and reviews before arriving at the detailed final design. Therefore it is possible that the final layout, geometry and shape of the cells and the central drainage zones will differ from those shown in this report, in order to ensure the project objectives can be best achieved. Any such changes would be reviewed with appropriate regulatory reviewers to ensure that no risk management targets are compromised through the proposed modifications. Prior to construction proceeding, the detailed design will again be subject to independent expert scrutiny and risk assessment in compliance with BHP Billiton's Health Safety Environment and Community and Investment Standards to ensure that all issues have been appropriately addressed.

Table 6.2 Requirements for high hazard TSF (Modified from ANCOLD for BHP Billiton purposes)

Modified for BHP Billiton from ANCOLD Guideline	Hazard Category – Use Highest Category Achieved From Structural Category or HSEC Incident From Table 1		
	High hazard	**Significant hazard**	**Low hazard**
Planning & design			
Life of asset plan	5 year plan, cost estimates, drawings and schedules and drawings in alignment with cap	5 year plan, cost estimates, drawings and schedules and drawings in alignment with cap	5 year plan, cost estimates, drawings and schedules and drawings in alignment with cap
Design – embankments, raises and internal features	Geotechnical investigation, design and detailed report led by specialist dam designer, using competent discipline professionals, reviewed by independent peer reviewer, for starter embankment , raises, and final expected configuration	Geotechnical investigation, design and report by competent geotechnical engineer/dam designer reviewed by peer reviewer for starter embankment, raises, and final expected configuration	Geotechnical investigation, design and report by competent geotechnical/civil engineer with peer review
Design and construction risk assessments	Identify design elements that require ongoing monitoring, maintenance and management to control and minimise design risks. Maintain risk register.	Identify design elements that require ongoing monitoring, maintenance and management to control and minimise design risks. Maintain risk register	Identify design elements that require ongoing monitoring, maintenance and management to control and minimise design risks. Maintain risk register
Facility and raise construction reporting	QA/QC plan, construction report; as built drawings; photographic record	QA/QC plan, construction report; as built drawings; photographic record	QA/QC plan, construction report; as built drawings; photographic record
Operation & maintenance			
Operating manual	Detailed dam operating manual – refer applicable guidelines (MAC, DoIR (WA), SABS – section 4) for minimum requirements. Independent peer reviewed.	Functional TSF operating manual – refer applicable guidelines (MAC, DoIR (WA), SABS – section 4) for minimum requirements. Peer review – internal BHPB acceptable.	Simplified operating manual – peer review – peer operation internal BHPB acceptable.
Daily inspection	Yes – recorded on inspection checksheet showing water position	Yes – recorded on inspection checksheet showing water	Yes – recorded on inspection checksheet showing water

	and level. Signed off daily by superintendent and responsible manager.	position and level. Signed off daily by superintendent and weekly by responsible manager.	position and level. Signed off weekly by superintendent and monthly by responsible manager.
Maintenance	Detailed Maintenance Manual/Plan and schedule – refer MAC Guideline Section 4. Cross-check in operations risk assessment and 5 year plan. Independent Peer Review to check adequacy for risk critical equipment.	Detailed Maintenance Manual/Plan and schedule – refer MAC Guideline Section 4. Cross-check in operations risk assessment and 5 year plan. Peer review.	Simplified Maintenance Manual/Plan and schedule – refer MAC Guideline Section 4. Cross-check in operations risk assessment and 5 year plan. Internal functional review.
Surveillance & Risk Management			
Dam break study	Rigorous probabilistic assessment – ref Section 3.6	Assessment required that estimates flow direction and extent. Qualitative or semi-quantitative permissible.	Simplified assessment to consider potential risks of containment break.
Operating Risk Assessment/Register	Operating risk assessment by multi-disciplinary team including competent geotechnical engineer / dam designer using risk ranking, including scheduled actions. A fault tree analysis is desirable. The requirement to perform probabilistic assessments may be an outcome of the risk assessment.	Operating risk assessment by multi-disciplinary team including competent geotechnical engineer / dam designer using risk ranking, including scheduled actions. A fault tree analysis is desirable.	
Emergency response action plan	Based on dam break assessment, operating risk assessment (and fault tree analysis if warranted).	Based on dam break assessment and operating risk assessment.	Based on dam break assessment and operating risk assessment
Compliance /Due Diligence Audit /Inspection	Annual inspection by competent geotechnical engineer / dam designer considering performance, risk response & adequacy of emergency response plans. Check currency and adequacy of risk assessment and cross check risk register against scheduled actions.	Annual inspection by competent geotechnical / civil engineer considering performance, risk response & adequacy of emergency response plans. Check currency and adequacy of risk assessment and cross check risk register against scheduled actions.	Annual inspection by competent geotechnical engineer / dam designer considering performance, risk response & adequacy of emergency response plans. Check currency and adequacy of risk assessment and cross check risk register against scheduled actions.

Closure			
Closure Plan	In compliance with Closure Standard. Cross check closure risks with Operating Risk Assessment	In compliance with Closure Standard. Cross check closure risks with Operating Risk Assessment	In compliance with Closure Standard. Cross check closure risks with Operating Risk Assessment
Documentation/Reporting			
Documentation	All documentation incorporated in the Tailings Management Plan and key TSF risks transferred to Operation's EWRM Risk Register.	All documentation incorporated in the Tailings Management Plan and key TSF risks transferred to Operation's EWRM Risk Register.	All documentation incorporated in the Tailings Management Plan and key TSF risks transferred to Operation's EWRM Risk Register.
Incident reporting	All HSEC incidents must be reported in compliance with the BHPB HSEC Incident Reporting Standard	All HSEC incidents must be reported in compliance with the BHPB HSEC Incident Reporting Standard	All HSEC incidents must be reported in compliance with the BHPB HSEC Incident Reporting Standard

6.4   EXPANSION TSF LAYOUT, GEOMETRY AND KEY INFRASTRUCTURE

Figure 6.1 shows the typical layout of each cell. The area of each cell is derived by the water balance and notably the liquor return requirements as well as the minimum capacity requirements (see Section 5.4.5) to allow for the operation of the 300m central pond as a separate entity (effectively a sealed pond) during the start up. Once the tailings rise above the pond, the additional area/volume provides a safety margin for irregular deposition, variations in beach slope, as well as contingency evaporation. The additional beach length and bigger cells provides the ability to work around operational issues without experiencing issues that might otherwise cause production interruptions.

Thus for the refined design, the nominal minimum wall length of 1,600m for each cell (derived from area obtained in section 5.4.5) has been increased to ~2,000m, resulting in an initial outside toe footprint of 2,050m x 2,050m per cell. The final cell size will be approximately 225m greater than this length to accommodate raising wall growth, roads and pipelines with an estimated total disturbance of ~ 4,400 ha after 40 years. The number and size of the cells will depend on the detail design stage water balance, the water saving initiatives that the current plant make and the final size of the expanded operation. Although the area of each cell is likely to change as the system is optimised, this is not expected to be significantly different to the arrangement described.

Furthermore, depending on the production ramp up schedule, the number of cells required at start-up will also be determined by the start-up tonnage, with other cells being brought on line ahead of incremental production increases.

Figure 5.5 shows the proposed layout of the first 8 cells of the expansion TSF for 70Mtpa of tailings. Note that the layout shows a contingent cell 13 which is based on the "worse case" water balance. Improvements in the reliability and confidence of the water balance as engineering progresses to the next stage will most likely make the requirement for this cell redundant. The staged approach to the design does allow for leanings to be incorporated into later cells should issues arise. Consideration will be given to foundation conditions and seepage risks, in finalising the location of TSF edge embankments.

The primary infrastructure on each cell is typical of the paddock discharge type system – a decant access embankment leading to the lined central decant area. The details of the central drainage area are discussed in section 6.6.
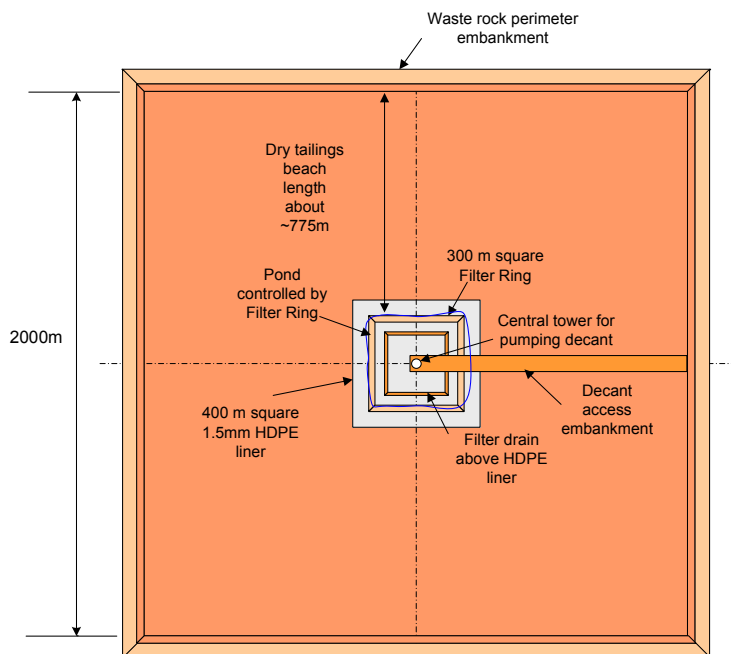

Figure 6.1 Layout of cell

6.5   EMBANKMENT DESIGN AND RAISE SEQUENCE

The concept embankment designs shown in Figure 6.2 used an upstream toe drain to control the phreatic surface, and utilise consolidated tailings layers to prevent seepage. In early discussions, Professor Richard Jewell (PIRSA Review consultant, pers comm July 2007) observed that for the 40m high embankment, seepage would probably still be able to pass through the embankment, and suggested that a drainage "barrier" should be put in place to collect seepage and maintain overall embankment stability.

Because weathered or oxidised (clayey) materials are scarce and not readily found in the cover materials in the pit zone, two alternative designs incorporating barrier drains are shown in Figure 6. and Figure 6.3. Both incorporate upstream and downstream toe drains which utilise the surface sediments between them as a basal drain underlying the full embankment width (i.e. any water seeping past the barrier will be picked up in either of the basal or downstream toe drains).

While both designs are practical to build, the second design alternative in Figure 6.2 is more likely as the first may encounter problems with tailings blocking the upstream drain. The final profile may differ from that shown, as there is an opportunity to optimise the shape and drainage configuration depending on the available materials.

The walls of the tailings storage facility will be constructed from non-acid producing, non-radioactive, and geochemically stable mine rock sourced from the overburden which are excavated in mining operations to expose the ore-body. Competent and durable rock will be stockpiled specifically for embankment and closure cover construction.

Figure 6.2 and Figure 6.3 also illustrate the raise sequence. The small downstream embankment covering the downstream toe would be constructed at the start of the facility, clearly delineating the extent of the embankment and construction zone while acting as a downstream catch embankment for any tailings spills. The final height is not yet defined as this requires more detailed geotechnical investigations but is expected to be 65m by year 40. As stated in section 5.4.5, if the operation continues pass the assessed 40 years the cells could continue upwards to be as high as 80m but this would be subject to further detailed geotechnical studies.

6.6   STARTER EMBANKMENT HEIGHT

The height of the starter wall will vary around the cell in line with the topography (Figure 6.4). The important aspect in defining the starter wall height is the crest elevation (constant around the cell) relative to the decant elevation.

The minimum height should ensure that when the first raise is about to commence, the tailings has "broken ground" around the entire perimeter, (i.e. the toe of the beach covers the floor up to the central decant).

The reason centres on the fact that the rate of rise is higher than 2m/year while the tailings beaches are breaking ground (fresh tailings cover on bare ground as the tailings beach toe advances towards the centre) because the base area of the volume stored increases as the floor is covered.

While more critical for an upstream raised TSF where the first raise needs to be founded on a stable platform, it may be possible for the rockfill wall to use a lower starter height, if the early raises can be safely sequenced to provide the additional storage volume as it is needed, and if the water inventory can be managed correctly.

6 m 4 m

Free-draining
Andamooka
Limestone

4 c

4 d

Run of mine
competent rock

4 b

3 c

3 d

2

3 b

1

Tailings

40m in 4 x
10m lifts

4 a

2 c

2 d

3 a

2 b

Final position of
downstream toe

2 a

1 a

1 b

1 c

Downstream toe
drain

Very low permeability
undisturbed Andamooka
Limestone

Clayey silty sand – used
as continuous basal drain
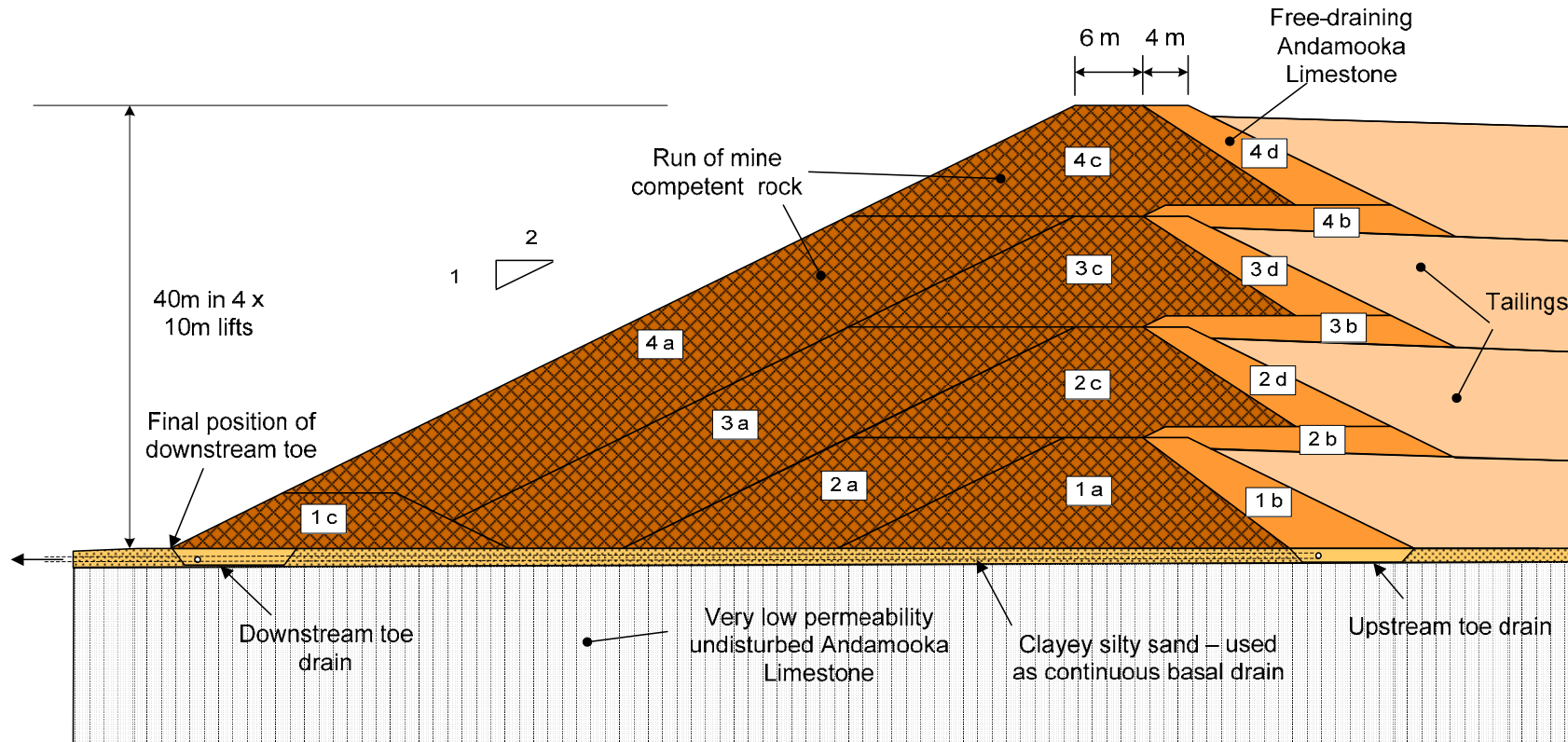
Upstream toe drain

Construction Sequence

Lift 1
1a – Starter embankment – waste rock
1b – Upstream seepage barrier – free-draining limestone (AL)
1c – Downstream toe seepage collector drain embankment (at extent of embankment)

Lifts 2, 3 and 4
a – Downstream section of raise 2 – construct during Stage 1 filling
b – Horizontal section of upstream drainage barrier – AL. Also provides base for toe of embankment on tailings
c and d – Simultaneous construction of centre-line portion of raise (c), and upstream drainage barrier (d)

Notes:
1. During deposition, tailings will migrate into the limestone – this depends on the size and grading of the "aggregate". If the Limestone is too large, a rockfill cover will be placed on the upstream face, the limestone becoming a "chimney" drain.
2. The drainage barrier will promote increased water collection during deposition – this is beneficial – it means that there is less water available for seepage.

Figure 6.2 Embankment Design with Upstream Drainage Barrier

Free-draining sized rock – Arcoona or similar Class C or D

Run of mine competent rock

14 – 20m

Tailings

65m

Proposed final position of downstream toe

1 d

Downstream toe drain

Very low permeability undisturbed Andamooka Limestone

6 m   4 m

Clayey silty sand – used as continuous basal drain
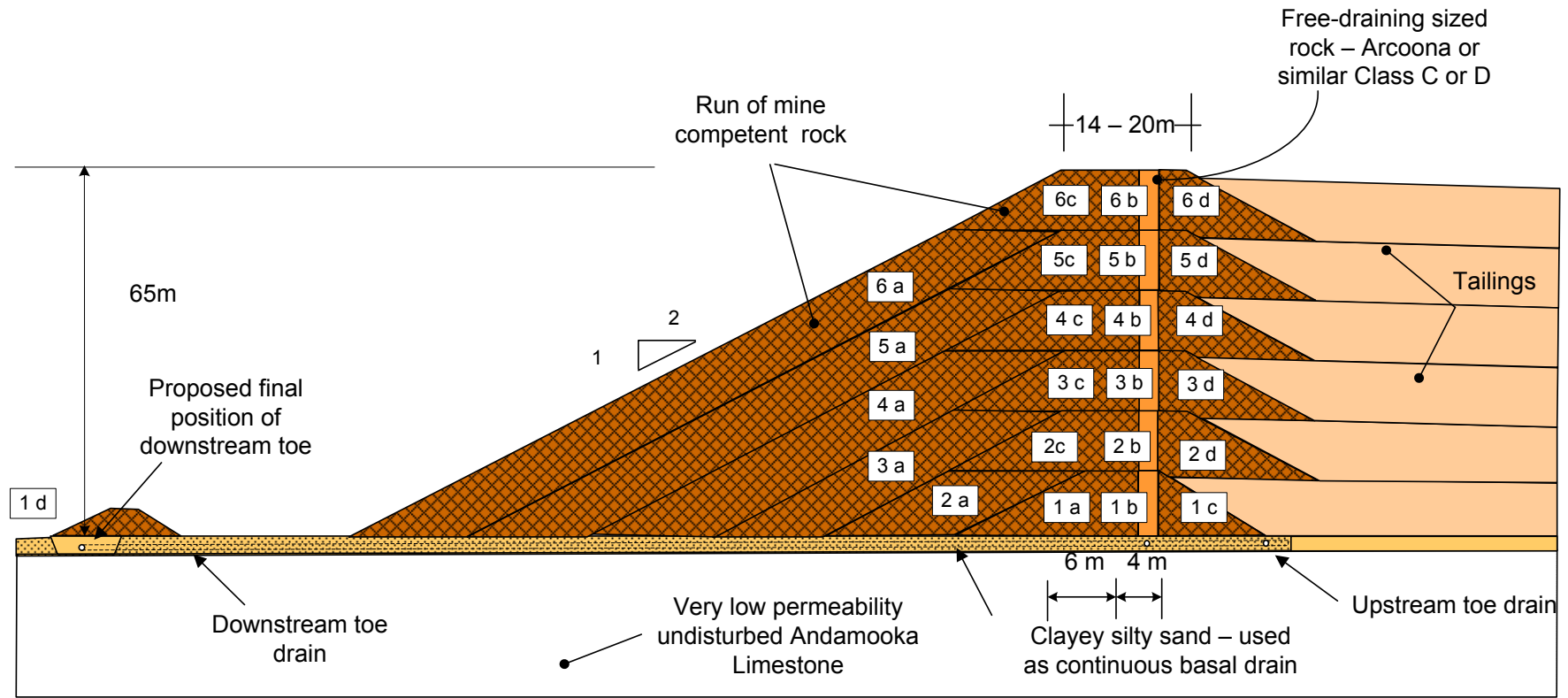
Upstream toe drain

Construction Sequence

Lift 1
1a, 1b, 1c – Simultaneous construction of waste rock and free-draining Limestone chimney cut-off barrier
1d – Downstream toe seepage collector drain embankment (at extent of embankment)

Lifts 2, to 6
a – Downstream section of raise 2 – construct during previous Stage filling
b, c and d – Simultaneous construction of centre-line portion of raise (c & d), and chimney drainage barrier (b)
Note: raise 2 – 6 etc wider to be able to construct walls with bigger equipment.

