7.0 Tailings Storage Facility

7.1 Summary

The overall strategy to manage the risk of environmental harm from the tailings storage facility (TSF), in particular seepage, comprises a multiple lines of defence strategy that has been developed for the three key stages of the life of the TSF as follows:

- Design Stage
  - Decommissioning the existing Cell 1
  - Incorporating seepage control measures in the design of the perimeter TSF embankment, including a compacted low permeability clay cut off into the foundation and a low permeability clay core to the embankment
  - Incorporating additional seepage control measures, including a low permeability geopolymer cut-off wall below the embankment to the eastern wall downgradient of the regional groundwater flow, as well as recovery bores downstream of the embankment for the full perimeter of the TSF, to intersect and capture seepage flows
  - Modifying the current tailings and water management practices, to keep ponded water away from the perimeter embankment.
- Operations Stage
  - Modifying the current tailings and water management practices, to minimise the risk of the tailings oxidising and generating acidic runoff
  - Monitoring the performance of the TSF to measure the actual seepage control performance against the predicted performance as part of an 'observational approach'
  - Managing the network of seepage recovery bores so that while seepage from the TSF is recovered, regional groundwater levels surrounding the TSF are not affected
  - Returning all recovered seepage water to the TSF water management dam, for re-use in the processing plant.
- Closure and Rehabilitation Stage
  - Tailings placement to the TSF ceases
  - Re-profile the tailings surface to provide a well graded surface that promotes surface runoff and prevents ponding
  - Construct a low permeability cap across the final landform surface
  - Construct a surface water management system across the TSF to collect rainfall and discharge this clean water to the surrounding environment in a controlled manner. Monitoring data and erosion modelling will be used to verify the rehabilitation design provides adequate protection against erosion.

- Maintain the recovery bores until the seepage head within the TSF has been lowered to the design level
- Monitor the groundwater levels around the perimeter of the TSF for a period of five years after the recovery bores have been decommissioned, to ensure that the ongoing seepage performance meets the design expectations, with limited impacts to the regional groundwater regime.

The approach to managing the TSF so that it will not impact on the receiving environment has been summarised in the Table 7.1.

Table 7.1

TSF Risk Management

Risk	Mitigation	Monitoring	Contingency
Surface water overflow	Runoff and decant water to flow to Water Management Dam Water Management Dam designed to be above the 1 in 500-year flood level All runoff and decant water in the Water Management Dam to be reused in the processing plant.	Regular updating of the OPSIM modelling of the site water management system, to minimise overflow risk Regular inspection of the decant system, to ensure efficient operation.	Pump water from Water Management Dam to the underground void storage Increase the capacity of the Water Management Dam.
Failure of TSF embankment	Design in accordance with ANCOLD guidelines for high hazard dams Engineering analysis of embankment stability has confirmed a factor of safety well in excess of minimum requirements.	Regular inspection of embankment integrity to be undertaken Monthly piezometric monitoring of phreatic surface levels within embankment.	Engineered remediation measures in accordance with ANCOLD guidelines.
Erosion of outer face of TSF embankment	Only hard durable NAF rock that is resistant to erosion, is to be used on outer face. Runoff from outer face to pass through sediment ponds.	Regular inspection of integrity of rock face to be undertaken. Monthly monitoring of sediment in sediment ponds.	Replace any rocks showing signs of erosion, with more competent material.
Seepage from TSF	Embankment to have clay core with cut-off key Ponded water in TSF to be kept away from perimeter embankment Geopolymer barrier to be installed around eastern embankment Network of recovery bores to be installed around entire TSF perimeter TSF to be capped with low permeability layer, to prevent ongoing entry of water at closure Maintain recovery bores post closure, until seepage head in TSF reaches design level.	Ongoing monitoring of seepage rates through recovery bores and observation bores Monthly inspection of embankment for evidence of seepage.	Increase the number or pumping rate of recovery bores Install seepage collection trenches.