Figure 6.3 Embankment Design with Internal Drainage Barrier
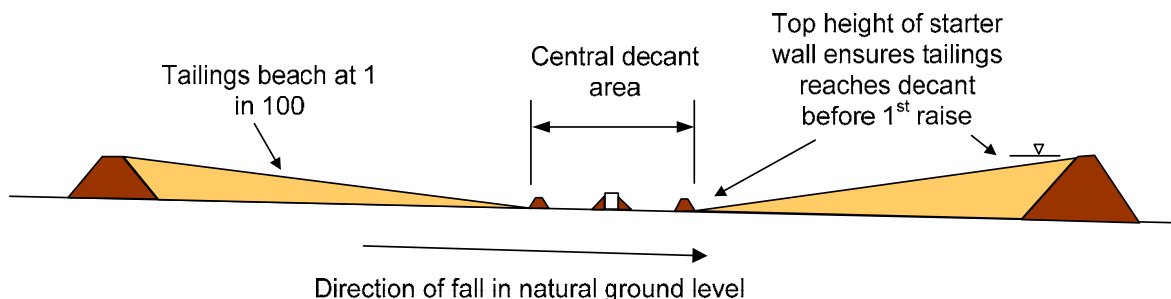
Figure 6.4 Illustration of Minimum Starter Wall Height

To facilitate construction sequencing, the starter heights will be staggered by about 1-2m which, together with the 8th cell which will be used while each of the 7 operating cells are raised, allows a practical construction period for raising each cell safely.

This sequence provides a raise construction period of 12 months for each cell (Table 6.3), but as Figure 6.3 illustrates, only the "centre-line" embankment ("b", "c" and "d") needs to be constructed during this period as the "buttress" portion ("a") will have been constructed in the period leading up to this.

Table 6.3 Staged Cell Construction Sequence for TSF cells to 70Mtpa

Cell Number	5	6	7	8	9	10	11	12
Starter height (m)	8	8	9	8	8	7	13	13
Capacity at startup of cell (M m^3)	22.7	21.8	25.5	23.0	22.4	19.8	37.7	37.7
Rate of rise (m/yr)	1.2	1.6	1.6	1.4	1.4	1.1	1.7	1.6
Time to reach ~top of starter wall – less 1m freeboard (years)	6	4.5	5.0	5.1	4.9	5.5	7.2	7.5
Construction time available (months)	18	19	15	12	14	12	19	16
Raise construction time (months)	12	12	12	12	12	12	12	12
Height of Raise 1 (m)	10	10	10	10	10	10	10	10
Raise 1 Volume (incl. surplus vol from starter wall (M m^3)	34.9	37.3	36.8	36.8	36.3	36.3	34.9	35.4
Rate of rise (full production)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Time to reach top of raise 1 (years)	6.3	6.5	6.4	6.4	6.3	6.3	6.2	6.2

Cells will be brought on line in a staged approach to match the ramp up schedule, noting that the additional cell is critical during the raise construction sequence. The contingent 13th cell would be built only if required.

6.7 CENTRAL POND CONTROL – FLOW-THROUGH ROCK FILTER WALL

The larger sized cells and the increased solids concentration of the deposited tailings slurry (less decant water) will enable a smaller and better controlled central pool.

Nevertheless a central pool still has associated risk issues:

1. Spreading of the pool extents caused by loss of beach control, potentially leading to increased seepage.
2. Attraction of birds to the contaminated water resulting in bird deaths.

To manage these risks, the expansion design incorporates a rock flow-through filter wall (example shown in Figure 6.5) which also provides a structure on which the supports and anchors for avian

control measures can be erected and maintained. The square rock ring wall with a central splitter wall is easier and safer to build using large trucks. One suggested method is bird netting that could be used to cover the central decant ponds is illustrated in Figure 6.6.

The use of bird-netting is a method of preventing birds accessing ponds that has been used elsewhere successfully. The netting does not reduce evaporation. The netting has some draw backs in that birds might become trapped and it is difficult to retro fit or change once installed. However, the netting aperture can be changed to as little as 32mm (or possibly smaller) which should avert the possibility of bird entrapment. It is envisaged that a trial and a risk assessment would be conducted prior to incorporation in the final design. The risk assessment needs to demonstrate that the residual HSEC risks are appropriately reduced by the netting. The risk assessment will consider if the netting can be installed and raised safely, and that bird entanglement does not create a risk issue, and that the netting is a cost effective long term solution.

Figure 6.6 Bird netting (NetPro) over pond (photos courtesy of AusLive Fish Farm Calliope, Queensland

The 300m square rock ring wall ensures that the pond is controlled to a limited size and located centrally over the 400m square lined area during normal operating conditions, thereby minimising both risk issues noted above.

At times (e.g. after rain) the normal operating pool may extend outside the ring wall (on the side where deposition is occurring), but as shown in Figure 6.5the pond is very shallow and is flowing through the rock ring. The objective of the ring is to create a controlled deeper central area for clarification, which reduces the lateral extents of an uncontrolled pool.

Figure 6.5 Rock Decant Control Wall (Photo courtesy Mt Rawdon Gold mine)

6.8   SEEPAGE CONTROL

While some seepage into the underlying foundation is acceptable (EPA, 2006), this is clearly conditional upon demonstration that the proposed design ensures control and minimisation of seepage, and that the existing requirement to keep the groundwater mound below 80m AHD can be achieved.

While the seepage will change the water quality, the Expansion EIS shows that seepage from the TSF into the underlying rock sequence is acceptable because it will not impact third party users or sensitive environmental receivers. Modelling of the regional groundwater regime predicts that the mound will dissipate towards the pit void and evaporate from the pit walls.

This section describes the controls which will be implemented to address the various seepage mechanisms.

6.8.1   SEEPAGE DURING START-UP

During the start-up period when the floor of the cell is being covered by the tailings which then consolidates to become an effective liner/barrier, seepage occurs because of water ponding on bare ground.

Figure 6.7 illustrates the start-up seepage minimisation plan which covers small sections of the floor rapidly, with decant and bleed water transferred to the central bunded and lined decant area where the water is returned to the process or evaporated.

The start-up measures proved successful in the start-up of cell 4, where groundwater levels confirm that seepage from this cell was less than seepage from the earlier three cells where ponding on the floor was not managed in this way.

6.8.2   CENTRAL DECANT LINER AND UNDERDRAINAGE DETAILS

Figure 6.8 shows the decant pond liner and drainage design which will be installed to control and minimise seepage. The design includes:

1. The lined central decant pond area (1.5mm high density polyethylene (HDPE) liner over an area approximately 400m square. The central pond is positioned above this during normal operations.

2. The central area is bunded so that the pond can store and dispose of excess water by evaporation during the start-up phase.

3. A sand layer on top of the liner (dune sand within the cell perimeter) to form a base drain. The sand layer may eventually become clogged by fine tailings, but assists with consolidation of the fine tailings to provide an effective tailings liner above the HDPE liner. The sand layer also acts as a protective cover to the liner.

4. A filter drain (designed not to be clogged by fine tailings) acting as a permanent underdrain above the liner.
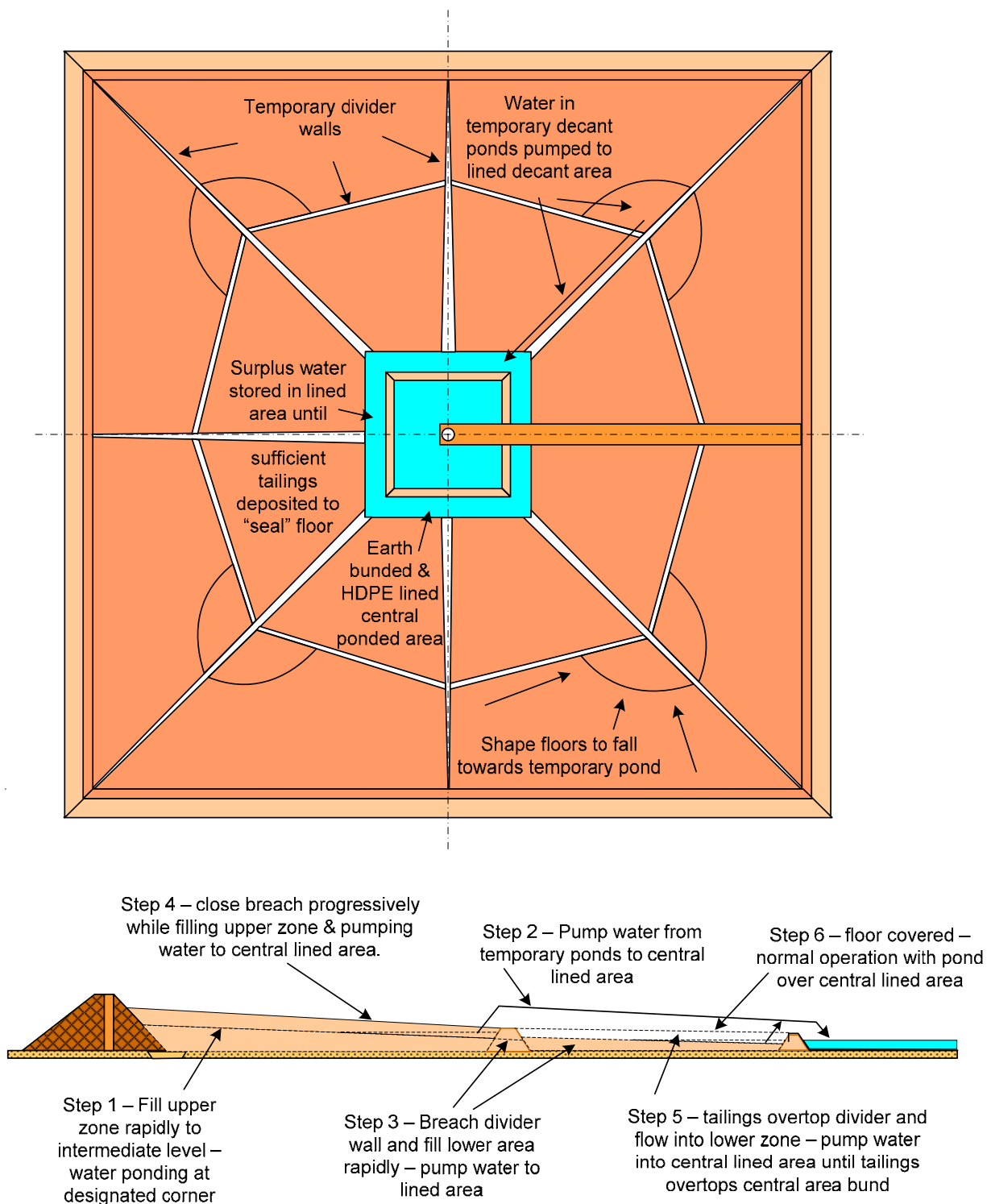
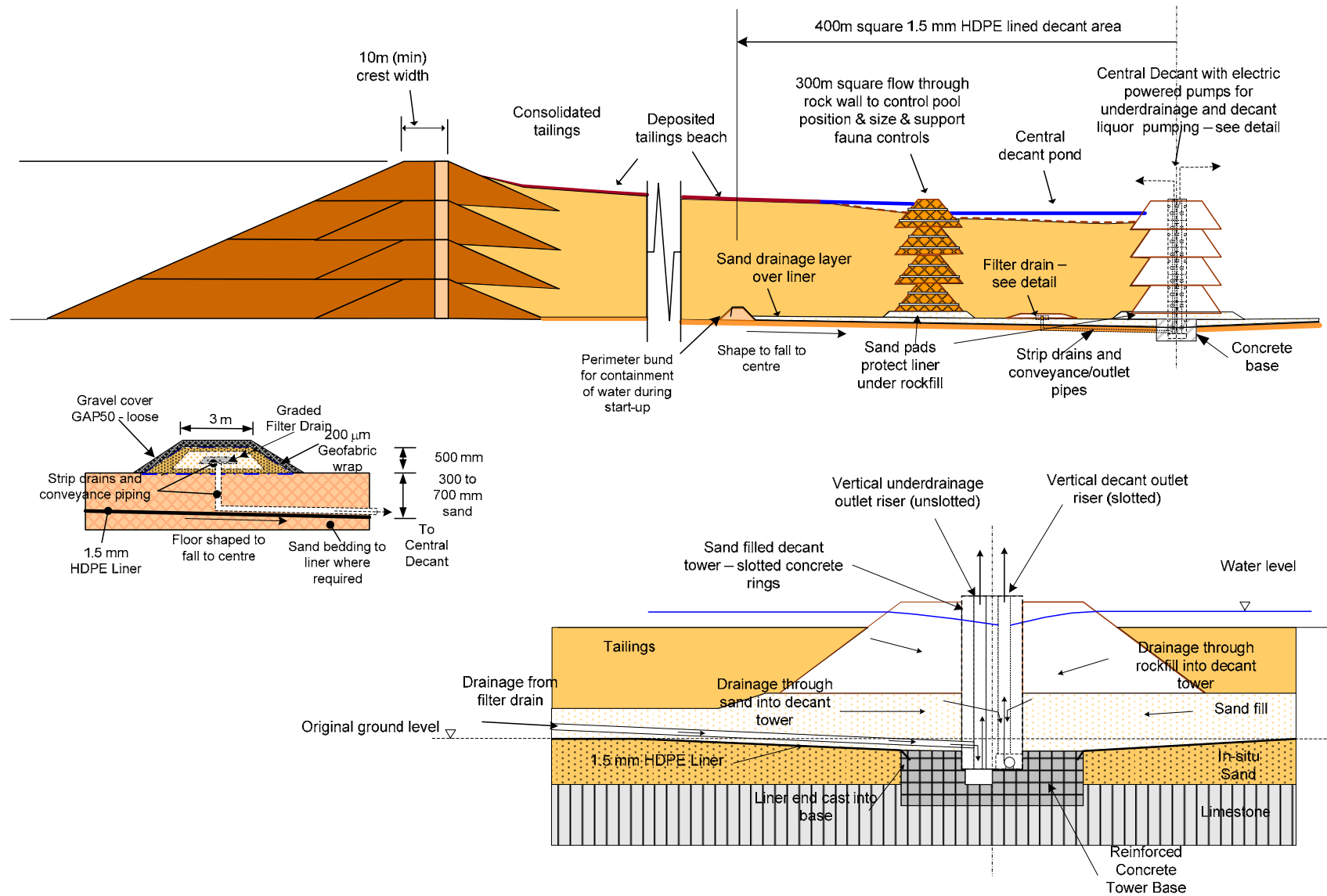**Figure 6.2 Start-up Seepage Minimisation Plan**

Figure 6.8 Central Pond Liner and Underdrainage Details

6.8.3   SEEPAGE CONTROL FOR HIGH POND LEVELS

There is a common perception that if the pond is positioned above a liner, seepage won't occur. In reality, water flows along the easiest path that is available to it. When a liner is positioned under the pond, the water simply flows laterally away from the pond promoted by the higher horizontal permeability caused by layering, and with a constant feed from the pool, the system eventually reaches a steady state condition as shown in Figure 6.9.

Figure 6.9 illustrates the two case of a cell with and without a liner. It shows that if tailings above a liner are consolidated only by free-settling, then it will be very permeable, (i.e. the fine solid particles are unconsolidated, and water flows freely passed them). The underdrains effectively "suck" the water out of the tailings causing the particles to consolidate, significantly reducing the permeability of the fine tailings.

The quantity of seepage is proportional to the permeability of the tailings through which it flows (more permeable, more flow) as well as to the head of water. Figure 6.10 shows the worst case seepage where the tailings in the pond are unconsolidated. Even if the pond is positioned above the liner, the high permeability and the high driving head resulting from the high piezometric water level (Figure 6.9), results in larger seepage volumes (denoted by the large seepage vectors).

Figure 6.9 also illustrates why the proposed underdrainage design is important in minimising seepage (denoted by the smaller seepage vectors) by:

1. Promoting the consolidation of the tailings thereby providing an effective liner/barrier to seepage flow from water ponding on the surface or flowing through from the wet-up beach, and:

2. Controlling the phreatic surface, reducing the head driving seepage through the base, and promoting the direction of seepage flow towards the central drainage area rather than towards the cell perimeter.

It is clear that the seepage from this configuration will be much less than the case where no liner is provided. It is also clear that once the tailings are effectively consolidated, the HDPE liner becomes redundant, and the underdrainage becomes the effective seepage control instrument. This method has been shown to work successfully in the current operation TSF cell 4.

After large storm events and above average rainfall years the phreatic surface rises in response to the higher pond level, and seepage increases. In Figure 6.9, in both the two cases shown, the increase in seepage when the pool rises is not significant, irrespective of whether the pond extends outside the liner limits. During average rainfall years, the central ponds are maintained at their design size (300m square) by transferring seasonal increases in water inventory (winter rainfall) from the cells to the surge/balancing pond (see water balance Figure 8.2).

Considering a phreatic surface 20m above natural ground (average over the 40m final height facility), a 1.65m increase in water (1 in 100 year storm (Section 8.2)) increases the seepage rate by only 8.25% (Δi (=h/L) = 1.65m/20m = 8.25%). The actual increase will be less as the pond will be returned to its normal size within one summer season, through transfer to surge and increased evaporation (from the increased pool size). Therefore, particularly in the case of the proposed design, temporary increases in the pond size beyond the liner extent will not affect seepage significantly.

Despite this small increase, the design models have been tested against much larger (50%) increases in seepage.

Top of tailings after "settling" under water

Consolidation from change in pressure caused by base drainage

Pressure distribution

h

$\gamma_w h$

Without base drainage

With base drainage

Unconsolidated settled tailings

$k_1 = 1 \times 10^{-5}$ m/s
Solids concentration $\approx 50\%$
$\omega = 100\%$
$e = 3.4$

Tailings consolidated by underdraining

$k_2 = 1 \times 10^{-8}$ m/s (permeability)
Solids concentration $\approx 70\%$
$\omega = 43\%$ (soil moisture content)
$e = 1.46$ (void ratio)

For flow through tailings - (seepage)

$Q_1/Q_2 = 10^{-5}/10^{-8}$

$\therefore Q_1 = 1,000$ times Q_2 (Check $- k \propto e^2$ $\rightarrow$ $k_1/k_2 = 1 \times 10^{-10}/1 \times 10^{-16} = 10^6$)

$\therefore$ Therefore underdrainage effectively reduces tailings permeability to liner equivalent

Figure 6.10 Schematic Representation of Drainage on Tailings Consolidation

Increase in pond size causes increase in driving head & seepage

Unconsolidated tailings in central pond area

h

$\gamma_w \times h$

Foundation seepage vectors

TSF with no underdrainage or central liner

Increase in pond size increases driving head & flow to drainage with minor increase in seepage over unlined area

Underdrainage reduces "driving" head

h

$\gamma_w \times h$

Potential seepage collected by underdrains

Foundation seepage vectors

Seepage reduced through central liner, underdrainage collection, and improved consolidation everywhere

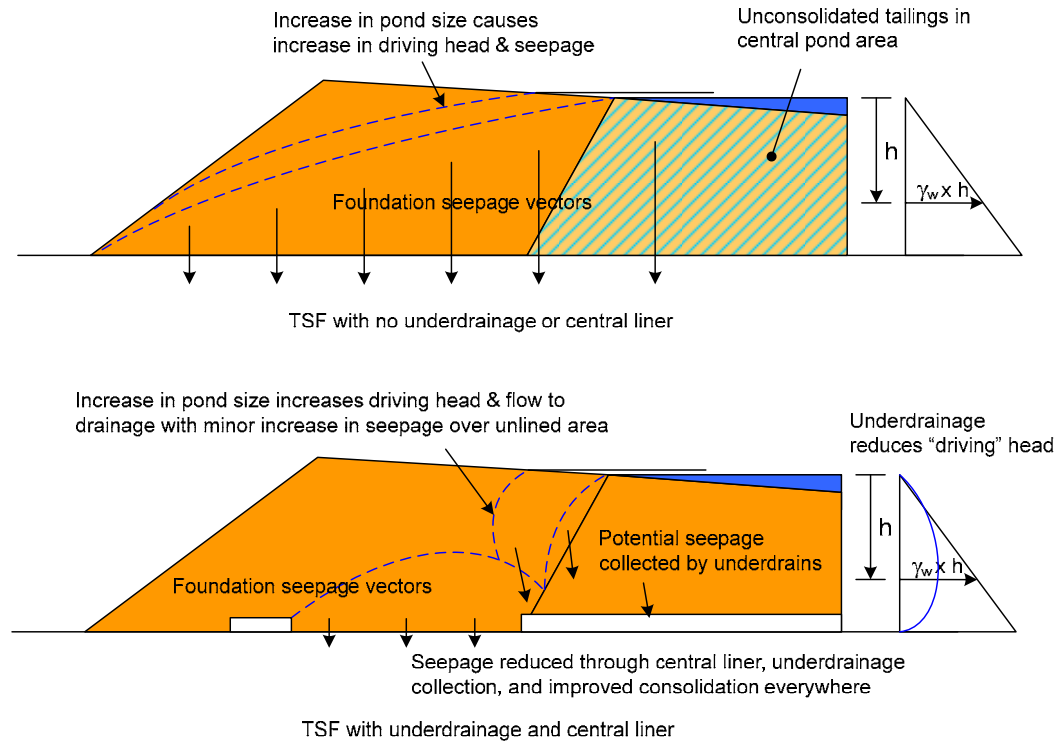TSF with underdrainage and central liner

Figure 6.9 Effect of Underdrainage on Seepage Flow Direction & Pressure

7   STABILITY

The stability of the pre-feasibility options was assessed using the software package SLOPE/W. The design methodology involved:

1.   Defining the design criteria – from ANCOLD (1999).

2.   Define the near surface geological environment and the design parameters for the various construction materials (mine rock, tailings and foundation) and the in-situ tailings. This was done using data from field and laboratory investigations for:

   a.   The design of Cell 4 (Coffey Metago, 1998) and associated evaporation ponds.

   b.   Knight Piésold check of the stability of the existing structures (Knight Piésold, 2004)

   c.   Test data from the geotechnical investigation carried out for this study (Coffey, 2007a)

   d.   Recent investigations of toe seepage at the existing TSF (Coffey, 2007b).

7.1   DESIGN CRITERIA

7.1.1   ACCEPTABLE FACTORS OF SAFETY (ANCOLD, 1999).

Table 7.1 lists factors of safety recommended by ANCOLD for embankments retaining tailings.

Table 7.1 Recommended Safety Factors (ANCOLD, 1999).

Loading Condition	Recommended Minimum Factor of Safety
Steady state seepage – high pool	1.5
Earthquake[2]	1.1
Construction	1.3

Knight Piésold (2004) appears to interpret the operational phase as "construction" and apply a minimum factor of safety 1.3 over the operational life of the TSF. The interpretation in this Design Report is that the minimum factor of safety of 1.3 applies to the period during which the embankment (starter or raise) is under construction to ensure the safety of construction personnel/equipment and lower consequences related to failure. This is because the consequences of a failure at this stage are low. On completion of the raise and re-commencement of deposition, the minimum factor of safety must be 1.5.

In order to ensure that the structure is stable under independent and combined loading conditions, a variety of failure modes are tested.

For this design, the following failure modes are applicable:

1.   An extreme high pool position caused by out of balance water inventory (large rainfall events and/or out of balance process water balance). Because of the long beaches in the

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[2] ANCOLD notes that If a pseudo-static analysis is used (an analysis that models the effect of the earthquake using a horizontal acceleration), then post-liquefaction properties of the tailings must be used (see 7.2.1).

proposed design, this is unlikely due to the large capacity of the central bowl (see Figure 8.1), but must be tested as it could conceivably occur.

2. Blockage of the upstream toe drains – which causes the phreatic surface to pass through the embankment structure. This is unlikely but possible. (Note that this would not be applicable to the engineered barrier drain in the rockfill embankment).

3. Loss of strength in the deposited tailings after an earthquake – post-liquefaction strength. Additional in-situ and laboratory testing carried out during the Knight Piésold (2004) investigation indicated that it was reasonable to assume from the material properties that the tailings are generally non-liquefiable. However as a precaution, Knight Piésold indicated that because liquefaction potential is not easily quantifiable (i.e. liquefaction is unlikely but could occur), their design checks were carried out assuming that the tailings may liquefy if dynamically loaded.

4. Positioning of the structure on a foundation weaker than assumed. The location of the tailings storage facility is in an area shallowly underlain by competent limestone rock (~ 1m below natural ground level). However recent investigations have shown areas where fracture networks have been filled in with weaker sediments – silty, clayey sands, requiring consideration of stability on a weaker foundation.

While the recommended factors of safety are guides, realistic minimum factors of safety must also be applied to the tested failure modes to ensure consistency.

7.2   DESIGN PARAMETERS

7.2.1   EARTHQUAKE LOADING

As a first estimate of the earthquake design loading, the seismic hazard map for South Australia (Australian Standard 1170.4 – 1993 Minimum Design Loads on Structures Part 4: Earthquake Loads) indicates the seismic coefficient for an earthquake having a 10% chance of being exceeded in 50 years (equivalent to a return period of 1 in 475 years) is 0.09 g (see Figure 7.1).

In low seismically active areas, and during earlier stages of a project when considering the suitability of alternatives, it is adequate to use an earthquake loading derived from the Australian Standard. If earthquake loading is a critical design factor, then more detailed analyses are required during the detail design phase.

During the stability review in 2004, Environmental Systems and Services Pty Ltd ((ESS) incorporating the Seismology Research Centre) was commissioned to carry out a seismic assessment of the site (report contained in Knight Piésold (2004).

The ESS report concludes that the earthquake hazard at the Olympic Dam site is quite low by Australian standards. "Long" recurrence intervals exist between all events, both small and large. The maximum credible magnitude for ground motion calculations was set at Mw 7.5, estimated after consideration of the tectonic setting and magnitudes of other large Australian earthquakes. There are several known faults in Australia that are large enough to produce an earthquake of magnitude Mw 7.5[3], and it is possible that other such faults exist and are hidden or not yet discovered. The choice of maximum credible magnitude does not significantly affect ground motion recurrence estimates for return periods up to hundreds of years."

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[3] The largest earthquake felt onshore in Australia struck near Meeberrie in 1941, with a magnitude just exceeding Mw 7.0
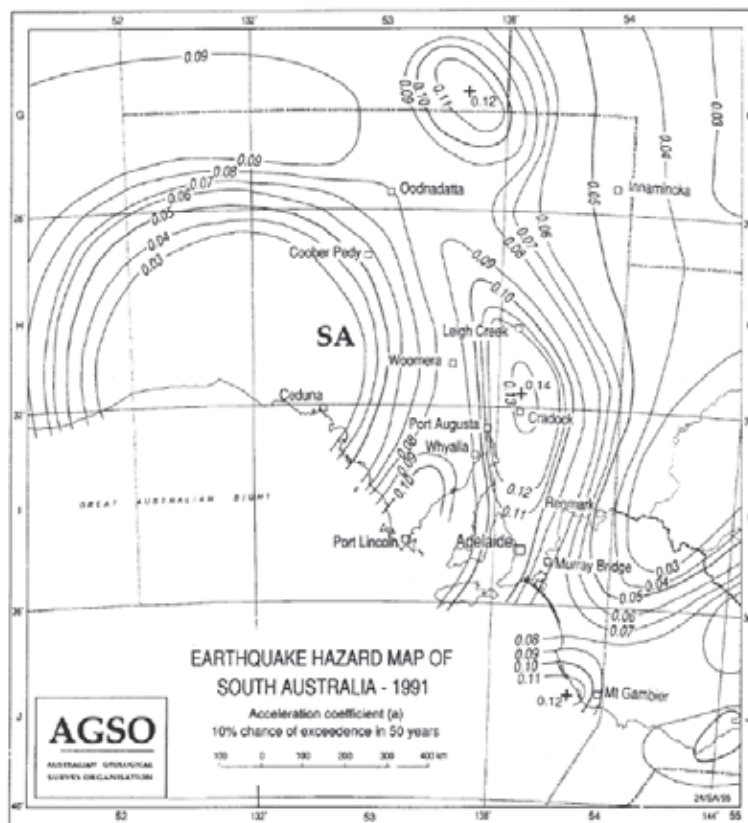
Figure 7.1 Earthquake Hazard Map of South Australia - 1991

The earthquakes considered in the ESS report are predominantly much larger distant events, with longer duration of strong motion – the type of earthquake that can cause damage to massive structures such as TSFs. In considering how various combinations of magnitude and distance contribute to ground motion, the ESS assessment found that in the case of Olympic Dam, the contribution to hazard from earthquakes closer than about 70 km is minimal, with most of the hazard being from larger distant events in the Flinders Ranges and its north westerly extension in the Denison seismo-tectonic zone (see Figure 7.2). Flinders Ranges is one of the more active areas within Australia. Assuming bedrock geology, the distance between Flinders Ranges and Olympic Dam would allow for most seismic waves from Flinders Ranges to be considerably attenuated before reaching the site.

As a guide for the analysis of tailings dams, ANCOLD (1999) suggests that the minimum Operating Basis Earthquake (OBE) should be:

- A 1 in 50 AEP event for low hazard dams

- A 1 in 100 AEP event for significant hazard dams

- A 1 in 1000 AEP event for high hazard dams

AEP means Annual Exceedance Probability. By virtue of the size (40+m height) and potential consequences of failure involved in this project, the new TSFs are classified as "high hazard" dams (see Section 6.3).
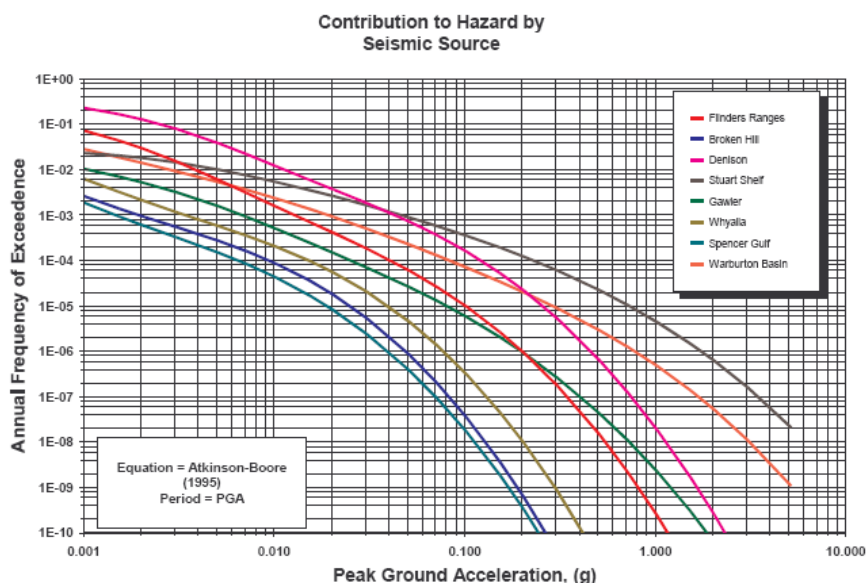
Figure 7.2 Peak Ground Acceleration by Seismic Source
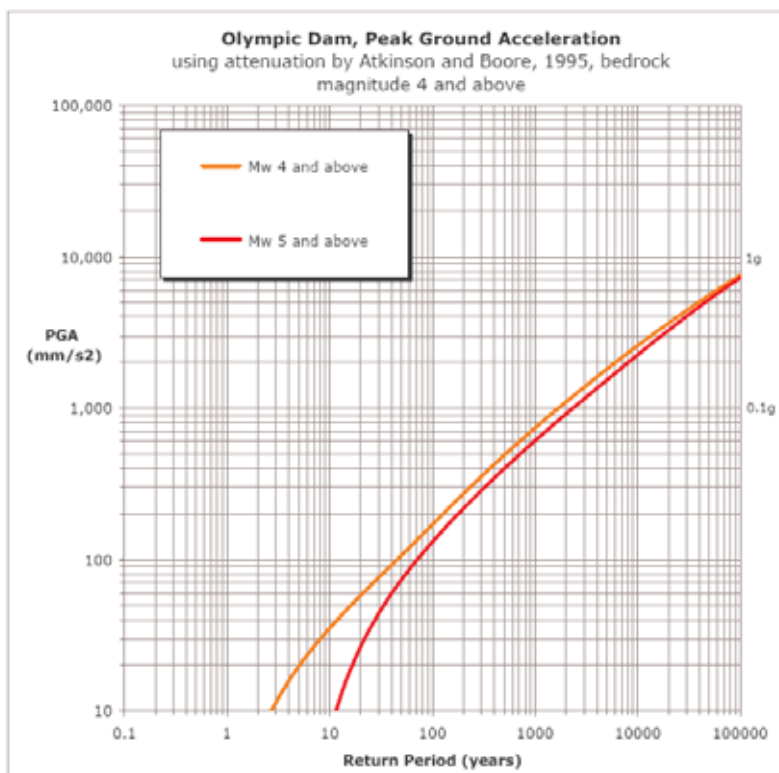
Figure 7.3 Olympic Dam Peak Ground Acceleration

The ESS assessment indicates that the peak ground acceleration for an event with a return period of 1000 years is 0.075g (see Figure 7.3). Knight Piésold (2004) uses a return period of 500 years for the OBE. This is correct for their analysis which categorises the existing facilities as "significant hazard" dams.

For the purposes of the comparative assessments in this study, in order to cover the uncertainty in knowledge, a peak ground acceleration of 0.1g has been used, together with an assumption of at least 50% loss in strength post-liquefaction.

7.2.2   SHEAR STRENGTH PARAMETERS

Strength characteristics of the tailings, embankment and foundation soils are summarised in Table 7.2 (Coffey Metago, 1998) and Table 7.3 (Knight Piésold, 2004). The foundation soils beneath the new cells generally comprise a layer of sandy topsoil overlying clayey sand and clay or sandy clay to depths of in excess of 3m.

Table 7.2 Coffey Metago shear strength parameters

SOIL TYPE	ϕ'	c' (kPa)
Tailings	36	5
Sandy Clay	25	5
Sand Dunes	25	0
Compacted sand dune embankment	30	-
Clayey Liner	25	10

The undrained shear strength of the in-situ tailings is s_u = 11 - 12 kPa   and ϕ_u 29^0

Table 7.3 Knight Piésold shear strength parameters

Material	c' (kPa)	ϕ'	γ_{moist} (kN/m^3)	γ_{sat} (kN/m^3)
Deposited Tailings	0	22–25	17-18	20–21
Embankment Materials				
Compacted Tailings/clayey/general fill	0 to 5	32 to 34	18	21
Crushed Rock	0	40	19	20
Foundation Materials				
Sand Dunes (clayey sand)	5	34	19	20
Limestone Foundation	20	45	20	21

Both Knight Piésold and Coffey Metago comment that the parameters they use are considered conservative.

It is difficult to measure the in-situ shear strength of deposited (undisturbed) tailings using field testing which requires conversion of measurement data into shear strength parameters using empirical equations derived for other materials. There does not seem to be support in the Knight Piésold work, or the results from this investigation, for the high friction angle (36^0) used by Coffee Metago. Triaxial shear tests conducted during this study indicated an angle of friction less than 30^0 for partly consolidated material which is the likely state of stress of the tailings through which the failure surface passes.

The material properties assumed for this analysis are summarised in Table 7.4, which is a consolidated summary of the previous results together with results from the most recent testing. It is evident that the shear strength parameters used in this study would therefore be more "conservative" than the previous studies.

Table 7.4 Shear Strength Parameters for Slope Stability Analyses

Material	c' (kPa)	ϕ'	γ_{moist} (kN/m^3)	γ_{sat} (kN/m^3)
Deposited Tailings	0	25	18	21
Embankment Materials				
Compacted Tailings/clayey/general fill	0	32	18	21
Rockfill	0	37	19	20
Foundation Materials				
Sediments	0	25	19	20
Limestone Foundation	20	37	20	21

7.3   SLOPE STABILITY ANALYSES

A series of slope stability analyses were carried out to determine what possible configuration options would give comparable safety levels. The following scenarios were tested:

1. An upstream raised embankment at 20^0 overall slope to a height of 30m (as in the existing system).

2. An upstream raised embankment at 20^0 overall slope to a height of 40m.

3. An upstream raised embankment at 20^0 overall slope to a height of 40m, with a rockfill buttress providing additional stability.

4. An upstream raised embankment to a height of 40m, with a rockfill buttress providing additional stability, with the overall slope flattened to 15^0.

5. A rockfill centre-line raised embankment at 25^0 overall slope to a height of 40m.

6. A rockfill centre-line raised embankment at 25^0 overall slope to a height of 80m.

By virtue of the increased risk associated with the scale of the expanded facilities, in compliance with ANCOLD (1999), this study applies more stringent loading cases, more conservative shear strength parameters, and increased safety factor passing criteria than the design for the existing system. Therefore the designs are not directly comparable, and no conclusions should be made regarding the acceptability of the stability of the existing system from the results presented in this analysis.

Figure 7.4 illustrates the output from the stability analysis for the normal operating conditions.

The results from these analyses are summarised in Table 7.5.

40 m High Rockfill Embankment
Crest width 10m
Centre-line Raise (25 degrees)

Stability under Normal Loading Conditions
Normal Pool position
Perimeter Drain Operating
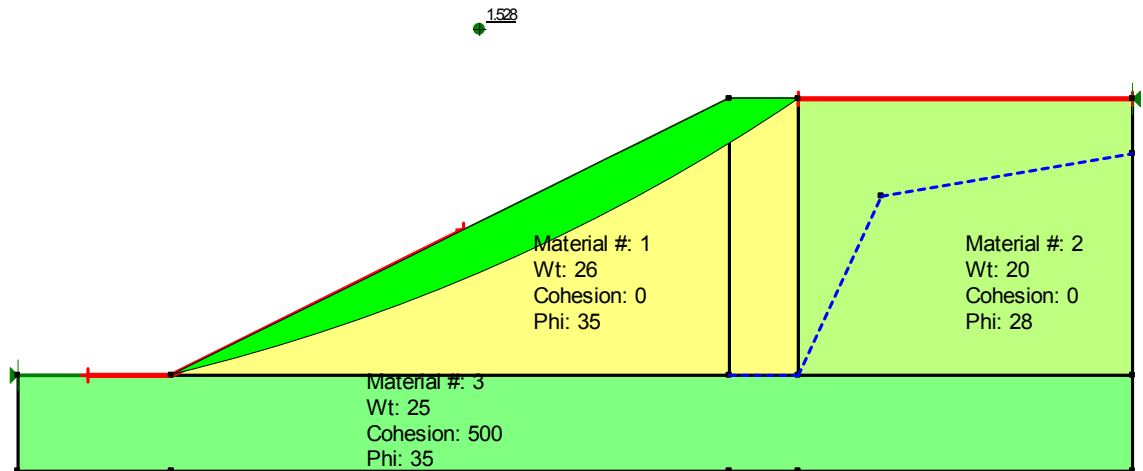
Figure 7.4 Stability of 40m High Rockfill Embankment - Normal Operating Conditions

The stability analysis results indicate that the rockfill embankment is stable under all loading conditions whereas the upstream raised TSF does not meet the stability requirements under seismic loading. In the case of an 80m high embankment, placement of an intermediate step in the outer wall was shown to improve overall stability by a factor of 0.109 (see Table 7.5). However, as the embankment wall will be constructed by a series of rock armour lifts, this increased factor of safety would be achieved anyway.

This appears to be similar for all the upstream raised tailings design cases, where the critical failure surface (the failure surface with the lowest safety factor that passes behind the crest and thus results in a release of tailings) passes through tailings.

Since there is doubt (or a lack of confidence) in the tailings ability to maintain its post-liquefaction strength after a major earthquake event, it is clear that for the embankment heights proposed, the upstream raised TSF cannot match the stability of the proposed centreline rockfill embankment where the critical failure surface passes through the rockfill. The centreline design would retain its strength under all loading conditions. The failure surface would need to pass through the rockfill upstream crest to result in a significant failure.

Table 7.5 Summary of Slope Stability Analyses Results

FACTOR OF SAFETY							
Loading Condition	Upstream TSF (20^0 Slope 30m High)	Upstream TSF (20^0 Slope 40m High)	Upstream TSF with Buttress (20^0 Slope 40m High)	Upstream TSF with Buttress (15^0 Slope 40m High)	Centre Raised Rockfill TSF (25^0 Slope 40m High)	Centre Raised Rockfill TSF (25^0 Slope 80m high)	Minimum Required
Normal Operating	1.36	<u>1.20</u>	1. 57	1.75	1.53	1.46 / 1.57[4]	1.5
High pool					1.31	1.31	1.3[(5)]
Drain failure	<u>1.10</u>		<u>1.21</u>	1.48	Not applicable	Not applicable	1.3[(6)]
Weak foundation				<u>1.19</u>	1.47	1.47[7]	1.5
Seismic loading				<u>0.59</u>	1.20	1.22	1.1

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[4] 80m stability can be improved by addition of 10m mid-height step in the embankment.

[5] The safety factor requirement for high pool condition is set at 1.3 as the modelled phreatic surface is extreme and will only occur after a PMP event. This is therefore an improbable, temporary condition under which it would be acceptable for the safety factor to be similar to construction conditions.