7.2 Design Strategies to Manage Environmental Impacts

7.2.1 Decommissioning Existing Cell

There has been a history of seepage from the current TSF cell expressing near the toe of the TSF and reporting to Surprise Creek. While there have been a number of measures taken to control these seepage issues, decommissioning the cell is the best option to control the seepage problem in the long term.

Key features of the strategy for cell decommissioning and rehabilitation of the final landform include:

- Stop placing tailings in the existing cell – this will limit the gradually increasing head of water within the stored tailings
- Re-profile the surface of the TSF to provide a well-graded final landform surface that promotes surface runoff and prevents ponding. This final landform would also eliminate the ponding of water against the perimeter embankment, as occurs at present
- Construct a low permeability cap across the final landform surface. This cap would reduce the infiltration of water, limit oxidation of the tailings surface to prevent the generation acid seepage, and provide a suitable medium for establishing vegetation across the TSF surface
- Construct a surface water management system across the TSF to collect rainfall, and discharge this clean water to the surrounding environment in a controlled manner. The surface water management system would include graded drains and rock lined chutes, with flows routed through sediment ponds during the establishment phase.

7.2.2 New Cell Embankment Design

The perimeter embankments of the proposed TSF cells have been designed by Alan Watson Associates in general accordance with the ANCOLD Guidelines (1999). A summary of the stability assessment of the embankments is given in Appendix G. Studies undertaken as part of the design include:

- Characterisation of the physical properties of the tailings, foundation materials and potential construction materials
- Development of design criteria for a range of embankment loading conditions
- Analysis of long-term embankment stability for a range of loading conditions.

Key seepage control features of the proposed embankment design include:

- A cut-off key comprising compacted low permeability clay, which would be included below the embankment to provide a barrier to seepage flows through upper zones of potentially higher permeability material. The key would comprise clayey sands and gravels that have been identified across the proposed TSF footprint.

- A perimeter embankment, comprising a central compacted low-permeability clay core, supported by NAF rock-fill outer shoulders. The clay core would be integral with the underlying clay cut-off.

A plan view and cross sections of the embankments of the new cells (Cells 1 and 2) are shown on Figures 7.1 and 7.2.

Table 7.2 presents the design criteria for long-term embankment stability, together with the calculated Factors of Safety (FoS) as presented by Alan Watson Associates. The results of this analysis demonstrate that the long-term embankment stability meets the design criteria.

Table 7.2
Adopted Target Factors of Safety

Loading Condition	Description	Design Criteria Minimum FoS	Calculated FoS
Long term/steady state	Considers embankment stability under assumed worst-case steady state seepage conditions.	1.5	1.8
End of construction	Considers embankment stability immediately following completion of construction. Incorporates excess pore pressures developed within the embankment.	1.3	1.3
Seismic condition	Considers embankment stability as per the steady state conditions, with seismic (earthquake or tremor induced) effects.	1.1	1.2

7.2.3 Additional Seepage Controls

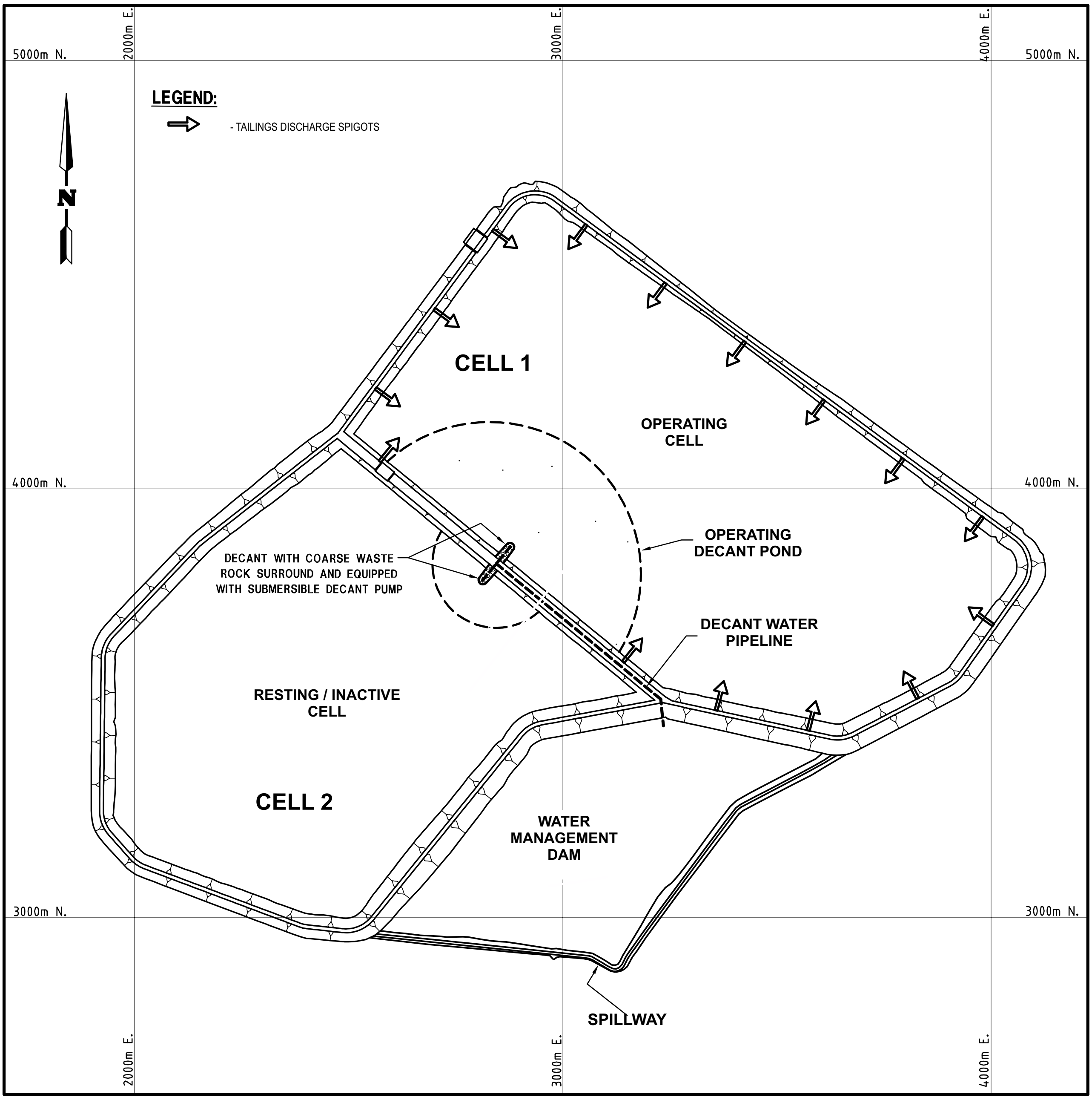
Given the historic seepage issues at the existing cell, further seepage control measures are proposed for inclusion in the design of Cells 1 and 2 as additional lines of defence to control seepage. These proposed measures, and risk assessments of the measures, are described further below.

Geopolymer Barrier

A geopolymer cut-off barrier was constructed as a trial around the existing cell in 2005. This barrier was constructed by drilling a series of boreholes along the perimeter of the toe of the TSF embankment, and injecting a geopolymer into the borehole that penetrated permeable zones, to form a low permeability material. The spacing of the geopolymer injection sites was of the order of 2 m.

Preliminary observations show that previously wet zones around the TSF toe and seepage to Surprise Creek have dried out. Further monitoring is proposed to confirm that the work has been effective in the longer term.