[6] The safety factor for the blocked drain is set at 1.3 as this is also an unlikely condition given the proposed drainage barrier design, and is also a temporary occurrence which will be rectified (or the affected zone modified e.g. with a stabilising buttress), when the symptoms of the blocked drainage conditions are observed.

[7] The results of Weak foundation are shown as a test only and are within the margins of error. The actual soils are defined as the "normal condition". Any weak foundation would be identified and treated during construction to increase FoS to required levels.

8   TSF SURFACE WATER MANAGEMENT

8.1   SITE METEOROLOGICAL CHARACTERISTICS

Rainfall is erratic and heavy rainfall can occur in any month, whilst most years experience periods of two to three months with no significant rainfall. Table 8.1 lists the monthly averages obtained from monthly rainfall and pan evaporation measurements on site. These compare well with average records of weather stations at Andamooka (40 years of records) and Woomera Aerodrome (55 years) and with the Australian Bureau of Meteorology monthly average maps. Over the period of measurement, the average annual rainfall at Olympic Dam was around 150mm, with an average annual Class A Pan evaporation rate of approximately 3,300mm.

Table 8.1 also shows monthly pan to pool and pool to beach factors. The average pan factor around 0.49 is lower than might be expected, but is due to the super saturated state of the liquor due to the content of dissolved minerals in the evaporation ponds where the evaporation factor has been determined. This conservative factor has been used when estimating free surface evaporation from the decant ponds even though the solution is not as concentrated. To put this in context, the higher the evaporation factor; the area required to dispose of the slurry is reduced; which in turn reduces the seepage profile. These values were confirmed by field investigations carried out in 1997 and are the values utilised in the water balance (Gavshon, 1997).

The beach factors have been measured in tests simulating beached tailings, and are higher than the pond factors because of the elevated temperature of the tailings when it is deposited on the beach (~45[0] Celsius) resulting in sustained high evaporation losses from the beach during cooler winter months.

Table 8.1 Average Rainfall and Evaporation

	Pan Evaporation (mm)	Pan Factor	Pool Evaporation (mm)	Beach Factor*	Beach Evaporation (mm)	Monthly Rainfall (mm)
January	463.9	0.48	222.7	1.16	258.3	10.9
February	390.8	0.45	187.6	1.16	217.6	22.9
March	358.5	0.47	172.1	1.16	199.6	2.9
April	254.0	0.45	121.9	1.58	192.7	6.2
May	166.8	0.53	80.0	2.63	210.5	5.0
June	104.6	0.55	50.2	4.20	210.9	17.8
July	113.2	0.48	54.3	3.36	182.5	6.7
August	152.7	0.50	73.3	2.52	184.7	10.4
September	208.4	0.51	100.0	1.68	168.0	12.0
October	302.0	0.49	145.0	1.16	168.2	19.3
November	357.0	0.46	171.3	1.16	198.8	20.8
December	417.6	0.47	200.4	1.16	232.5	14.0
Total	**3289.4**		**1578.9**		**2382.3**	**148.9**

* As a function of pool evaporation

Long sustained periods of intense rainfall are rare. However, large falls can occur over short periods due to thunderstorm activity.

The 1-in-100 average return interval (ARI) rainfall event (Table 8.2) is 155 mm over a 72 hour period and the 1-in-500 ARI event is 272 mm over a 12 hour period. Rainfall Intensity-frequency duration data for design of stormwater management systems are as tabled (Gavshon, 1997), together with the probable maximum precipitation (PMP).

Table 8.2 Statistical Precipitation Figures

Average Return Interval (years)	5-minute duration storm (mm/h)	12-hour duration storm (mm/h)	72-hour duration storm (mm/h)	Maximum Precipitation (mm)
1	42.2	1.80	0.42	30
50	172.0	8.34	1.80	130
100	204.0	10.10	2.16	155
500	395.0	22.70	3.34	272
Probable Maximum Precipitation (PMP)			800mm	

8.2   STORM FREEBOARD PROVISION

The design intent is that no water will be released from any of the storage facilities under any condition (zero release principle). All water containing structures will be sized to contain all inputs without overtopping. For the final sizing, a probabilistic analysis will be done using the final process water balance inputs combined with historical and future potential rainfall events. There is also a commitment in the existing operation Emergency Response plan to stop production if this is necessary to prevent an uncontrolled release.

ANCOLD[4] minimum freeboard allowances for high hazard category dams are as follows:

The operating freeboard must accommodate:

1.   A probable maximum flood (PMF) on top of highest pond level in normal year or

2.   The worst wet season on record plus 1 in 100 year AEP storm plus waves, plus a contingency allowance of 0.5m.

To check the adequacy of the facility, the assumed worst case for overtopping is when:

1.   A raise is about to commence and the top of the beach tailings level is coincident with the crest[8].

2.   The 1:100 AEP – the probable maximum precipitation (PMP) event – estimated at 800mm occurring on the highest pond level equivalent say to a 1 in 100 year storm event on top of the normal operating pool level.

With a beach slope of 1% and cell size of 1850m (the beach slope is likely to be more than 1%, not less) a beach length of 725m (925 m less 200m for operating pond) provides a freeboard of 7.25m. This is the minimum freeboard which will occur for normal operating pond position, just before a raise.

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[8] Operating risk management procedures (DOIR, 2006) require at least 0.5m tailings freeboard to ensure that tailings do not spill backwards over the crest. Therefore there is always an additional 0.5m freeboard between the top of the beach and the embankment crest.

The storage capacities required for the storms considered are:

1. For a 1 in 100 year storm of 155mm, the volume of rainfall from the PMP to be contained on each cell is 530,000m^3.

2. For a probable maximum precipitation of 800mm, the volume of rainfall from the PMP to be contained on each cell is 2,738,000m^3.

Figure 8.1 illustrates the "bowl" in which the water is contained. The figure illustrates that after the PMP on top of the 1 in 100 year storm, there is still 3m freeboard remaining with significant volume, with the edge of the pool some 300m from the crest, providing more than sufficient safety margin.
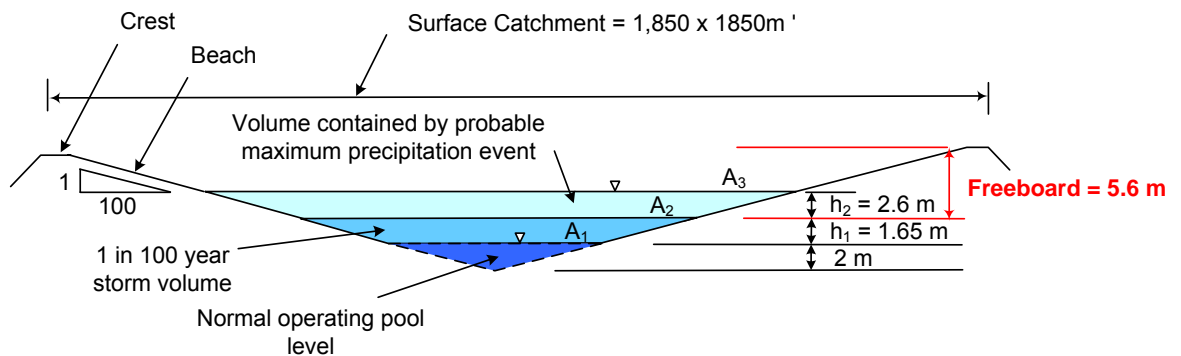
Volume contained by 1 in 100 year = $(A_1 + A_2) \div 2 \times h_1$ = 530,000 m^3

$\rightarrow$ $h_1 \approx 1.65$ m

Volume contained by PMP = $(A_2 + A_3) \div 2 \times h_2$ = 2,380,000 m^3

$\rightarrow$ $h_2 \approx 2.6$ m

Figure 8.1 Illustration of Available Freeboard

To fully illustrate the safety margin available in the proposed system, the case of two PMP events occurring in succession has been tested. While this may be inconceivable, a similar case could be argued for a single PMP occurring when the pond is high after a 1 in 100 year storm on top of a higher than normal rainy season, combined with problems in the plant which have caused additional water volumes on the dam. Such highly improbable, but conceivable scenarios have occurred resulting in wall failures at other operations.

For this case, there is a much larger base area containing the PMP volume (1,250m x 1,250m), and the rise in water level for the same PMP volume would be only 1.6m, with a further 1.4m remaining freeboard illustrating that the chosen configuration would also safely accommodate two successive PMP's on top of the 1 in 100 year storm.

8.3   TSF WATER BALANCE

Figure 8.2 illustrates the various elements included in the water balance for the tailings retention system.
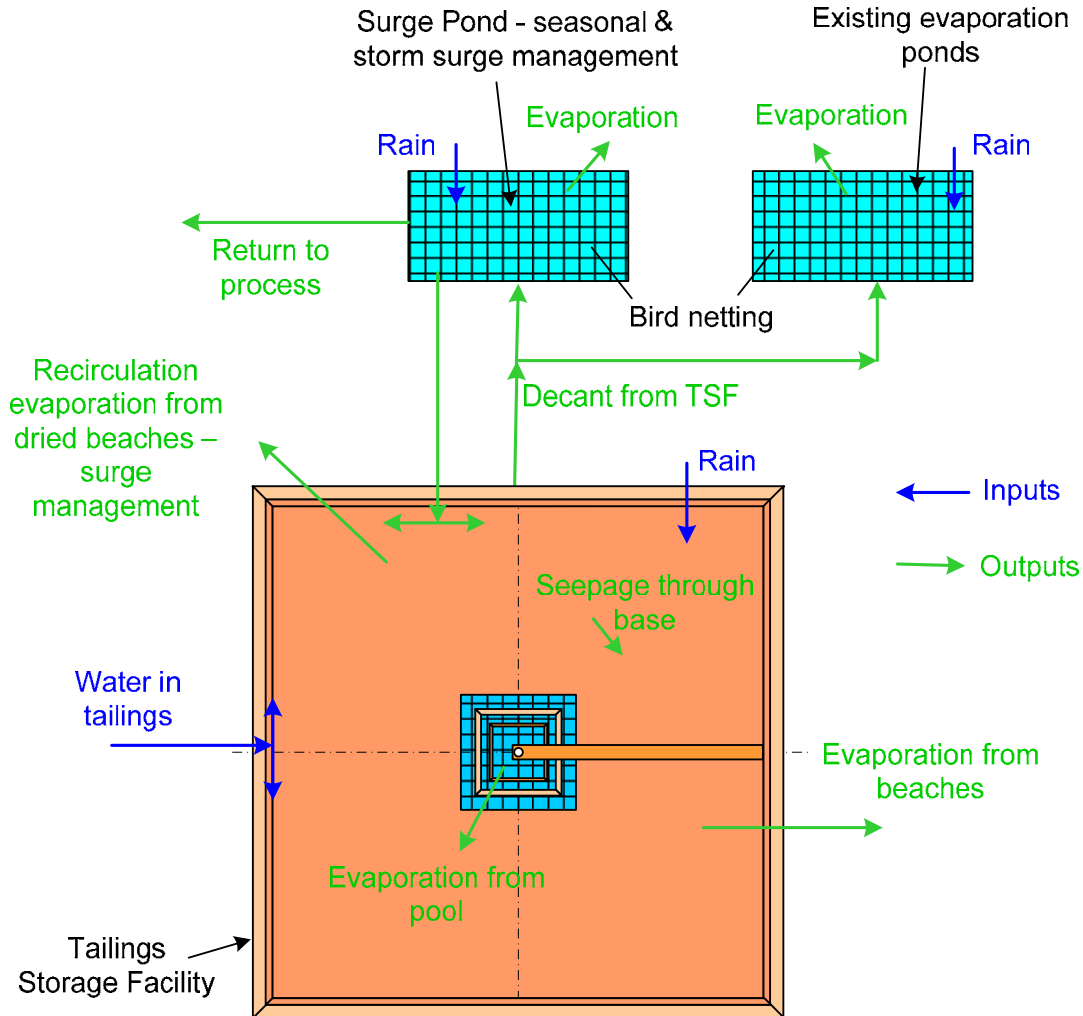
Figure 8.2 Schematic TSF Water Balance

A step-by-step spreadsheet water balance model has been developed for the tailings storage system (represented schematically in Figure 8.3 and Figure 8.4) and calibrated using more than 10 years of operating data collected for the existing tailings retention system. Detailed testing was also done on the tailings beaches during the 1997 expansion study.

It is intuitively obvious that the tailings mineralogy and physical properties have varied since the 1997 study. With further expansion of the mine, the tailings constituents will evolve, thus affecting the overall water balance. Recommendations to continue testing annually are being incorporated to accurately define the geochemical properties of the tailings slurry. The current TSF design allows for subsequent changes in deposition patterns to be made, which maintain an effective hydrological flux. This can be achieved by either:

1. Utilising the extended area of the new TSF and spreading tailings more thinly over a larger footprint. This will increase evaporation and subsequently the deposited solids density, or

2. Increasing the deposition rate upon one sector of the cell, thus increasing compression upon successive deposited layers. This reduces the permeability in the tailings pile and increases overall stability.

The current water balance model considers an average scenario where a layer of tailings are deposited on the beach and the subsequent solids density increases as water is removed from the layer. Figure 8.3 illustrates the "deposition" cycle for each cell at a deposition rate of 10 Mtpa and a target "dry beach depth" of 200mm. The actual beach thickness varies depending on operating conditions, but typically for thin layer deposition at OD where partial saturation is achieved in each layer (i.e full utilisation of the evaporation potential), the layer depth should not be thicker than 250 to 300 mm.
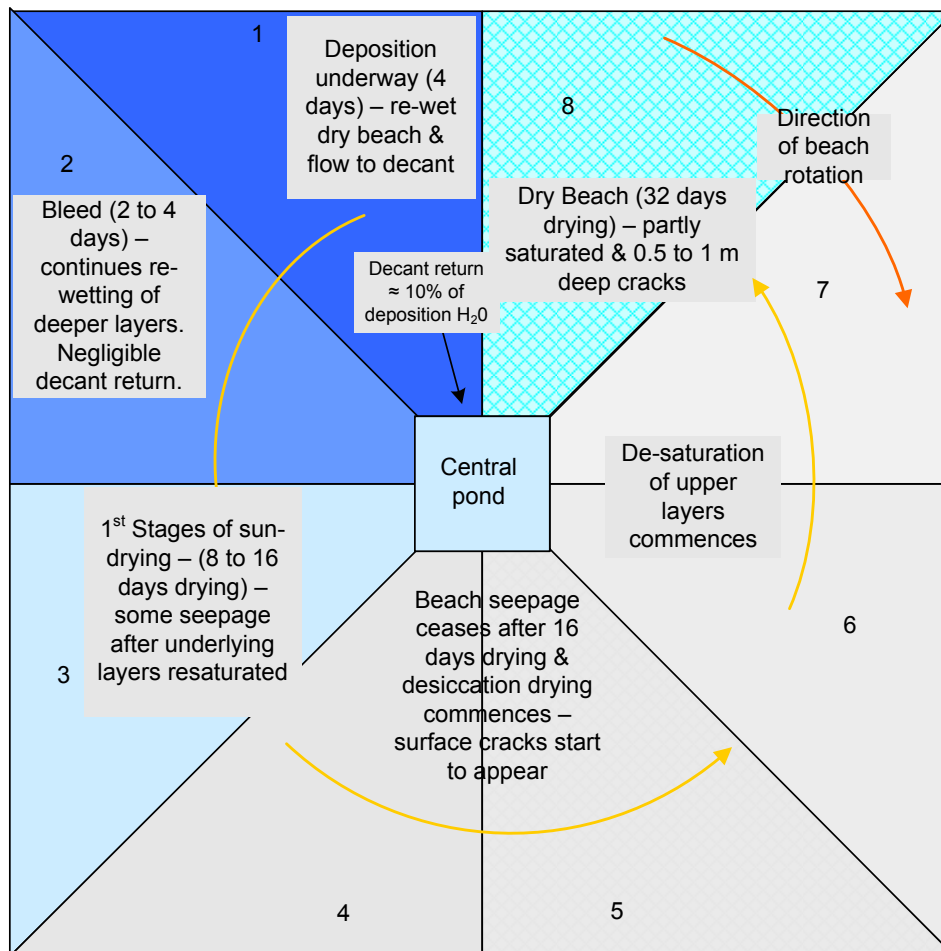
Figure 8.3 Forty-eight Day Beach Deposition/Drying/Desiccation Cycle

Each segment (1 to 8) receives tailings over a 4 day period, after which it is allowed to dry (Figure 8.4). This is also a practical measure as the 4 days deposition allows valve changing on each cell every 5th day. In practice the rotation is unlikely to follow the numerical sequence shown. It is necessary to control the pool position by depositing from the opposite side i.e. segment 5 after segment 1 to push the pool back over the centre. However, the overall effect is that al segments are deposited and allowed to dry, before the next layer is laid down.

At least 10% of the surface of the facility is "active" at any time to achieve this layer rotation and deposition. On active beaches, drainage of water down the slope to the decant pool and evaporation during deposition, result in an increase in the "post-deposition" solids density". At a tails slurry solids concentration of 45% , the average post-deposition solids density has been measured at around 60% (higher at the top of the beach and lower towards the pond) which

corresponds with a moisture content around 70%. At this solids concentration the tailings have little shear strength which develops in the remainder of the cycle.

Figure 8.3 illustrates each step of the model where water is removed from the deposited tailings layer by the following processes:

1. To wet up the underlying partially saturated dry beach as tailings flows over the previous layer. The volume of water taken up is equal to the volume required to re-saturate the underlying layer(s).

2. Decant reports to the central pond as tailings solids which are deposited on the *"active"* beach. For a given deposition solids concentration and beach and pool setting, the decant volume must match a measured decant volume in the case of the existing system, or a realistic estimate for the expansion case.

3. Through evaporation which occurs at different rates in the different drying phases:

    a. At higher than the free water-surface evaporation rate (the "beach evaporation rate in Table 8.1) from the "active" beach because of the elevated temperature of the tailings. For the modelled case, evaporation at this rate occurs over the active beach occurs for the 4 day deposition period.

    b. At the free water-surface rate during the period immediately after deposition and lasting 2 to 4 days when the tailings are still settling (as opposed to consolidating) and free-water rises to the surface (called "bleed"). The evaporation rate during this period is assumed to be about the same rate as during the four day deposition cycle.

    c. During the early stages of drying once the "bleed" process has finished, and lasting around 8 days, when most of the water is still loosely bound in the tailings and can be easily evaporated, but evaporation is nevertheless hindered. During this phase, an evaporation rate of 40% is assumed[9].

    d. During the later stages of sun drying when the pore water becomes more tightly bound. A hindered settling rate of 25% is assumed. Observations indicate that drying for this period of time will achieve partial saturation, and that there is still likely an excess evaporative potential available i.e. the beaches could conceivably be used to evaporate excess water and reduce pond size more rapidly after storms and high rainfall seasons.

    Through seepage which occurs when:

    e. The underlying desiccated tailings layers have been re-saturated and there is excess water available in the unconsolidated tailings layer to freely gravitate downwards. The model allows for seepage by determining the excess water available during a given period, which is not withdrawn by evaporation i.e. seepage logically occurs when the volume evaporated is less than the volume available for evaporation. The potential for "beach" seepage ends when evaporative drying de-saturates the tailings, and under the resulting suction conditions, there is no more free water available to seep downwards unless rainfall re-saturates the upper layers.

    f. From rainfall infiltration – which has the same effect as described in i. If there is excess water after rainfall has re-saturated the tailings layers, seepage occurs. This is allowed for in the model by reducing the evaporation rate by the net annual rainfall (145mm) less an estimate for runoff (80mm) which is the rainfall in excess of 5mm/month (used in re-saturation the beach) which occurs in months where rainfall exceeds 10mm/month.

    g. From the elevated pond central pond. The seepage varies with the size of the pond, and also depending on the seepage controls which are in place. Because the seepage from the pond interacts with seepage and rain from the beach, and because the tailings are not homogeneous (they are layered, and drying effects and particle size differences cause property differentials both within a layer (coarse at the bottom, fine at the top) and

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[9] The evaporation rates must ensure that all aspects of the water inventory are in balance. These rates must also match rates observed in field tests.

along the beach (coarse at the top, fine near the pond)), the seepage from the pond cannot simply be estimated by estimating the steady state seepage from the beach alone.

h.   The pond balance for the existing system (45% deposited solids concentration) indicates that around 8 to 10% of all the water entering the pond is lost to seepage[10]. The volume of seepage would reduce when the deposition solids concentration is increased to 55% (less water available for seepage), and when improved seepage control measures are installed. For the expansion case, the seepage from the pond is left at 8% to 10% of incoming water.

i.   In the longer term, from consolidation when the successive layers of tailings surcharge the earlier layers. The additional load squeezes water from the tailings which then contributes to seepage. The model does not consider consolidation seepage as the quantity of seepage (40mm for the highest loaded layer) occurs over a 20 year cycle at about 0.3mm per drying cycle which is negligible compared with the 185mm of water lost from each layer during the deposition cycle (Figure 8.4).