Following the success of this previous work, it is proposed that the geopolymer barrier will be extended underneath the cut-off key of the eastern embankments of Cells 1 and 2, which are down-gradient of the TSF footprint. The primary purpose of the cut-off barrier is to provide an additional line of defence to cut



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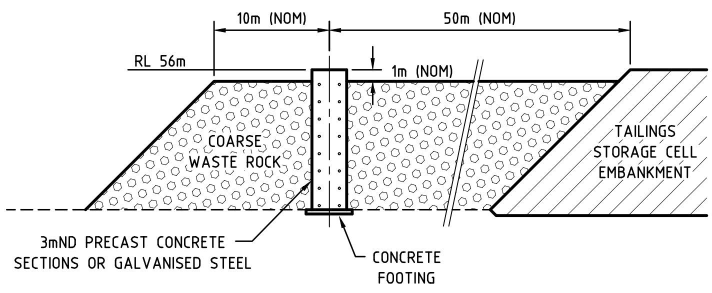

DECANT CONCEPT

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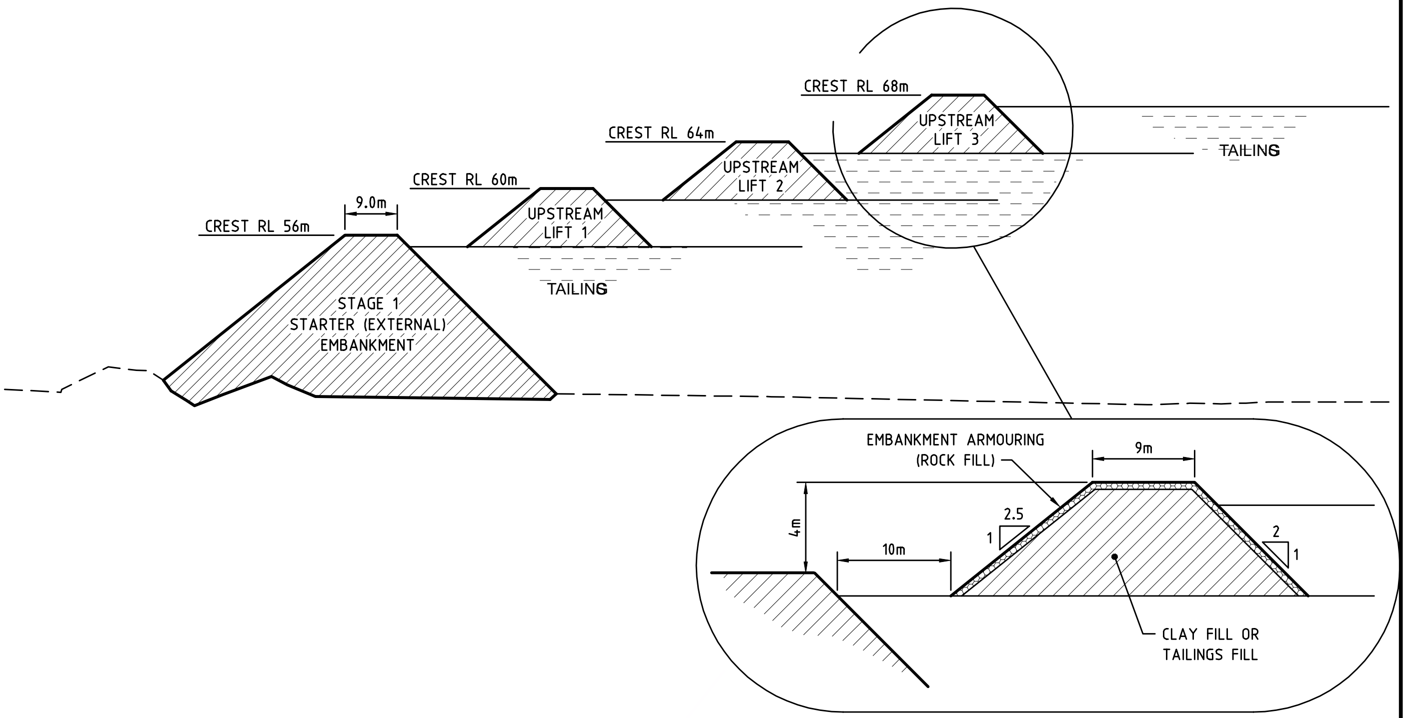
Source: Allen Watson Associates, Cad file 0102-AUS-001-010, Sept. 2003

xstrata / URS	McARTHUR RIVER MINE OPEN CUT PROJECT PUBLIC ENVIRONMENTAL REPORT			**CONCEPTUAL TAILINGS STORAGE CELL OPERATION AND DECANT DETAILS (CELLS 1 & 2)**	
	Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **7.1**	Rev. A
	Job No.: **42625552**	File No. 42625552-g-199.cdr			A4



EXTERNAL EMBANKMENT LIFT CONFIGURATION

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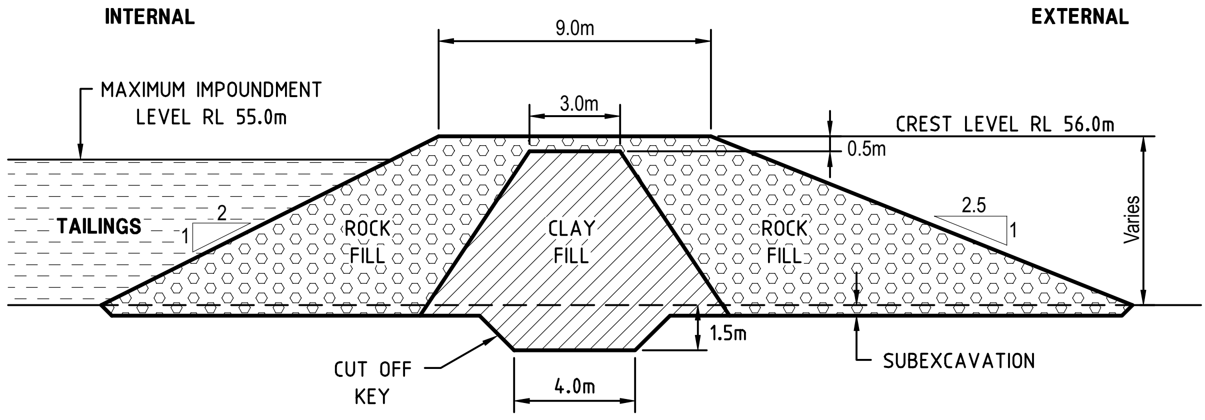


TYPICAL EMBANKMENT SECTION

NOT TO SCALE

Source: Allen Watson Associates, Cad files 0102-AUS-001-006 & 0102-AUS-001-010, Sept. 2003

xstrata

URS

McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

TAILINGS STORAGE FACILITY EMBANKMENT CROSS SECTIONS

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **7.2**	Rev. A
Job No.: **42625552**	File No. 42625552-g-172.cdr			A4

off seepage through the upper sand and gravel soils, as well as through the upper fractured zones of the underlying dolomitic siltstone.

Modelling of the seepage performance of proposed Cells 1 and 2 predicts that the cut-off barrier will reduce surface expression of seepage. However, this modelling also indicates that an elevated groundwater mound would extend outside the footprint of the TSF, which may, in the latter period of the mine life (25 years), express in localised depressions such as old borrow pits, drainage channels and creek systems. This has been addressed in the risk assessment provided below.

The key risks associated with the proposed geopolymer barrier have been assessed. These include:

- A risk of ongoing seepage passing beneath the cut-off barrier and expressing downstream of the TSF. This is indicated by the results of long term seepage modelling for the final proposed TSF geometry, and is primarily a function of the higher permeability of the basement rock and the driving head within the TSF. This risk increases towards the end of the 25 year mine life, as the level of the TSF is raised, however it reduces after closure when the groundwater mound within the TSF reduces.
- A risk that the geopolymer material could break down with time, reducing its effectiveness. This risk is considered to be relatively low in the short to medium term, given the expected reasonable quality of seepage flows that could be expected. However, when considering the longer term, there is limited precedent to confirm the longevity of the cut off wall.

The cut-off barrier would provide a benefit in the short to medium term in limiting the risk of seepage flows expressing at the surface downstream of the TSF. However, given the key risks described above, a long-term seepage control strategy will be required. In this respect, recovery bores are proposed, which would provide an additional and robust long-term management solution to control any seepage risks from the TSF. This is discussed further below.