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[10] The water inventory of the pond must also balance. Therefore the seepage can be estimated from the balance using evaporation data.
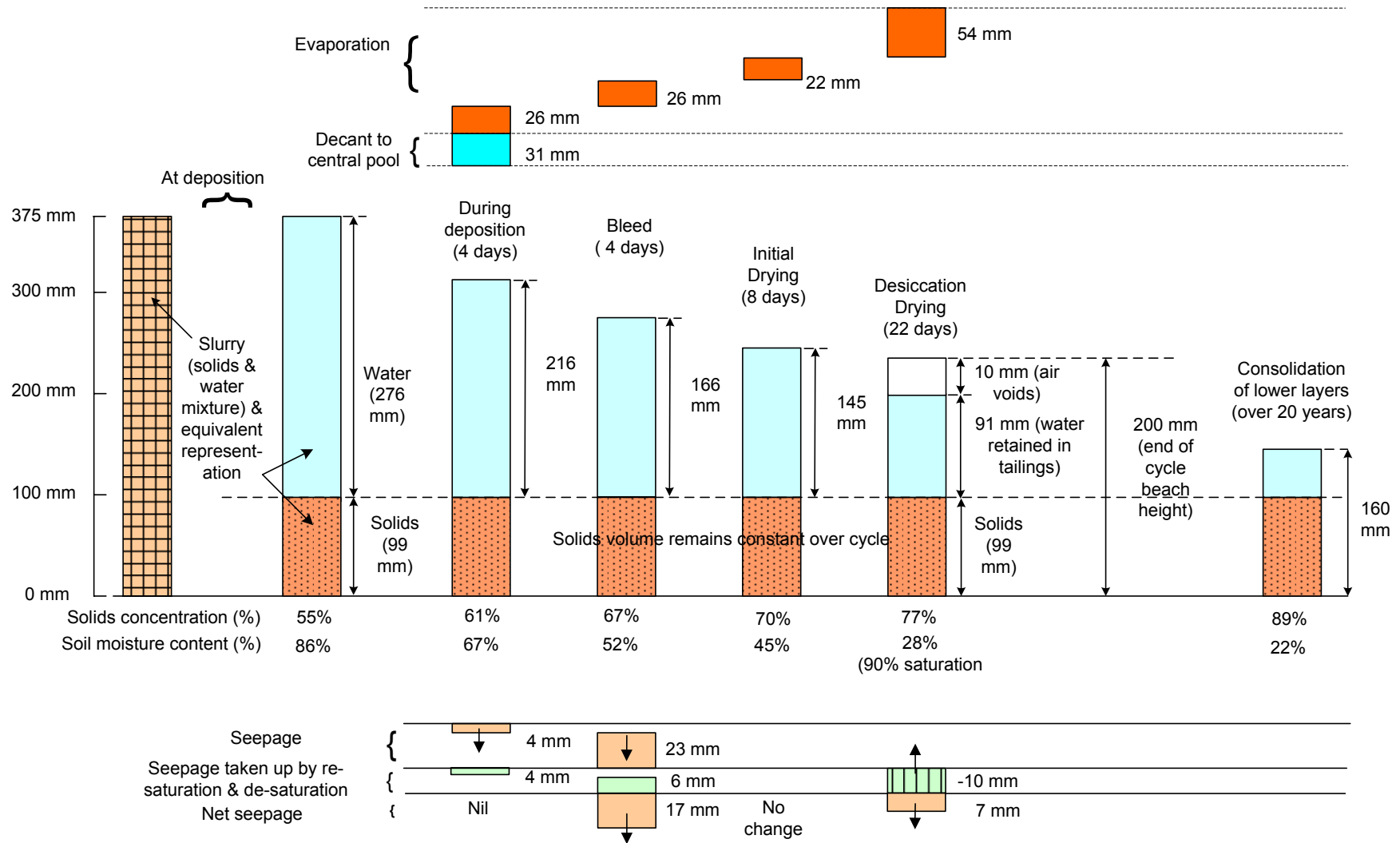
Figure 8.4 Step-by-step Volume Changes for 200 mm Tailings Layer during 48 Day Deposition/Drying/Desiccation Cycle

8.4   AVERAGE STEADY STATE WATER BALANCE SIMULATIONS

Tables 8.3, 8.4, 8.5 and 8.6 illustrate the average water balance simulations for the existing system (at 45% and 48% solids deposition densities) and the proposed expansion TSF. This balance is based on the "worse case" scenario where the Hydromet plant receives 65% solids concentration paste thickener tails from the Concentrator. The design case is 70% solids where significantly more liquor is returned from tailings for dilution in the Hydromet plant and subsequently, the TSF size is significantly smaller with 8 * 1850m cells as opposed to this case of 9 * 2000m cells.

Table 8.3 summarises the TSF water balance, while Table 8.4, Table 8.5 and Table 8.6 summarise the central, evaporation and surge pond balances i.e. the key components making up the TSF balance.

Table 8.3 TSF Water Balance

	Existing Operation		Expansion[11]
Tailings Tonnage (Mtpa)	10	10	68[12]
Deposition Solids Concentration (%)	**45**	**48[13]**	52.9
Number of tailings cells	3[14]	3	9
TSF Balance			
Into TSF	kl/day	kl/day	kl/day
From Process	30,700	27,200	144,900
Rainfall	1,500	1,500	14,500
Total In	32,200	28,700	159,400
Out of TSF			
Retained in deposited tailings	8,300	8,000	62,300
Evaporation/re-saturation	17,700	14,800	85,200
Seepage[15]	2,100	1,900	3,600
Decant to Evaporation Pond[16]	4,100	4,000	0
Decant to Balance Pond	0	0	8,270
Total Out	32,200	28,700	159,400

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[11] Existing cells are likely to be close to their end of life when expansion starts up. Hence the expansion TSF has been designed to accommodate the full expansion capacity.
[12] Based on 72.3 Mtpa production, 68 Mtpa reports as solids to tails disposals

[13] Increase in solids density achieved through 2007 Water Conservation Project system improvement.
[14] Cells 2 and 3 are combined into a single Cell 2/3.
[15] The seepage quantity shown in the table is used as the input into the ground water seepage analysis.
[16] Evaporation area increases with construction of EP5 at end of 2007.

Table 8.4 Central Pond Water Balance

Pool Balance	Existing Operation		Expansion
In	**kl/day**	**kl/day**	**kl/day**
Decant from beaches	5,750	4,700	2,170
Rain runoff beaches	1,050	1,050	10,400
Incident rain	200	120	330
Total In	7,000	5,870	12,900
Out			
Pool evaporation	2,200	1,300	3,500
Seepage	700	640	1,100
Decant to Balance Pond	0	0	8,300
Decant to Evaporation ponds	4,100	3,930	0
Total Out	7,000	5,870	12,900
Pond Size (diameter (m)	450	350	300 square

Table 8.5 Evaporation Ponds Water Balance

Evaporation Pond Balance	Existing Operation		Expansion
In (Net)	**kl/day**	**kl/day**	**kl/day**
From TSF	4,100	3,930	0
Rain	470	400	0
Total In	4,570	4,330	0
Out			
Evaporation	> 4,570	> 4,330	0
Evaporation Pond Size	105 Ha	100 Ha	0 Ha

Table 8.6 Balance Pond Water Balance

Balance Pond Balance	Existing Operation		Expansion
In			**kl/day**
From TSF decant	Not applicable	Not applicable	8,300
Raffinate Bleed			16,400
Incident rainfall			250
Total In			24,950
Out			
Evaporation			2,600
Return to OD Process			0
Return to ODX Dilution			23,500
Surplus (+ve)/Deficit (-ve)[17]			-1,150
Total Out			24,950

8.5   VARIABILITY AND UNCERTAINTY IN WATER BALANCE

The values shown in the table are average values calculated for average annual meteorological (rainfall and evaporation) and beach drying and wetting characteristics.

In reality, the accuracy of the operational water balance will vary within seasonal and operational ranges. Infrequent extreme storm events (and droughts) or process plant perturbations will also cause variations in the inventory and the balance.

A shortage of water from the TSF is an indication that the TSF is surpassing requirements for water risk management. Make-up water will be required in this case.

In retaining the existing evaporation ponds to manage potential out-of-balance events and storms, the refined design has a contingency capacity of some 25% (average 4,400kl/day evaporation capacity compared to an average decant output of 17,600 kl/day).

Nevertheless, the water balance is sensitive to the various inputs, and can be expected to be accurate to around 10% at best during operation (the figures in the tables are quoted to 1kl accuracy for simplicity only).

During the detail design phase, the water balance will be optimised to maximise both the tailings slurry deposition solids concentration and the recycle liquor quantity in order to minimise the quantity of "fresh" water used. This will be done in detailed consideration of the soluble salts load (iron sulphates, chlorides etc) which are bled from the process into the tailings system. If these are not entrained in the deposited tailings, they can influence the process, and thus may at times limit the quantity of recycle until the salt load is diluted back to a usable concentration.

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[17] A deficit signifies extra evaporative capacity available

Also, contingency controls to manage various out-of-balance scenarios will also be investigated and developed, for example the ability to recirculate excess water over unsaturated beaches during hot weather.

It is clear from the water balance (45% compared with 52 - 55%) that a significant reduction in seepage can be achieved by ensuring as high a target disposal solids concentration as possible, combined with recycling of surplus decant water to the plant. Because of the size and in-homogeneity of the TSF system, there will always be uncertainty involved in calculating the water balance, and hence the need to manage various operational scenarios.

The calibration of the model using 10 years of historical data, provide an element of support for the simulations. Nevertheless, it is important to acknowledge potentially significant unpredictable variations in the water balance inputs (weather conditions, process plant outputs), as well as uncertainty in assumed parameters (evaporation rates, seepage rates etc) for which the system needs to be able to manage. Table 8.7 lists the potential risk issues associated with the water balance, and the measures available to better quantify, eliminate the risk, or provide contingency capacity to manage the risk. The risk issues have common consequences, being excess water inventory, larger central ponds, and increased seepage.

It is noted that while improved confidence and reduced uncertainty will increase the confidence in risk management, none of the issues noted will significantly or materially change the proposed design. Nevertheless further work will be carried out during the detailed design phase to improve the confidence in the process, the TSF water balances, and the controls and contingency measures to manage these.

Table 8.7 Management of Water Balance Uncertainty

Risk Issues	Potential Consequences	Available Controls
High rainfall Low evaporation – overestimated evaporation parameters High process output (unidentified bleed streams, solids concentration lower than target)	Excess water inventory, larger TSF central pools, increased seepage Ground water level rises above 80m AHD in the underlying aquifer.	Additional contingency TSF cells increase evaporation drying Probabilistic process water balance – modelling realistic operating and meteorological ranges and events. Hydrogeological testing, depressurising bores. Larger surge pond to accommodate variability Recirculation system – respreading excess water over dry beaches when excess evaporative capacity available Using existing evaporation ponds to manage commissioning period and plant perturbations Key operations performance objectives around water usage & conservation – opportunities for water treatment &/or re-use Treatment of water to quality required for recycle
Incorrect seepage parameters 1. From pond 2. From beach	Increased seepage into groundwater Excess water inventory Seepage mound beyond predicted extents	Sensitivity analysis for increased seepage from TSF (up to 100%) to determine maximum mound extents Risk assessment to check risks associated with larger mound Monitoring system with lead indicator triggers Contingency plan to extract groundwater (using production bores) if required to control mound
Incorrect predictions of deposition phase densities (e.g. assumed post deposition solids density is higher, implying more water reporting to decant)	More decant than predicted Excess water inventory Increased seepage	Increased recycle to plant Additional TSF cell – increased evaporation Additional surge pond Recirculation system – respreading excess water over dry beaches when excess evaporative capacity available Disposal in bird netted evaporation ponds Treatment of water to quality required for recycle

9   HYDROGEOLOGICAL MODEL

9.1   CONCEPTUAL HYDROGEOLOGICAL MODEL

Figure 9.1 illustrates the conceptual hydrogeological model for the proposed expansion TSF in relation to the groundwater system response in the vicinity of the existing TSF, known geology, groundwater flow controls, and the predicted groundwater response to the open pit void. The conceptual model forms the basis of the numerical model, developed to aid in the prediction of the groundwater flow. The conceptual hydrogeological model is represented by the following sequence:

1.   During planned life of mine (0 to 100 years), separate saturated mounds form within the tailings (perched) and potentially within the sediments overlying the Andamooka Limestone.

     The extent of the TSF mound is determined by the seepage within the TSF and by "intermittently" saturated zone, i.e. the parts of the beach that are wet up during deposition, but are sufficiently desiccated during the drying cycle to cause partial saturation (Figure 8.4).

     Seepage will occur from the tailings into the underlying unsaturated sediments beneath the tailings. The seepage will eventually generate a subtle groundwater mound within the calcareous sediments and the Andamooka Limestone. The rate of mound development and lateral distribution and depth will be determined by the quantity of seepage from the TSF, and by the permeability contrasts within the shallow sediments (discontinuous clayey sequences) and the Andamooka Limestone.

     A seepage mixing zone develops in the vicinity of the TSF, in which the groundwater chemistry is changed when seepage percolate from the TSF mixes with the surrounding groundwater system by dispersion and diffusion, locally changing the groundwater chemistry. Saturated and unsaturated flow through the calcareous sediments in the mixing zone would lead to the effective neutralisation of the percolate and attenuation of the metals for as long as excess neutralisation capacity remains. The zone of percolate neutralisation is referred to as the "attenuation zone". Sorption and co-precipitation are secondary mechanisms that also contribute to solute removal in the attenuation zone. The attenuation zone extends to where percolates diffusion can be detected.

2.   After closure (100 to 500 years), the perched TSF mound and the groundwater mound begin to recede as a result of the shutting down of the seepage by the closure capping. Indications are that the recession of the tailings mound would be quite rapid (Draft EIS, Appendix K6). During this period, contained seepage water is neutralised further thereby reducing the size of the "attenuation" zone.

3.   In the long term (500 years), the mounds recede further and the groundwater moves towards the open pit void, where neutralised seepage is discharged through evaporation on the pit walls. Downward vertical leakage into the deeper groundwater system also assists in the reduction of the mound. Groundwater flow directions and the mixing zone distribution may be influenced by geochemical changes and potentially by other influences such as seepage from the rock storage facility RSF to the east which could modify the response of the groundwater mound.

     Preferential flow can develop through geological structures, geological anomalies, or possible alteration of the geological structure by water and geochemical interactions. Preferential flow structures are likely to exist and could locally modify groundwater flow in the vicinity of individual TSF cells. Groundwater contours for the Andamooka Limestone and underlying Arcoona Quartzite aquifers indicate an almost radial response to groundwater stresses (existing TSF and underground operations), indicating that any preferential flow structure would be well connected on a larger scale (overall TSF footprint), limiting the irregular dispersion and diffusion of the mixing zone. A well connected aquifer system would be conducive to various groundwater mitigation strategies, if required. The presence and extent of preferential pathways are being investigated further, but allowance for this possibility has been incorporated in the design and analysis by:

     1)   Plan for rigorous foundation investigations to identify and treat preferable flow paths. While the tailings will effectively seal off the seepage supply to these preferential flow paths, there is a risk that continuous or interlinked structures could increase dispersion.

2) Identification of doline structures which could present a construction hazard. Voids have been detected in the Andamooka Limestone during previous drilling and are likely to exist across the new TSF area. These structures must be identified using survey techniques such as GPR to reduce the risk of structure collapse.

3) Designing monitoring plans around the occurrence of preferential seepage paths. These should also take into account the results of continued geochemical modelling to define the most likely seepage flow paths.

4) Performing numerical modelling and uncertainty analysis on the expected case, and testing the sensitivity of the model to extreme ranges of seepage in combination with rock hydraulic parameters and attenuation capacities.

This will ensure that the prediction incorporates the potential risks, and that operation monitoring and management plans can mitigate any potential issues before they become unacceptable.
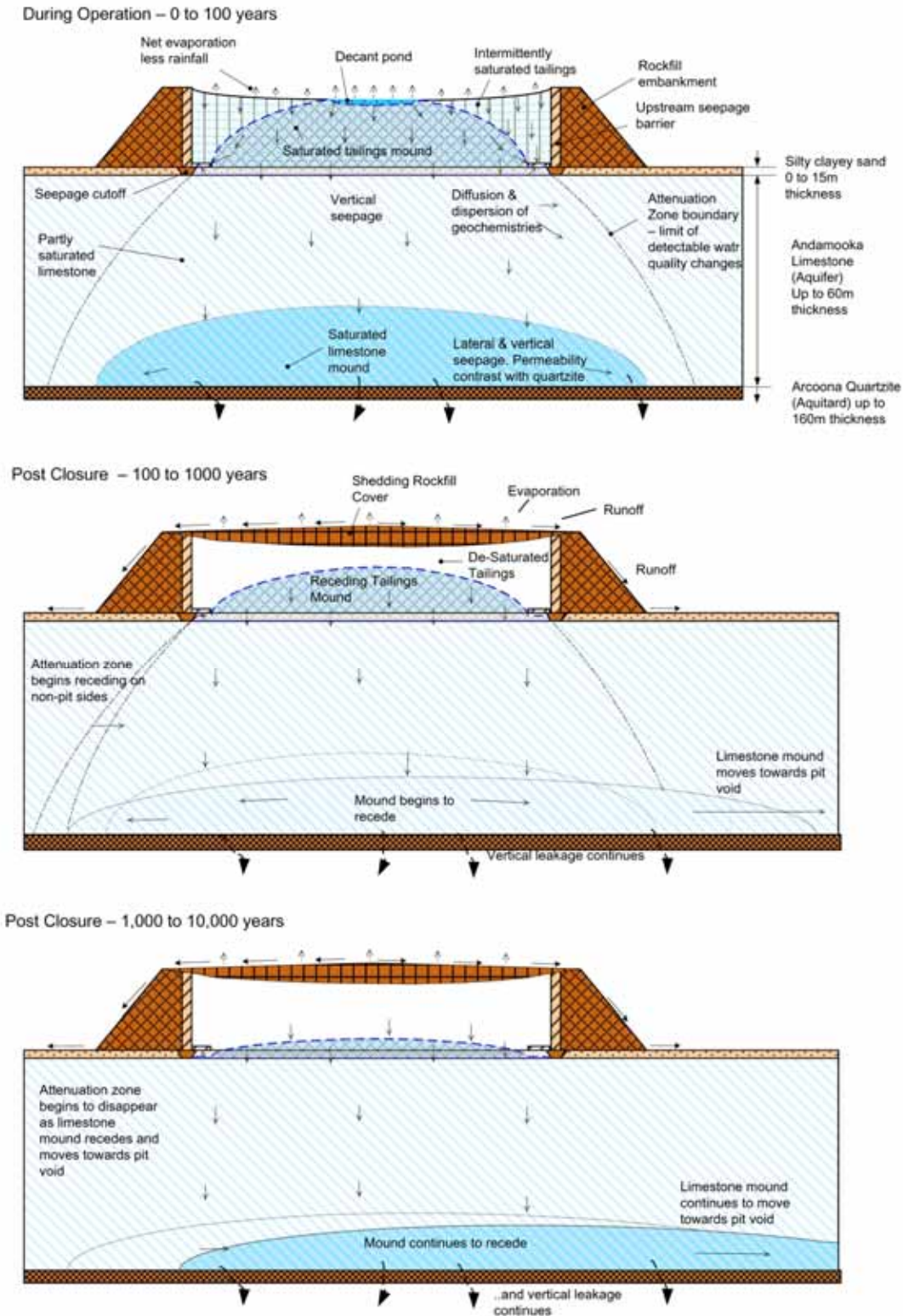
During Operation – 0 to 100 years

Post Closure – 100 to 1000 years

Post Closure – 1,000 to 10,000 years

Figure 9.1 Conceptual Groundwater Model over Indicative Timeframes

9.2   NUMERICAL SEEPAGE MODELLING

9.2.1   INPUT - SEEPAGE FROM TSF

The seepage from the TSF derived from the TSF water balance simulations in Section 8.4 are the input into the groundwater numerical model.

The seepage estimates were carried out using the design parameters (section 6.2) to ensure that these realistically represent a steady state system. The initial seepage during commissioning are conservatively estimated to be $4m^3$/Ha/day but after steady state is achieved, the seepage is modelled to drop to about $0.88m^3$/Ha/day. Figure 9.2 illustrates a steady state seepage model where the beach seepage (distributed uniformly across the beach) is combined with the pond seepage through a heterogeneous system ($k_h/k_v = 10$) and then released across a uniformly permeable base[18]. The system was modelled in SeepW and supports saturated and unsaturated flow conditions prevalent in a cell.