Recovery Bores

To mitigate against the risk of an elevated groundwater mound developing in the long-term outside the footprint of the TSF, it is proposed that a series of recovery bores will be drilled at regular intervals near the toe of and and around the full perimeter of the TSF, to pump out seepage flows from the TSF.

The design of the recovery bores will be further developed during detailed design, but conceptually comprises bores based within the underlying dolomitic siltstone. The bores would be between 10 m and 30 m deep, and spaced between 50 m and 200 m apart, depending upon the subsurface conditions. Water will be pumped from the bores on a regular basis to the water management dam, and will be re-used within the processing plant. After mine closure, the seepage flows collected will be pumped to the pit.

Seepage modelling indicates that the recovery bores will lower the groundwater mound under and around the general TSF area over time, and will limit the advancement of the groundwater mound significantly beyond the recovery bores.

An ‘observational approach’ is proposed to be used to manage seepage flows from the TSF, comparing the predicted seepage performance from the mathematical models to the actual seepage performance determined by regular monitoring. This observational approach would include:

- Additional site investigation undertaken to design the recovery bore system. This investigation will include test pumping of the foundation strata.
- Revising the mathematical seepage model to consider the results of the additional site investigation
- Designing the recovery bore system will be designed based on the revised mathematical seepage model
- Implementing a monitoring program will be implemented to assess the seepage performance of the TSF. The results of the monitoring will be audited and reviewed on an annual basis and compared to the mathematical model. Adjustments to the mathematical model may be warranted depending upon the results of the monitoring and revised predictions of performance may also be required.
- Additional recovery bores installed as a contingency measure, additional recovery bores can be installed if the monitoring indicates poor seepage performance which could occur, say, due to an unexpected localised high permeability zone within the foundation. Seepage collection trenches may also be utilised in areas where the bedrock has a low permeability, which may limit yields from the recovery bores.

The key risks associated with the proposed recovery bores after mine closure have been assessed. These include:

- Power supplies may be decommissioned and alternate power supplies such as solar or wind power may need to be provided
- Ongoing management of the recovery bores will be required including collection and interpretation of monitoring data until the seepage head within the TSF is reduced to the design level. MRM has made a commitment to provide resources for the ongoing management of the monitoring of the site until closure criteria have been met.
- Infiltration of rainfall into the TSF surface could be an ongoing source of seepage water, which would need to be pumped out. This risk will be managed by developing a robust design for the cover of the TSF, and establishing a sustainable vegetative cover to evapo-transpire moisture from within the upper surface of the cap. The ongoing competence of the cap will be checked by inspections undertaken as part of the regular monitoring program.

MRM has made a commitment to the long term (post mine closure) operation, including monitoring and maintenance of the recovery system, until closure criteria have been met and recovery wells are no longer required.

Water Balance

The TSF seepage recovery bores will return the collected seepage to the water management dam. There is potential for the returned seepage water to affect the water balance of the mine water management system and the overflow probability of the water management dam if the net rate of seepage return is large relative to other inflows to the TSF.

Water management planning using OPSIM water balance modeling for the Open Cut Project has assumed a conservative assumption of no seepage losses from the TSF. Thus any seepage that is returned to the

TSF from the recovery bores has already been included in the water balance modelling. However, there is a risk of natural groundwater in the vicinity of the TSF being intercepted by the recovery bores and pumped to the TSF. This could increase the total volume of water in the system beyond that assumed by the OPSIM model. The effect of any additional natural groundwater to the water management system will be assessed with revised OPSIM modeling to ensure that the water management strategies (procedures, and infrastructure for transfers and storage) will maintain the containment criteria of 1 in 500-year overflow protection. The OPSIM modeling will be audited annually and used by trained site personnel for operational reviews of the overflow risk.

The MODFLOW groundwater modeling of the TSF seepage recovery system indicates that the additional natural groundwater return to the water management dam may be up to 1,300 m^3/day during the first 10 years of operation. This represents approximately 20% of the average total water inflow to the water management dam (URS, 2005b). The return rate would decrease after the first 10 years. This additional volume of water will be accommodated within the water management system to maintain the 1 in 500-year TSF overflow criterion.

Several contingency options for water management can be employed to achieve the containment criteria. These include the following:

- Reducing the water intake from the MIMEX borefield. As can be seen from Figure 3 in the EIS Supplement (URS, 2005b), the average daily water makeup from the MIMEX borefield is 1,282 m^3/day. This is almost identical to the additional volume likely to be input from the TSF recovery bores (1,300 m^3/day). Substituting one source of groundwater for the other will have virtually no impact on the overall water balance.
- Optimising the elevation of the TSF water management dam embankment and spillway to increase capacity of wet weather containment storage
- Strategic disposal of seepage water recovered from the TSF related to quality and available storage as described in Table 7.3.

Table 7.3
Seepage Return Disposal Options Relative to Quality

Seepage Return Quality	Disposal Options
Worst Case	
Dirty relative to TSF Water Management Dam.	Dry Weather - Application of seepage return water as low rate wide spread irrigation over the TSF active cell during dry weather. Application rate and area monitored daily and adjusted to ensure no net generation of runoff and ponding across the tailings surface. Wet Weather - Transfer to underground void storage Contingency for full underground void storage can be a new temporary water evaporation dam (up to approx 20 hectares area for 1300 m^3/day seepage return) in Stage 3 footprint of OEF-PAF zone. Overflows contained by PAF Pond. Contaminant residue from temporary evaporation ponds buried in PAF cell upon pond decommissioning. Ponds not required later in mine life when rate of seepage return reduces
Likely Case	

Seepage Return Quality	Disposal Options
Similar quality to TSF water management dam. Dirty relative to PAF Pond.	Apply irrigation within the internal area of the TSF water management dam to increase evaporation loss. Increase application frequency (consumption) of dust suppression water in the pit and plant catchments during dry weather.
Possible Case	
Similar quality to PAF Pond.	Dust suppression consumption in the active working of the OEF PAF cell.
Best Case	
Suitable quality for irrigation.	Applied as irrigation of OEF progressive rehabilitation areas.

The OPSIM water balance modeling will be used to determine the most effective contingency option to regularly assess the risk of overflow relative to amount of stored mine water, infrastructure capacity and operational practices. The OSPIM model updates will take account of data obtained from the comprehensive monitoring program of the overall water management system including:

- Automated continuous monitoring of free surface water levels and corresponding storage volumes in all mine water storages
- Water quality in mine water storages and mine water sources
- Quarterly monitoring of phreatic surface levels of water in the tailings
- Flow meters on water transfers, mine water sources and consumption including seepage recovered from the TSF and process plant water balance and pit dewatering
- Monitoring of rainfall and evaporation with the existing site weather station
- Groundwater levels and quality in the area of seepage recovery and groundwater levels beyond the area of seepage recovery
- As-constructed storage curves (elevation-area-volume characteristics) of the key water storages updated as required for dams subject to sediment accumulation or upgrade over mine-life
- Audits of water sources and consumption.

7.2.4 Tailings and Water Management

As discussed above, there have been historic seepage issues at the existing TSF cell. At McArthur River mine, the historic tailings placement has been by a central thickened discharge, which builds a 'cone' of tailings in the centre of the TSF, with water shed to the perimeter embankment from where it flows to the water management dam.

Central thickened discharge has the advantage of providing a final landform that sheds water and looks relatively natural, and requires minimal final rehabilitation earthworks. It is a commonly used tailings management method. However, during operation, it does pond water against the perimeter embankment, which increases the risk of seepage along the embankment perimeter.

Because of the concerns about seepage expression under the embankment, it is proposed that a new tailings and water management strategy will be implemented for Cells 1 and 2. Key features of this strategy include:

- Tailings will be beached against the perimeter embankment by use of a perimeter main with spigot discharge points
- The placed tailings are expected to provide a low permeability layer (of the order of $5x10^{-8}$ m/sec) against the perimeter embankment
- Decant water will be ponded in the centre of the TSF, away from the perimeter embankment
- The decant pond will be managed to limit the volume of water stored across the surface of the TSF.