Worst Case Seepage Model - Phreatic Surface Extends to Outer Drain

40m High Embankment
200m Diameter Pool
kh/kv = 10
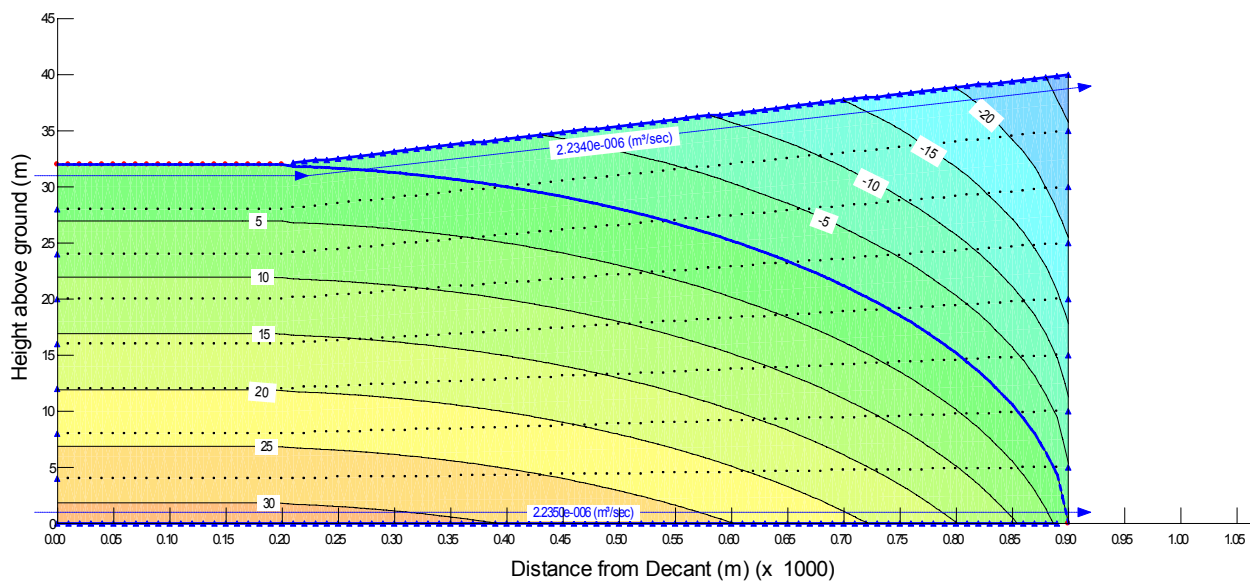
Figure 9.2 Seep/W Simulation of Steady State Combined Beach and Pond Seepage

9.2.2   GROUNDWATER MODEL

A numerical groundwater model has been developed as a tool to aid in the identification of potential impacts and seepage management requirements. The model incorporates other

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[18] The affects of the liner and underdrainage are ignored as these are difficult to model and give overly optimistic results as the seepage biases towards the underdrain. Therefore the uniform representation shown has been adopted despite this being conservative.

groundwater stresses and solute sources influencing the regional groundwater system, such as groundwater discharge to the pit and seepage through the base of the RSF.

This model and technical report (Draft EIS, Appendix K6) builds on several earlier models which have been developed and calibrated over a number of years. The results of these earlier models have been reported in the Olympic Dam Annual Environment Reports.

Key conclusions are summarised below. The context, setting and basis of recent modelling is not discussed here, as readers interested in the development, calibration and full results of the groundwater model are referred to the full report (Appendix K6 and Draft EIS Chapter 12) to appreciate the detail therein.

The model has been used as a tool to aid in the predictions of potential changes to groundwater flow and mixing zones. The numerical groundwater modelling assumes porous flow media, relative isotropic flow conditions and therefore the results delivered from numerical models must therefore be analysed with recognition of the uncertainty introduced by such assumptions.

The modelled scenarios simulated various seepage rates for the TSF and RSF to address uncertainty in hydraulic parameters and attenuation capacities. The results demonstrate that under likely scenarios the development of a groundwater mound and the surrounding attenuation zone from the expanded TSF and RSF will be constrained by leakage to the lower aquifer system. Percolate from the TSF will be captured within the radius of the long term cone of depression induced by the deeper groundwater system (Corraberra Sandstone or lower Arcoona Quartzite). Seepage will not migrate with the regional groundwater flow north-east toward Lake Torrens. Attenuation of the seepage percolates within the calcareous sediment will also limit the diffusion and dispersion.

The modelling (Figure 9.3) suggests that under likely groundwater flow scenarios the groundwater levels in the Andamooka Limestone will take between 50 – 100 years to decline below the pre-mining levels and between 100 – 500 years to stabilise at new lower levels.

Figure 9.3 illustrates steady state groundwater flow paths after closure. Due to the attenuation properties of the Andamooka Limestone outlined in section 4.11.5 (and Draft EIS, Appendix K4), much of the radionuclides and heavy metals will be removed from any residual seepage by the time it reaches the pit.

Numerical modelling indicates that the attenuation zone is likely to be limited to a confined area below the TSF.
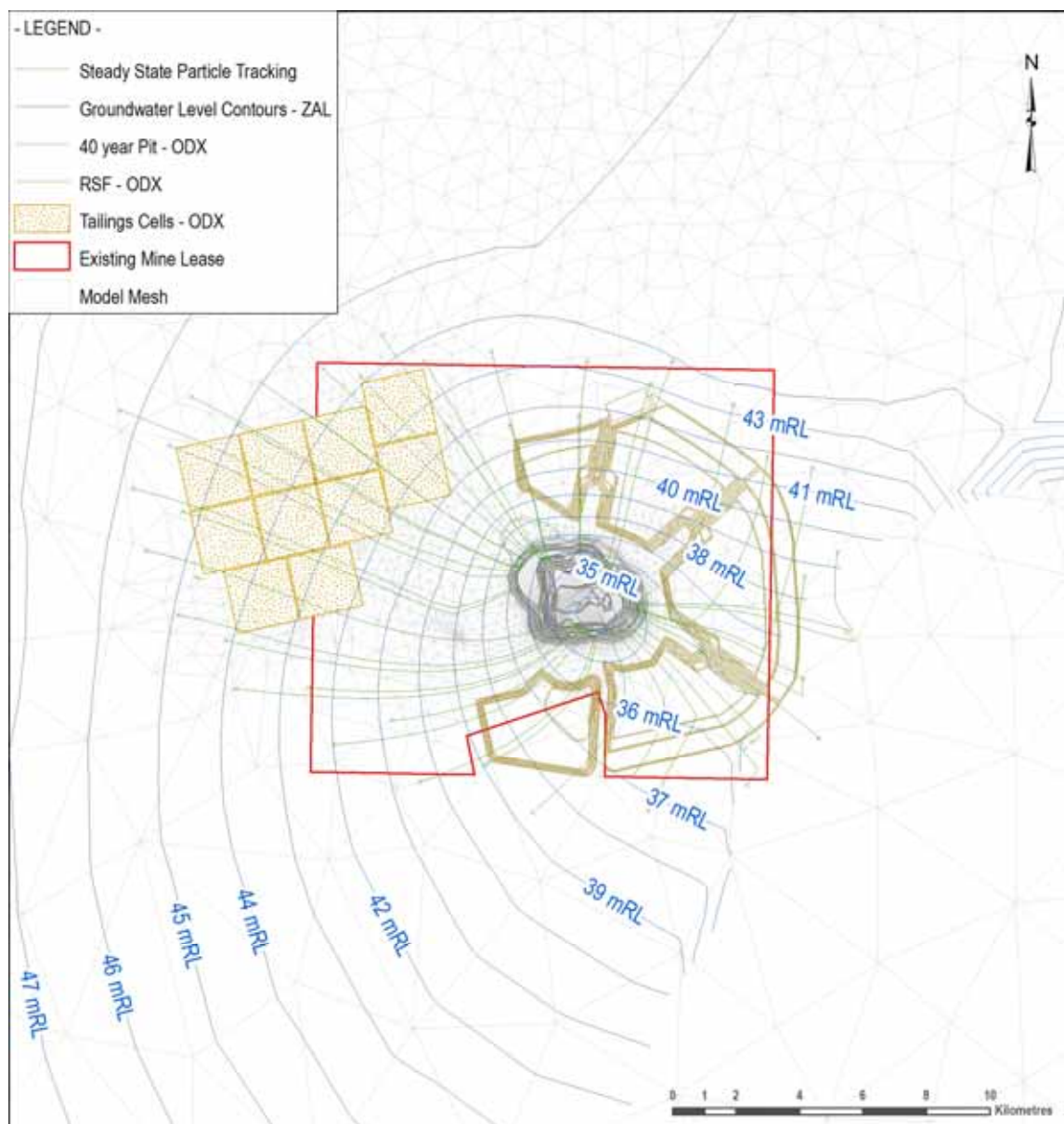
Figure 9.3 Steady State Particle Tracking in the Andamooka Limestone, 500 years post closure

9.3   UNCERTAINTIES IN GROUNDWATER FLOW AND GEOCHEMICAL MODELLING

Improved water management practices effectively minimise seepage rate and the potential for seepage to cause unacceptable environmental impacts.

Table 9.1 lists the potential risk issues associated with groundwater seepage, and the measures which can be taken to better quantify, eliminate the risk, or provide contingency capacity to manage the risk. The common consequences are a larger mound than predicted, movement of groundwater and/or percolates outside of the attenuation zone, and possible impact to environmental receptors and third party users.

As in the water balance, the increased deposition solids concentration to 55% together and the proposed seepage control measures assist significantly in reducing the groundwater seepage rates, while the calibration of the existing groundwater model also gives strong support to the risk evaluation.

Table 9.1 Management of Ground Water Seepage Uncertainty

Risk Issues	Potential Consequences	Available Controls/Mitigation Measures
High seepage from TSF	Groundwater mound larger than predicted	Seepage reduction measures Control of groundwater mound by abstraction (dewatering)
Incorrect model parameters (e.g. greater lateral permeability in Andamooka Limestone)	Movement of seepage outside of predicted attenuation zone Change to regional groundwater geochemistry and potential impact to a receptor	Seepage reduction measures Control of groundwater mound by abstraction (dewatering)
Unidentified preferential flow paths - geological structures	Movement of seepage outside of predicted attenuation zone Change to the regional groundwater geochemistry	Geotechnical investigations Dewatering targeting structural zones & features[19]
Incorrect geochemical model	Movement of metals and percolates outside of predicted attenuation zone Potential impact to a receptor	Improve geochemical model confidence – quantify whether an issue Seepage reduction Control and removal of soluble process derived metals through dewatering
Alteration of rockmass properties and/or structural features through chemical reactions	Increased seepage (but limited by supply from TSF) Movement of seepage outside of predicted attenuation zone Change to the groundwater geochemistry	Improve geochemical model confidence – check effects of reactions in different rock types Seepage reduction Control and removal of soluble process derived metals through dewatering

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[19] Note that preferential flow structural zones (very difficult to locate) are viewed as advantageous in controlling groundwater seepage as these facilitate drainage of the groundwater mound by abstraction.

10   CLOSURE DESIGNS

The primary closure objective for the TSF is to design and build an engineered cover system utilising the large quantities of available non-radioactive mine rock that ensures long term tailings containment possible. Once constructed, the covered tailings impoundment should require minimal and ideally no ongoing monitoring and supervision.

The TSF Closure Plan will ultimately be developed prior to closure of the mine in consultation with Federal and State regulators. This will happen after many years of operation during which trials of appropriate, practical and safe methodologies will be carried out to ensure that the closure design will manage all post-closure risk issues in the very long term. The project closure strategy is further detailed in the Draft EIS, Chapter 23.

10.1 POST-CLOSURE RISK ISSUES

As identified in Section 4, the key post-closure risk issues associated with the TSF are:

1. Embankment stability

2. Surface water erosion

3. Flora & fauna impacts

4. Dust

5. Seepage

6. Radiation

10.2 COVER DESIGN

The proposed closure methodology and design would potentially utilise two principles:

1. "Water shedding" where incident rainfall is transported laterally to the cell perimeters and shed into the surrounding natural environment without significant erosion or entrainment of the cover;

2. "Store and release" where infiltrated water is temporarily retained within the cover, and evaporated or where appropriate topsoil materials are available, consumed in evapo-transpiration processes associated with the shallow rooted cover vegetation.

Because of the large scale of the structures being covered, the final design will incorporate both methods to arrive at a balanced solution that manages seepage, erosion and HSEC risks.

A schematic design illustrates the shedding principle in Figure 10.1, while Figure 10.2 illustrates a conceptual store/release option. The initial TSF cells will be closed progressively during the operation phase, by considerable depths of mine rock as the RSF advances and this aspect will be considered in the closure plan. Sequential cell closure will also provide the opportunity for trialling and continual improvement of the TSF closure design.
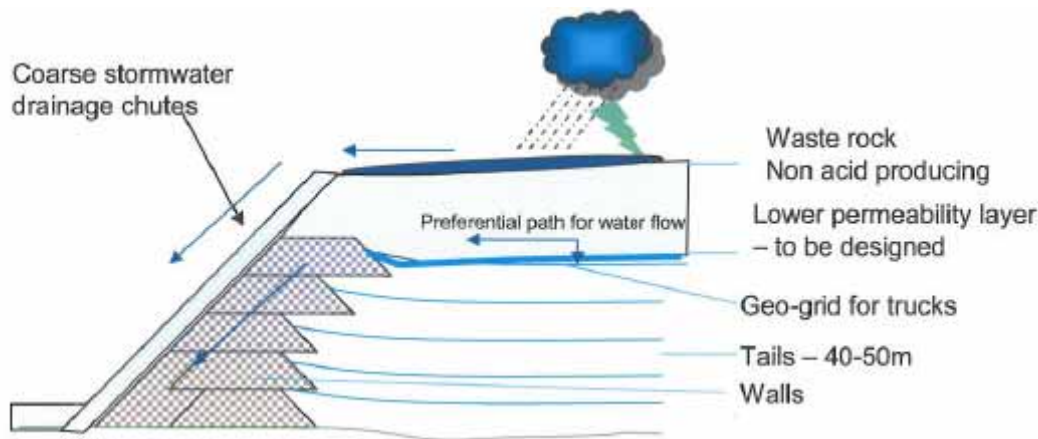
Figure 10.1 Schematic Illustrating Shedding Type System

The closure design proposed for the effective management of the key post closure risks involves providing a hard, durable, non-oxidising and non-radioactive cover on all faces (preferably rock types similar to limestone or durable sandstone/quartzite), that will:

1. Maintain the stability and integrity of the embankments and crests into perpetuity.

2. Provide erosion protection for any intermediate cover layer materials and the underlying tailings.

3. Not encouraging deep rooted vegetation and having sufficient thickness of rock cover such that borrowing animals cannot access the tailings.

4. Minimise dust by preventing the uncontrolled erosion and release of fine tailings material.

5. Minimise seepage by a method(s) such as:

    a. Appropriate surface area store/release zones that will safely store and release the incident rainfall from average annual rainfall and events up to around 1 in 25 years (will depend on detail design). A typical "store and release" (Williams, 1996) cover system illustrated in Figure 10.2 is designed to safely dispose of water retained on the surface without increasing the net seepage into the tailings, or

    b. Shed excess rainfall from higher ARI events safely into the adjacent environment.

    At all times, the cover would seek to keep the net average seepage into the underlying tailings (over the total closure surface area) below an infiltration level that matches the assumed infiltration rates used in post-closure groundwater mound dissipation modelling predictions. (See Chapter 12, Groundwater of Draft EIS, for further details).

6. Provide 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.
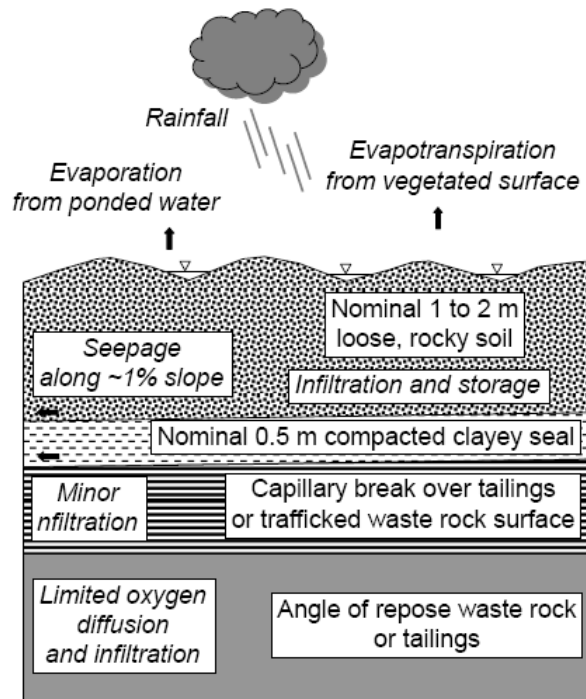
Figure 10.2 Schematic illustrating store/release capping system

The shedding cover system would typically fall gently along the final mounded tailings surface towards the perimeter. Typically, the cover may include a rock surface erosion protection and radon release barrier cover. This layer will shed some water, but water will still percolate vertically through the layer, and hence will be underlain (or gap-graded at its base) by a free-draining gravel layer. The upper protective and transmissive layers would be underlain by a basal layer which will be suitably graded and constructed to provide a low permeability and erosion resistant layer over which the shed water can flow without infiltrating the underlying tailings.

The erosion and dust protection provided by the rock embankment greatly simplifies the closure design but there remains some potential for erosion and gullying of the rock armour in water from major storm events. It may therefore be necessary to provide specially armoured sections of wall (Figure 10.3) to accommodate the high velocity runoff from these extreme storm events.

Preferably, the optimum closure solution can be achieved by fully incorporating the TSF within the rock storage facility footprint into an integrated waste landform (which allows the TSF sides and top surface to be covered with many meters of mine rock materials). However, further work will be carried out with the design during the operation period, to optimise the location of the TSF as well define the design aspects that need to be addressed in the lead up to closure. The final Closure method selected as well as the materials to be used, will be confirmed by conducting field trials during the operation period using the various cover sequence materials stockpiled for this purpose.
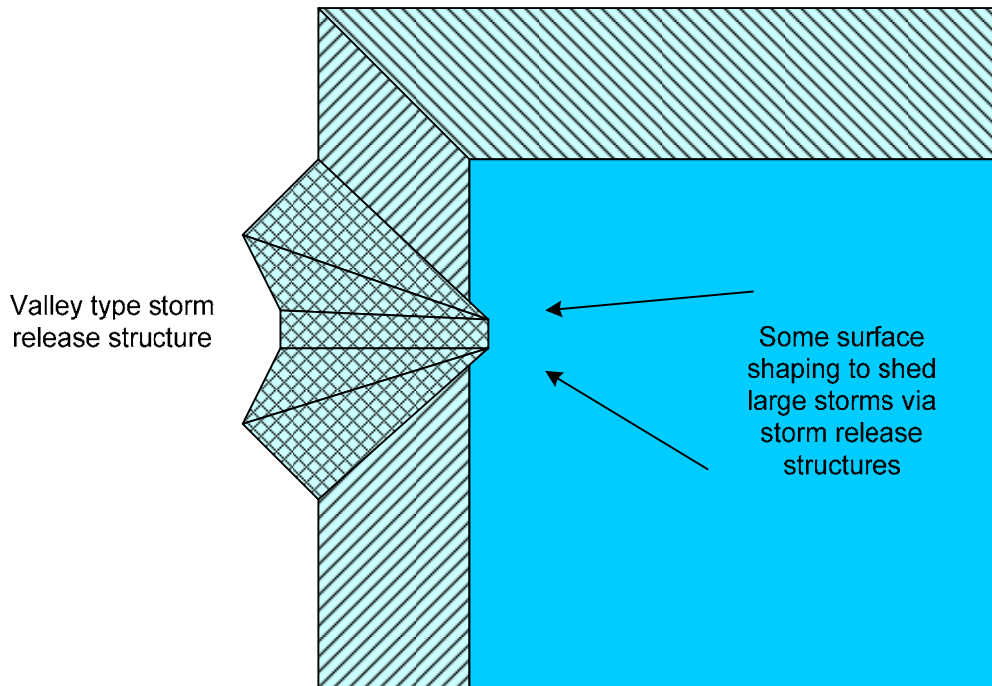
Figure 10.3 Schematic illustrating storm release structure

10.3   TIMING OF THE COVER PLACEMENT

The timing of the placement of cover will be determined by:

1.   The timing of the decommissioning of a specific cell relative to the final mine closure. Cells can be closed as they become available as long as it is safe to do so. They would be closed sequentially as they reach their top height, or allowed to stand until the desired degree of consolidation has been achieved in throughout the tailings facility.

2.   The degree of consolidation of the tailings. Sufficient consolidation must have occurred to ensure that cracking of the cover and subsequent exposure of the covered tailings does not occur. Also, the residual settlement potential must be sufficiently small that it does not materially change the slope or drainage patterns on the cover surface.

3.   The potential for dusting, radon emanation and erosion if the tailings surface is left uncovered. The self-armouring that occurs on the existing cells may be adequate to minimise dusting, but dusting can also be suppressed by surface spraying or temporary cover measures (e.g. artificial techniques such as chemical barriers and retardants) during the period of consolidation.

4.   The equipment that will be utilised in the construction of the cover. Heavier equipment can be used once the tailings achieve adequate shear strength.

If early access is required, the cover will need to be sufficiently flexible to accommodate consolidation settlements, and a method of accessing weak tailings may be required to facilitate construction of the cover. This can be achieved through products such as synthetic geogrid.

11   RISK AND EMERGENCY ACTION PLANS

In accordance with ANCOLD Guidelines (1999), risk and emergency action plans will be developed prior to operation of the expanded facilities commencing. These plans will build on the existing tailings management plans, operating manuals, monitoring and emergency response plans, and will consider:

1.   An assessment of persons, property and features of environmental significance in areas that would be influenced by failure.

2.   Actions to be taken in a range of emergencies.

3.   Information relating to any warning or emergency alarm systems proposed, with a description of proposed procedures.

4.   In the unlikely event of a significant uncontrolled release due to failure of an external embankment structure, appropriate measures must be taken to minimise impacts on the surrounding environment and remediate accordingly.

As noted in Section 4.11.3, specific controls have been included in the planning and design, to accommodate uncontrolled releases from the tailings cells:

1.   A normal minimum freeboard allowance of 7.5 m between the crest & pond just before a raise, reduced to 3m freeboard remaining after a 1 in 100 year storm (see section 8.2). This large volume will prevent overtopping and mass movement of liquefied tailings during the operational phase.

2.   Drainage gullies around the base of the external embankment walls will provide a conduit for runoff and materials that may have migrated from the tailings pile during a potential breach in retaining wall integrity. These will be maintained and regularly cleaned during the operational phase as a safeguard against this unlikely occurrence.

3.   Visual Inspection of the embankment walls following earthquake and large storm events. The risk of large magnitude earthquake events in the region is very low and a physical breach in the tailings embankment extremely unlikely. However, should visual signs such as cracking or seepage be evident on the embankment, appropriate actions will be taken to maintain the required stability criteria.

4.   Inspection of the upstream toe around the TSF perimeter. Knight Piésold (2004) recognized the high potential for near surface seepage due to the variable nature of the underlying geology and the likelihood of the occurrence of higher permeability near surface features which have not been previously identified and treated during construction. The downstream zones will be monitored (aerial photographs, geophysical surveys) to future impact.

5.   Appropriate PPE will be distributed to personnel inspecting any uncontrolled release to prevent exposure to acidic tailings liquor.

6.   Hydrogeological monitoring bores shall be placed around the cell perimeter and regularly checked so that anomalous levels of heavy metals or acidic species in local groundwater can be quickly detected. Appropriate mitigation measures can then be undertaken.

7.   More detailed investigations will be carried out to detect the presence of voids or fracture networks in the proposed TSF area. This will reduce the likelihood of collapse of the cell floors following construction on unstable ground.

The Expansion TSF Emergency Response Plan will be modelled off the existing operations TRS Incident Response Manual, (BHP Billiton, unpublished internal report, 2006). This report defines actions in case of each of the main incident types including wall failure, earthquake or vehicle accidents.

12 ABBREVIATIONS, TERMINOLOGY, NOMENCLATURE AND UNITS

Abbreviations

AEP	Annual Exceedance Probability – or a rainfall or seismic event. Probability that a certain sized event will be exceeded during a given year
AHD & RL	Above height datum / Reduced Level (above sea level)
ALARP	As low as reasonably practical
ANCOLD	Australian National Committee on Large Dams
ARI	Average Recurrence Interval - The average, or expected, value of the periods between exceedances of a given rainfall total accumulated over a given duration
CAF	Cement aggregated [back]fill – backfill into underground mine stopes
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EWRM	Enterprise wide risk management – risk management tool used within BHP Billiton
GPR	Ground penetrating radar – geophysical detection technique
HDPE	High density polypropylene (plastic pipe or liner)
HSEC	Health, safety, environment & community (social)
ICOLD	International Commission on Large Dams
OBE	Operating Basis Earthquake - Operating basis earthquake ground motion is the vibratory ground motion for which those features of the facility/plant necessary for continued operation will remain functional without undue risk to the health and safety of the public.
ODO	Olympic Dam Operation – the existing mining operation
ODX	Olympic Dam Expansion – the project developing the proposed expansion
PIRSA	Department of Primary Industries and Resources of South Australia
PMF	Probable maximum flood - is the largest flood that could physically occur at the location of interest. It is an extremely rare event which is associated with a Probable Maximum Precipitation (PMP).
PMP	The theoretically greatest amount of rainfall-given current knowledge-for a particular duration that is physically possible over a given area
RSF	Rock Storage Facility – mine rock dumps
SML	Special Mining Lease
TRS	Tailings retention system is the entire Tailings Management System. It includes the Disposal pumps & Pipelines, Tails Storage Facility, Liquor recovery and storage ponding (Balance ponds & evaporation ponds) and return systems to the Plant.
TSF	Tailings Storage Facility is a permanent structure for the long term containment of tailings. The TSF excludes the evaporation ponds and liquor return systems.

Units

k_v/k_h	K is measure of permeability with subscript "v" or "h" equivalent to either vertical or horizontal. Expressed in m/sec		kPa	Units for pressure - kilo Pascals
Bq/g	Becquerel per gram – SI measure of radioactive activity		kl/day	Units of flow – 1000 litres per day or m^3 per day
Mtpa	million tonnes per annum		Ha or ha	hectare = $10,000m^2$
Ml/a (d)	megalitres per annum (day)		ppm	Parts per million
m^3	cubic meters		t	Tonne's (1,000 kg)
mm	millimeters		w/w	Concentration of solids by weight expressed in %

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TAILINGS MANAGEMENT BENCHMARKING STUDY

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31 July 2008

CONTENTS

1   Executive Summary

BHP Billiton (BHPB) is looking to expand the Olympic Dam operation from 10Mtpa to a combined production of about 50Mtpa. Tailings produced from the existing and expanded metallurgical operations are to be deposited into a new Tailings Storage Facility (TSF).

A benchmarking study was undertaken for the proposed Olympic Dam Expansion (ODX) to compare key design features of the TSF with those of other operations. The study was restricted to design and operations only, benchmarking of rehabilitation practices would require comparisons with a different scope of operations.

The study commenced with a review of various TSF designs as applied to both uranium mines and other mines with similarities to the Olympic Dam Expansion project.

During the review a number of key generic risks associated with TSF were identified. Each of these risks were benchmarked against various operations to determine the range of key design components and management techniques implemented for mitigation. Information was then collected on these components and compared with the ODX proposal.

The spillage of tailings material being pumped for disposal or return process liquor for water management is a risk for all TSF and the only mitigation found was the use of earthen bunds. The ODX design proposes the pipe work be bunded and impervious.

The geotechnical failure or deformation of the wall of a TSF is one of the fundamental risks that require management. Mitigating this risk via elimination was found to be common practice and was achieved using in pit disposal. Since this option is not possible for all situations, other mitigation techniques are required. The ICOLD and ANCOLD guidelines provide details of calculating safety factors in design to ensure this risk is mitigated appropriately for these situations. The reviewed sites that do not undertake in pit disposal utilised a range of wall construction methods. Design details could not be found for all, however for those that had information available; all were based wall construction on the ICOLD/ANCOLD safety factors. The proposal by ODX to construct the TSF using the centre raise method is an improvement on the current operation and exceeds the ANCOLD safety factors.

Water management at most operations involved the recycling of water back into the process. Some operations were found to undertake a water treatment process followed by controlled release to the environment. ODX proposes to return water back into process for re-use, without extensive treatment. In its arid environment, evaporation are sufficient to remove the need for any alternative treatment of the liquor.

Designing the facility to withstand major stormwater events is common practice among most operations. Most operations also manage stormwater runoff by diverting clean runoff away from process areas and capturing all that lands in process areas. This is consistent with the proposed ODX design. Operations located in areas of high rainfall have constructed their TSF walls to minimise effects from erosion.

From the review it was found that all tailings facilities required a certain amount of seepage to ensure consolidation of the tailings mass for final closure; therefore seepage is common to all TSF studied. The key design features of the ODX TSF that target seepage management are:

- Upstream and downstream toe drains in the external walls

- During the start-up phase, the floor is covered as rapidly as possible with a cover of fine (low permeability) tailings that acts as an effective liner.

- Ponded area base lined with a HDPE liner

- Under floor drainage system

- Deposition to consolidate tails to target a low vertical permeability (Kv of 4x10-8m/sec) to minimise final landform seepage volumes;

These are consistent with mitigation management practices identified at other operations. Most operations were found to have some form of underfloor drainage system and some operations cover the TSF floor with an initial layer of fines and install side wall drainage. One facility was found to have a HDPE liner, this being under the water pond area, similar to the proposed ODX design. None of the tailings facilities reviewed were fully lined with HDPE. Two operations were found to have installed dewatering wells to manage seepage. Based on a risk assessment and local hydrogeological assessment, this is not proposed for ODX. However, dewatering well may be used to extract water from below the TSF when there is a demand.

No operation was found to undertake active avifauna management. Most claim to have no impact of local bird life. The proposal by ODX to engineer a solution to prevent access to ponded water by local birds appears to be unique.

The review of radiation management, specifically for dust and radon minimisation demonstrated that wetted beaches are sufficient to manage the risk to workers and members of the public. The proposal by ODX to use thin layer deposition will ensure recently deposited material will be sufficiently wet and where material starts to dry before the next cycle of deposition a crust will form restricting the processes of dusting and radon emanation.

2   Introduction

BHP Billiton (BHPB) is looking to expand the Olympic Dam operation from 10Mtpa to a combined production of about 50Mtpa. Tailings produced from the existing and expanded metallurgical operations are to be deposited into a new Tailings Storage Facility (TSF), to be located adjacent to the current TSF.

BHPB has completed a conceptual design and sizing of the new TSF to store tailings for a 40 year+ mine life [61]. Part of this design process was to review how other operations have designed their facilities to mitigate against key risks.

This document details the results of a benchmarking study undertaken for the proposed ODX TSF to compare key design features with those of other operations and where appropriate implement key learning's. The study was restricted to design and operations only, benchmarking of rehabilitation practices would cover a different scope of operations so, if required, will be addressed separately.

The conceptual TSF will consist of about 20 cells covering an area of approximately 10 by 4 km. The initial operation will use 6 cells for 20 years and then progress on to the next set of 6 and so on. The estimated total area of the first 6 cells is 2400 ha. The final height of the TSF structure is assumed to be 40m.

Tailings will be pumped to the top of the TSF and allowed to flow across large areas called 'beaches' in the TSF to maximise evaporation. The free liquor that is not evaporated on the beaches is collected in the centre of each cell, where it is decant to liquor storage? ponds. This minimises the potential for seepage from the base of the TSF and maximises the opportunity for reuse of liquor through recycling back to the processing plant.

The rate of tailings production is directly proportional to the rate of ore processed, with approximately 98 percent of the ore becoming tailings.

To facilitate the benchmarking, a number of comparison criteria were chosen. These are discussed along with an explanation of their selection in section 3.

Section 4 provides a summary of the ODX TSF design, further details are provided in Appendix 1 along with the information collected from each benchmarking site selected. This information is also summarised in table form within the appendix.

3   Benchmarking Methodology

The benchmarking study commenced with a review of various TSF designs as applied to both uranium mines and other mines with similarities to the Olympic Dam Expansion project. When selecting sites to benchmark against, consideration was giving to the climate, geology, milling process, size of facility and local environment (amongst others) to facilitate accurate comparisons, a list of these comparison criteria are provided in table 3.1 and details for each operation in Attachment 1.

Consideration was given to including some of the US uranium facilities. The differences between uranium tailings facilities in the US and in Australia make it difficult to undertake direct comparisons for the purposes of a benchmarking study and were therefore not included. Differences include; small size of facilities in US, high grade of ore and subsequently quite different tailings storage facilities as well as the regulatory system and the licence conditions. Further detail on 2 US Facilities is included in section 7.

The main features of US tailings systems; are total containment with multi-lining, leak detection and under drainage systems and reclamation for final disposal. These should be considered within the context the US regulations as they are not applicable to the Olympic Dam tailings system.

It was found that each tailings facility chosen was unique and that direct comparison with one or two sites was not feasible. As a result, a multitude of locations were selected. A list of each site, along with justification for each selection follows.

ERA – Ranger Mine – As the only other operational open pit uranium mine in Australia this was chosen; however, there are a number of significant differences including:

- the operation is significantly smaller;

- the climate is wet/dry tropical having rainfall in the order of 1500mm pa;

- the orebody is unconformity style, rather than Breccia complex IOCG;

- there are flowing, wet/dry dominated hydrogeology units present; and

- the local terrestrial environment has dense vegetation and experiences flooding for several months during the wet season.

Initially tailings were placed into a tailings dam, similar to the ODX proposal, however current operations dispose of tailings into the mined out Pit #1.

Nabarlek – Is now rehabilitated; however, was chosen because it was the only other *modern* uranium mine in Australia with a tailings storage facility. The operations was similar to the Ranger Mine, in a similar location and a smaller scale. All tailings were disposed of in the mined out pit.

Rössing – A uranium mine of a moderate scale in an arid environment. It has a similar milling process, geology and hydrogeology, making it reasonably comparable to the ODX situation. The mine has been in operation since 1976 and as such much of the design is not representative of modern practice.

Langer-Heinrich – Was chosen because it was the newest uranium mine and is located in an arid environment, near to the Rössing mine. However, the process is alkaline leach and the orebody is calcrete style producing tailings with significant differences to ODX and of much smaller scale.

McClean Lake – This operation was chosen because it is a uranium mine with a technologically advanced. However the climate, geology, hydrogeology and terrestrial environment are significantly different in the northern reaches of Canada, where the mines are surrounded by lakes that due to the climate are covered with ice for half the year.

Prominent Hill – Even though this mine does not produce uranium it was chosen because of its proximity to ODX, its similar geology (IOCG), moderate scale and having only recently commenced commissioning is considered representative of modern practice. The orebody also contains low grades of uranium which are included in the tailings stream.

Escondida – This is also not a uranium mine but was chosen because of its similar scale and for its arid environment. The geology is different; however the hydrogeology of the area has resulted in mounding of seepage liquor under the TSF, similar to the current OD situation.

Ernest Henry – Was chosen because it is a moderate scale IOCG mine having similar geology in an arid region of Australia. However it does not produce uranium and milling involves grinding and multi stage floatation only, concentrate is shipped to the nearby Mt Isa mines for processing, meaning the tailings are different to ODX.

Century Zinc – Was chosen because it is a moderate scale mine, having a similar environment in an arid region of Australia. It has a large tails dam with a large filter wall and downstream evaporation pond which is similar to the system proposed for ODX. The important comparison aspects that were thought to exist with this mine were the environmental and ground water issues that were thought to pose similar challenges.

Collahuasi – This was chosen because it is of similar scale to ODX and is located in an arid environment; however, it is not a uranium mine and has different geology.

Table 3.1. Comparison Criteria for each Benchmarked Operation

Comparison Criteria		Details
General Information	Location	Country of operation along with description of area
	Company	Name of operator
	Products - pa	Products (s) produced and amount per year of each (eg 5000 tpa of U3O8)
	Mill Production - pa	Amount of ore moved in the mining operation per year (not mine production which is significantly higher in most cases)
	Tailings Production (tpa)	Volume of tailings produced per year
Climate	Description	Description of the regional climate (eg Arid or Wet/Dry Tropical)
	Temperature range	Maximum and Minimum temperatures experienced in region
	Average Rainfall	Average annual rainfall to region
Local Setting	Ore Type	Description of Deposit Geology type
	Surrounding Geology	Basic summary of local geology
	Terrestrial Environment	Description of the surface land and soils
	Hydrogeology	List of the number of local aquifers, location and water quality
Legislation		List of key regulators and any Act, Regulations, Guidelines and Standards that apply to the TSF
Process description		Summary of the basic milling process

Comparison Criteria		Details
Tailings Description	Treatment	Any treatment process undertaken prior to disposal, eg Neutralization
	Solids Density	Target and achieved density of tailings
	Tailings contaminants in contained water	The following contaminants were chosen for there potential for risk to human health and the environment. U, As, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn, pH, Acidity
	Permeability of Tails	The average or targeted permeability (k value) cm/sec
	Surface area of TSF	Expressed in meters squared (to enable comparison with ODX)
	Scale of TSF as a percentage of ODX	Simple percentage for size comparison purposes
	Seepage Volumes	The amount of seepage volume per year (If available)

It should be noted that the Beverley Mine, even though it is an operational uranium mine in Australia, was not chosen for comparison because it is an In-Situ Leach operation and does not have a TSF.

Information was then collected on the key design components and management techniques at each operation along with those currently utilised at Olympic Dam (OD) and those proposed for ODX. A list of the information collected is given in table 3.2, this information is reported in Appendix 1.

Table 3.2. Design and Management Criteria for each Benchmarked Operation

Design Components & Management Techniques		Details
Tailings Facility Basis for Design	Style of Facility	Brief description of TSF design (eg: in pit or paddock)
	Deposition Method	Brief Description of the method used to place tailings into TSF
	Wall Construction	Brief Description of method used to build wall (eg: Upstream, Downstream etc.) And summary of approximate dimensions
Seepage Management		Description of techniques used to minimise the amount of seepage and/or prevent seepage from impacting on environment
Fauna Management		Techniques used to restrict access to facility by local fauna, especially birds.
Water Management		Description of techniques used to manage water in the TSF circuit and stormwater management
Radiation Management		The main issue concerning tailings disposal in above ground storage facilities is the potential for exposure to members of the public and to a lesser extent workers at the mine. This section details how the following pathways for exposure are managed: • Radon emanation from the surface of the tailings; and • Dusting from the surface; Other pathways, including; Leaching of radionuclides from the tailings into groundwater, and dispersal of solid tailings from poor long-term stability or erosion are covered by other comparison components.

4   Olympic Dam Expansion Tailings Facility Basis for Design

Details regarding the design of the TSF are provided in Environmental Impact Assessment Tailings Storage Facility Design Report [62]. The following provides a summary of the key design features.

Prior to undertaking the design, a detailed risk assessment was conducted for the TSF [69]. The design was then conducted in consideration of these risks and the following references minimum design standards:

1. Draft BHP Billiton Tailings Management Guideline [64];

2. ANCOLD – Guidelines on Tailings Dam Design Construction and Operations [65];

3. ICOLD – Various guidelines and design standards (ICOLD Bulletins) [66];

4. Leading practice sustainable development program for the mining industry - Tailings Management [52];

5. Tailings and Tailings Storage Facilities, EPA/PIRSA Guideline, Draft Issued May 2007 [67]; and

6. ARPANSA – Code of practice on radiation protection and radioactive waste management in mining and mineral processing, 2005 [68].

Key design features of ODX are [62]:

- The walls will be constructed from mine waste rock;

- Construction methodology will be centreline raises;

- Factors of safety to equal or exceed those required by ANCOLD guidelines;

- Toe drains in the external walls;

- Operational control would be achieved by the construction of a flow-through rock filter wall to decant zone;

- HDPE Lined central decant zone;

- Sand layer on top of HDPE liner (dune sand within the cell perimeter) to form a base drain, assist with fine tailings consolidation and act as a protective cover to the liner;

- Filter drain above the liner;

- Commissioning:

   o Rapid placement of low permeability floor lining using tailings; and

   o bunded central area so that the pond can store and dispose of excess water by evaporation during the start-up phase;

- Low vertical permeability of the tails under the beaching areas outside the pond area also ensures that seepage volumes are very low. Seepage rates are comparable to a HDPE liner [values]. Consolidated tails have a Kv of 4 x 10-8 m/sec;

- During the uranium leach process, large amounts of soluble salts such as chlorides and sulphates are taken up into the process liquor. The tailings stream acts as a bleed in the water balance to remove impurities from the circuit by the

evaporation of water on the tails beaches and subsequent entrainment of salts into the tails solids mass that would otherwise build up to intolerable levels in the circuit;

- Surge capacity for up to a 1:100 ARI 72 hour storm as per the ANCOLD guidelines;

- Bird netting over decant zone; and

- Pipe work to and from TSF placed in lined bunds.

5 Benchmarking of Key Generic Risks

During the benchmarking review a number of key generic risks associated with the operation of a TSF were identified [1, 2, 3, 4, 6, 7, 12, 14, 18-33, 37, 52, 55, 73, 75]. Not all these risks were present at the proposed Olympic Dam expansion TSF [69].

1. Spillage: Rupture of the tailing slurry delivery pipe or decant water return pipe;

2. Wall Failure: Geotechnical failure or excessive deformation or the containment wall;

3. Water & Rainfall:

   a) Water Balance outside design limits - surplus or deficit of liquor created;

   b) Overfilling of the TSF with tailings leading to overtopping of the containment wall by water;

   c) Stormwater event resulting in excess water;

   d) Rainfall induced erosion or piping of the outer tailings face;

4. Seepage:

   a) seepage through the containment wall;

   b) contaminated seepage into groundwater;

5. Radiation: Radon or Dust emissions;

6. Exposure of Fauna:

   a) birds;

   b) other fauna.

To facilitate comparisons between sites, an assessment of these risks for ODX, OD current operation and each benchmarked operation was made to identify:

- If the risk was present for that operation;

- If present, was it mitigated; and

- If mitigated, how was it mitigated (design or management techniques).

It should be noted that no assessment of the effectiveness of the mitigation was made.

Table 5.1 provides a summary of which operations had the risk and which operations mitigated the risk. Details of the various mitigation techniques employed by the reviewed operations are summarised below.

5.1 Spillage

The spillage of tailings material being pumped for disposal or return process liquor for water management is a risk for all TSF.

Details on how this was managed could not be located for some operations. All operations that did have data managed this via the bunding of pipe work, similar to the current OD operation. The proposed ODX design has the pipe work installed in an impervious bund.

5.2 Wall Failure

The geotechnical failure or deformation of the wall of a TSF is one of the fundamental risks that require management.

This risk was not present at all operations as many had eliminated the hazard by using "in pit" disposal. However, since this is not practicable for all situations other mitigation techniques are required. For the ODX situation, in pit disposal is not an option because there are currently no mined out pits in the vicinity and the pit continues in operation during the entire mine life.

Of the sites reviewed that do not undertake in pit disposal, the following range of construction methods were utilised.

- Integrated Waste Landform (IWL)

- Downstream Raise

- Centre Raise

- Upstream Raise

For all operations that construction details the choice of wall construction method was based on the ICOLD [66] or ANCOLD [65] guidelines. These guidelines require the calculation of safety factors for the particular operation. Based on these factors the appropriate wall construction method is chosen. The proposal by ODX to construct the TSF using the centre raise method is an improvement on the current operation [59] and exceeds the ANCOLD safety factors [65].

5.3 Water & Rainfall

The appropriate management of process and stormwater is critical to the successful operation of a mine and mill. For some operations, those in high rainfall areas, this is more critical than others. Additionally, the management of water at all facilities was found to be critical to tailings consolidation and thus seepage management and closure.

The recycling of water back into the process to minimise total water usage appears to have become a standard, with all operations undertaking some form of water recycle and re-use.

Some operations, largely those in high rainfall areas, undertake water treatment processes followed by controlled release to the environment (when set criteria are met). The arid environment at ODX ensures evaporation is high enough to remove the need for any release to the environment, thus water treatment is not proposed.

The management of stormwater to restrict its ingress into contaminated areas and to ensure complete catchment of waters that enter contaminated areas occurred at all operations that had data available.

Operations located in areas of high rainfall have constructed their TSF walls to minimise effects from erosion using rock armouring.

5.4 Seepage

Seepage was found to occur at all tailings facilities studied. The review also found that seepage is a factor in ensuring effective consolidation of the tailings mass, critical during both operations and for final closure.

All studied operations utilised some degree of seepage management, whilst not eliminating seepage altogether. Seepage management techniques undertaken by the reviewed operations are listed below:

- Under mass drainage system;

- Down stream capture of seepage, including collection in the mined out pit;

- Seepage limiting barriers on side walls;

- Side wall floor or toe drains to manage lateral seepage;

- Rock ring or wall to a decant pond that removed water from tailings;

- Impermeable Liner under areas that has water ponds;

- Dewatering ring;

- Tailings wicks to remove water and consolidate tails;

- Thickened or paste tails and techniques to consolidate the tailings mass and limit vertical seepage;

- Target tails density to maximise deposition and minimise permeability; and

- Treatment of tailing to limit or prevent leaching of metals/contaminants into groundwater;

One operation stood out as having a technologically advanced seepage management system, the McClean Lake JEB TSF [53, 54]. Seepage management at this facility has many layers including an elaborate well curtain (de-watering ring) installed around the facility to restrict the ingress of groundwater into and through the tailings mass during operational phase and an underdrainage system pumping water back into the process to collect seepage and consolidate the tails mass. The target final hydraulic conductivity of the mass is significantly lower than the surrounding sandstone to ensure no flow of groundwater occurs through the tails material post closure. ODX also has the potential to dewater the groundwater mound using abstraction wells if the need arises and has a monitoring plan in place to trigger a risk evaluation which will result in the most appropriate seepage risk mitigation plan being implemented.

The key design features of the proposed ODX TSF to manage seepage are [62]:

- Upstream and downstream toe drains in the external walls

- During the start-up phase, the floor is covered as rapidly as possible with a cover of fine (low permeability) tailings that acts as an effective liner.

- Ponded area base lined with a HDPE liner

- Under floor drainage system

- Deposition to consolidate tails to target a low vertical permeability (Kv of 4×10^{-8} m/sec) to minimise final landform seepage volumes;

- Rock ring wall that helps mitigate the risk to bird fauna. The rock ring is in the centre of the cell that acts as a method to "control" the liquor pond. The rock also will enable "netting" and or other bird control measures to be put in place.

These are consistent with those mitigation techniques identified at other operations. Most operations were found to have some form of underfloor drainage system, the covering the floor with an initial layer of fines and the installation of toe drains were utilised by some operations. One other facility was found to have a HDPE liner this being under the water pond area [43]. None of the tailings facilities reviewed were fully lined with HDPE (or equivalent impervious material).

Century Zinc is the only facility that has a method of physically separating off the recovered liquor via a filter or rock ring wall; into a pond in which it subsequently removes it from the system via evaporation [41].

The use of seepage downstream capture as a mitigation technique was utilised by several operations. With all the other mitigation techniques in place for ODX this is not thought to be required.

5.5 Radiation

The review demonstrated that the radon emanation and dust re-suspension from beached tails can be managed effectively if the tails material remains moist [55, 56, 57, 58, 72, 75].

A study undertaken at the Nabarlek operation showed no effect on worker or member of the public health from inhalation of radon when the process changed from having a complete water layer over the tailings to depositing semi-dry tailings [58]. Similar studies have been undertaken at the Ranger mine and they also now operate with semi-dry tailings during the dry season reference.

The proposal by ODX to use thin layer deposition will ensure that recently deposited material will be sufficiently wet and where material starts to dry before the next cycle of deposition a crust will form restricting the processes of dusting and radon emanation [55, 56, 57, 58].

5.6 Exposure of Fauna

Many sites reviewed indicated that they restrict access to the TSF by fauna with some form of fencing; this was either the TSF or the mine lease area.

All sites reviewed (with data available) indicated that the risk to local avi-fauna from their TSF is low, the most extensive study has been conducted by Ranger mine [63]. Many of these sites undertake tailings neutralisation which can reduce the impact on bird life landing on ponded areas. Operations that do not neutralise tails have indicated that they do not experience bird activity on their facilities, this is either because they do not have ponded areas or there is little bird life in the region. The majority of sites monitor bird activity and have not recorded any adverse impact.

The ODX risk assessment [69] has indicated there is a risk to avi-fauna from the TSF and have proposed mitigation with some form of access restriction, likely to be bird netting.

Table 5.1 – Summary of Key Generic Risks in the context of each operation reviewed.

Key Risks P = Present (Y/N) M = Mitigated (Y/N)		ODX		OD		Ranger		Nabarlek		Rössing		Langer-Heinrich		McClean Lake		Prominent Hill		Escondida		Ernest Henry		Century Zinc		Collahuasi	
		P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M	P	M
Spillage	Rupture of the tailing slurry delivery pipe or decant water return pipe	Y	Y	Y	Y	Y	Y	Y	?	Y	?	Y	?	Y	?	Y	Y	N		N		Y	Y	Y	Y
Wall Failure	Geotechnical failure or excessive deformation or the containment wall	Y	Y	Y	Y	Y	Y	N		Y	?	N		N		N		Y	Y	Y	Y	Y	?	Y	?
Water & Rainfall	Water Balance outside design limits - surplus or deficit of liquor created	Y	Y	Y	N	Y	Y	?	?	N		?	?	Y	Y	Y	Y	Y	Y	Y	?	Y	Y	Y	Y
	Overfilling of the TSF with tailings leading to overtopping of the containment wall by water	N		N		N		N		N		N		N		N		Y	Y	Y	?	Y	?	Y	Y
	Storm water event resulting in excess water	Y	Y	Y	N	Y	Y	Y	Y	N		Y	Y	Y	Y	Y	Y	N		Y	?	Y	Y	Y	Y
	Rainfall induced erosion or piping of the outer tailings face	Y	Y	Y	Y	Y	Y	N		N		N		N		N		N		Y	Y	Y	Y	Y	Y
Seepage	seepage through the containment wall	Y	Y	Y	N	Y	Y	N		Y	Y	N		Y	Y	N		Y	Y	Y	Y	Y	?	Y	Y
	contaminated seepage into groundwater	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Radiation	Radon or Dust emissions	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	?	N		Y	?	N		N		N		N	
Exposure of Fauna	Birds	Y	Y	Y	N	N		N		?		N		N		N		N		N		N		N	
	Other fauna	Y	?	Y	?	Y	Y	Y	Y	?	?	Y	Y	?	?	N		N		Y	Y	?	?	N	

6 Benchmarking of Key Design Features

In this section various key design features implemented at the reviewed operations to mitigate risks are compared. The purpose was to identify:

- Whether other operations utilise similar design criteria to ODX for mitigating risks; and

- Any design criteria common to other operations that are not part of the ODX design.

A summary of this comparison is provided in the table 6.1. No significant differences were found in the design components proposed for ODX compared to those of the other operations. The following summarises the results of this benchmarking:

- The use of mine waste rock as wall construction material is a common practice;

- Various methods of tailings wall construction are utilised, no particular design was more common than the rest, each making use of local influences and environment;

- One other operation utilises HDPE lining. This lining is also restricted to water pond areas only;

- A number of different seepage management designs are utilised by the reviewed operations. The following seepage design components, proposed by ODX, were consistent with those at other operations:

  o Upstream and downstream toe drains in the external walls;

  o Covering the floor as rapidly as possible with a cover of fine (low permeability) during facility commission so that the tailings act as an effective liner;

  o Ponded area base lined with a HDPE liner;

  o Under floor drainage system;

  o Deposition to consolidate tails to target a low vertical permeability to minimise final landform seepage volumes; and

  o Decant or rock ring filter wall to control pond size;

- Two operations have installed dewatering wells as a seepage management technique. This is not currently planned for ODX, although remains a potential mitigation measure and source of construction water should monitoring reflect a need for its implementation;

- Not a lot of information was available on tailings pipe work bunding. Details were found from only one other operation and they have all pipe work bunded, however this bunding is not lined as proposed by ODX.

- All sites but one utilise recycle of water as part of their water management; and

- Designing the facility to withstand major stormwater events is common practice among most operations. Most operations also manage stormwater runoff by diverting clean runoff away from process areas and capturing all that lands in process areas is proposed for ODX;

- Management of radioactive dust and radon by the maintenance of wetted tails is consistent with two other uranium mines. The McClean Lake facility maintains a complete water layer, however this is for the additional purpose of ensuring tailings do not freeze in the winter months.

7   US Facilities

7.1.1. Introduction
US facilities were identified as important to discuss in the context of a benchmark study. The aim of this section is to provide information on two key tailings facilities in the US that have subsequently been identified as the main facilities in operation at the current time. These are;

-        Shootaring Canyon Uranium Mill Tailings Facility (Shootaring)

-        White Mesa Mill Tailings Facility (White Mesa)

This note was prepared by reviewing publicly available information and the references are provided.

7.1.2. Background
The aim of the main benchmarking study was to review existing information on current uranium tailings systems and to provide advice for the design of the proposed expanded Olympic Dam tailings systems.

A decision was taken early in the benchmarking process to exclude US systems for a number of reasons as follows;

1)   The US is only a small producer of uranium

2)   There are generally no new large uranium deposits in the US, with the deposits being small or reworked existing mines

3)   Typical uranium ore grades are between 0.2 and 0.6% with some small areas up to 1 to 2 %, - the tailings is correspondingly more radioactive than Olympic Dam tailings

4)   A significant proportion of the US production comes from in situ leaching (ISL) processes similar to the operating Beverly Mine in South Australia - the ISL process is significantly different from conventional uranium milling and does not produce tailings.

In addition to these technical reasons, another key reason for not pursuing the review of US related tailings systems is because of the tight regulatory framework which sets standards based on containment and eventual reclamation of tailings to a final, permanent and geologically stable disposal site. These requirements have resulted in relatively few facilities receiving operating licences. The difficulties in obtaining construction and operating licences for both processing and tailings systems results in those processing plants that do have licences, undertaking "toll milling" of uranium ore.

A specific requirement of the licencing process is that the operating tailings systems are defined as temporary storage facilities and that tailings must be eventually be reclaimed and finally disposed.

In comparison to Olympic Dam;

1)   The Olympic Dam tailings facility is in a region of geological stability and therefore does not require reclamation and disposal.

2)   The uranium ore grade is low (< 0.2 %)

These considerations mean that the US uranium tailings systems are considerably different from the tailings system used (and to be used) at Olympic Dam, and therefore were not considered in the main report.

7.1.3. Tailings System Characteristics
Information on the two tailings systems that are currently (or near to) operational is provided below.

<u>Shootaring</u>

This facility is planned to be operational in 2008 and consists of two 40 acre tailings cells. The new cells have been constructed adjacent to existing tailings cells. The owner is Uranium One.

- Key features of the facility are as follows;

- Multilayered liner system

    o Compacted lay layer

    o 2 HDPE geomembranes

- Leak detection system resides between the two layers of HDPE

- Leachate collection system above HDPE liners which is either; reclaimed to processing plant, discharged to evaporation ponds or retained on tailings

- Final reclamation and disposal of tailings

<u>White Mesa</u>

This consists of a relined existing tailings cell in a facility containing 4 cells associated with the White Mesa uranium mill operated by Denison in Colorado. The relined cell is to have an operational life goal of 200 to 1,000 years. The cell was licensed to become operational in 2008 storing tailings and barren solvent extraction raffinate. Solid contamination is also able to be placed in the cell. It is approximately 28 acres and a capacity of approximately 1.6 m cubic metres.

- Multilayered liner system

    o Compacted soil

    o Geosynthetic layer

    o Bentonite soil

    o Geosynthetic layer

- Leak detection system resides between the two layers of HDPE

- Slimes drainage systems above HDPE liners which is either; reclaimed to processing plant, discharged to evaporation ponds or retained on tailings

- Final reclamation and disposal of tailings

7.1.4. Summary

The differences between uranium tailings facilities in the US and in Australia make it difficult to undertake direct comparisons for the purposes of a benchmarking study. Differences include; size of facilities, grade of ore and subsequently the tailings, regulatory system and the licence conditions.

The main features of US tailings systems; are total containment with multi-lining, leak detection and under drainage systems and reclamation for final disposal. These should be considered within the context the US regulations as they are not applicable to the Olympic Dam tailings system.

Table 6.1 – Comparison of key design components used at each operation to mitigate risks

Key Design Component Y = Yes, N= No	ODX	OD - Current	Ranger Mine	Nabarlek	Rössing	Langer-Heinrich	McClean Lake	Prominent Hill	Escondida	Ernest Henry	Century Zinc	Collahuasi
The walls will be constructed from mine waste rock.	Y		Y		?			Y	N	Y	?	Y
Construction methodology - upstream raises	N		N	N	Y	N	N	Y	N	Y	N	N
Construction methodology - centreline raises	Y		N	N	N	N	N	N	N	N	Y	N
Construction methodology - downstream raises	N		Y	N	N	N	N	N	N	Y	N	Y
Construction methodology – Integrated Waste Landform	N		N	N	N	N	N	Y	N	N	N	N
Construction methodology – In pit disposal	N		Y	Y	N	Y	Y	N	N	N	N	N
Factors of safety to equal or exceed those required by ANCOLD/ICOLD guidelines	Y		?	?	?	?	?	Y	?	?	?	?
Engineered drains in the external walls	Y		N		Y			Y	N	Y	N	N
During the start-up phase, the floor is covered as rapidly as possible with a cover of fine tailings.	Y		N	?	?	Y	N	?	?	?	?	?
Decant rock ring or wall (with culverts) to pond	Y		N	N	N	N	N	N	N	?	Y	Y
Water coverage area base lined with HDPE liner on top of which is constructed a filter drain.	Y		N	N	N	N	N	N	N	N	N	Y
Target high consolidation of tails (high hydraulic conductivity compared to surrounding formation)	Y		Y	Y	N	Y	Y	Y	Y	?	Y	Y
A compacted clay core keyed into the underlying rock to reduce seepage.	N		Y	N	N	N	N	N	N	N	N	N
Seepage collector system to trap the majority of the seepage through the floor of the structure	Y		Y	N	N	N	Y	N	N	N	N	N
Downstream capture of seepage in engineered facility or pit.	Y		N	N	Y	N	N	Y	N	Y	Y	N
Filter bed under tailings and de-watering pumps to collect seepage (in pit)	N		Y	N	N	N	Y	N	N	N	N	N
Seepage limiting barriers in side walls (in pit)	N		Y	N	N	N	N	N	N	N	N	N
Wicks to de-water and consolidate tails	N		Trial	Y	N	N	N	N	N	N	N	N
production boreholes installed to de-water tailings	N		N	N	Y	N	N	N	N	N	N	N
Bunding of delivery and water return pipe work	Y		Y	?	?	?	?	?	?	?	?	?
Lining of the pipe work bunding	Y		N	?	?	?	?	?	?	?	?	?

Key Design Component Y = Yes, N= No	ODX	OD - Current	Ranger Mine	Nabarlek	Rössing	Langer- Heinrich	McClean Lake	Prominent Hill	Escondida	Ernest Henry	Century Zinc	Collahuasi
De-watering ring surrounding TSF (well curtain)	N		N	N	N	N	Y	N	N	N	N	Y
Treatment of tailings to lock up contaminants.	N		N	N	N	N	Y	N	N	N	N	N
Maintain wetted tails or crusting to reduce radon and dust emissions	Y		Y	Y	?	?	Y	?	N	N	N	N
Maintain a water cover over tails to reduce radon and dust emissions	N		N	N	N	N	Y	N	N	N	N	N
Water re-cycle back into plant	Y		Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Water treatment and disposal to environment	N		Y	Y	N	N	Y	N	N	N	Trial	N
Constructed to withstand high rainfall events	Y		Y	Y	?	Y	Y	Y	N	?	Y	?
Stormwater diversion away from process areas	Y		Y	Y	?	Y	Y	Y	N	Y	Y	?
Collection of all Stormwater landing on process areas	Y		Y	Y	?	Y	Y	Y	N	Y	Y	?
Open evaporation ponds	Y		Y	Y	Y	?	Y	Y	?	Y	Y	Y
Covered intermediate storage tanks	Y		N	?	?	?	?	?	?	?	?	?
Fauna deterrent systems installed	Y		N	?	?	N	?	N	N	N	?	N
Fencing of TSF or mining lease to restrict access by fauna	N		Y	Y	?	Y	?	N	N	Y	?	N
Restriction of access by birds (eg. Bird netting)	Y		N	N	?	N	?	N	N	N	?	N

8 Glossary

ODX	Olympic Dam Expansion
TSF	Tailings Storage Facility
RSF	Rock Storage Facility – storage area for rock that has an ore grade below economic cut off.
OD	Olympic Dam
ANCOLD	Australian National Committee on Large Dams
ICOLD	International Committee on Large Dams
IWL	Integrated Waste Landform – style of TSF and RSF construction such that both are integrated
GAB	Great Artesian Basin – Australia's largest groundwater resource
EPA	Environment Protection Agency
ML	Mega Litres
mg	milligrams
Bq	Becquerel – unit of radiation activity
ALARA	Acronym for "As Low As Reasonably Achievable." It means making every reasonable effort to maintain exposures to ionising radiation as far below the dose limits as practical taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations.
ARI	Average Recurrence Interval (measured in years) is a term used to describe flood size. It is a means of describing how likely a flood is to occur in a given year. For example, a 100 year ARI flood is a flood that occurs or is exceeded on average once every 100 years. The terms 100 year flood, 20 year flood, 5 year flood etc, have been used in this study. See also annual Exceedance probability (AEP)
AEP	Annual Exceedance Probability, is a term used to describe flood size. AEP is the long-term probability between floods of a certain magnitude. For example, a 1% AEP flood is a flood that occurs on average once every 100 years. It is also referred to as the '100 year flood' or 1 in 100 year flood'. The terms 100 year flood, 20 year flood, 5 year flood etc, have been used in this study. See also average recurrence interval (ARI).

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