7.3 Operational Strategies To Manage Environmental Impacts

There are a number of operational strategies proposed to be implemented to reduce the risk of the TSF generating environmental harm. These are discussed below.

Tailings Management

Placing tailings using a spigotted discharge system around the cell perimeter will minimise the risk of seepage from the TSF, with key benefits including:

- The tailings will be deposited sub-aerially in thin layers to maximise the density of the tailings beach against the embankment, providing a low permeability beach of tailings between the decant water pond and the perimeter embankment.
- The perimeter spigot discharge system also maintains an appropriate level of saturation/moisture within the tailings beach during the cycling between spigots. This limits the potential for oxidation of tailings that could generate sulphates/acidic water.
- The sub-aerial beach achieves relatively high strength tailings adjacent to the perimeter embankment that allows for further increase in the TSF capacity using upstream lifting (i.e. the embankment raise is supported directly on the tailings). The concept is shown on Drawing 010 in Appendix G. This approach allows for
  - Progressive rehabilitation of the outer slopes of the perimeter embankments
  - Providing access to the various upstream lift benches to install seepage control measures, such as drains, if required
  - Flatter overall slopes and phreatic surface (groundwater) profiles that improve geotechnical stability.

Monitoring

Monitoring the performance of the TSF is an important component of demonstrating that the design assumptions and mitigation measures are effective in controlling the potential environmental impacts from the TSF, both during operations and after closure. Monitoring data will be compiled and assessed at regular intervals and reported as part of the mine's annual environmental monitoring report, which is submitted to DPIFM as part of MRM's obligations under its Mining Management Plan.

It is proposed that the TSF monitoring program will include the following components.

- **Piezometric Levels within the Embankment -** Monitoring bores will be used to measure the phreatic surface through the embankment during the operating life of the TSF, and additional monitoring bores will be progressively installed in each embankment lift. The monitoring bores would comprise slotted uPVC standpipes along the base of the TSF embankment. Monitoring of all bores would be conducted at monthly intervals whilst the tailings dam is being operated.

- **Surface Water Management -** Inspection of the surface drainage system will be undertaken on a monthly basis and also after significant rainfall events. A photographic record of selected locations will be maintained to assess progressive erosion/sedimentation within the drains, and this record will be used to assess whether maintenance work will be required to improve drain performance.

- **Groundwater Management** - Groundwater levels will be recorded at observation bores constructed downstream of recovery bores to assess the effectiveness of the seepage control measures. Samples of groundwater will also be taken to assess water quality. The volume of water pumped from the recovery bores will be measured using a totaliser flow meter.

- **Water Quality –** Samples will be collected for water quality analysis from areas adjacent to the TSF including the sediment ponds, Surprise Creek and the tributary to Barney Creek to the south-east of the TSF. Samples would be taken following significant rainfall events and, if water is present, on a monthly basis. The parameters will be the same as described in Section 8.4 for the NAF runoff water quality monitoring.

- **Decant Pond Water Level -** The decant water pond level shall be observed regularly during inspections of the TSF. The maximum decant pond level shall be clearly marked across the tailings surface. This marker shall be checked on an annual basis in order to assess whether settlement of the tailings has altered the nominated top water level of the decant pond.

- **Decant Pond Water Quality -** Decant pond water quality testing will be undertaken in conjunction with the surface water and seepage monitoring described above (i.e. following significant rainfall events or on a monthly basis if there has been no rainfall event).

- **Embankment Condition** – The condition of the embankment will be inspected on a regular basis, with a particular focus on evidence of surface expression of seepage around the perimeter of the TSF embankment, and surrounding areas.

Typical frequency of the monitoring described above is presented in Table 7.4.

Table 7.4
Summary of Monitoring Frequency

Inspection	Frequency			
	Daily	Monthly	Annual	Special
Piezometric levels		●		
Surface water management		●		
Ground water management		●		
Water quality		●		●
Decant pond water level	●			
Decant pond water quality		●		
Inspect embankment for evidence of seepage		●		
Audit of monitoring results and reporting			●	

7.4 Closure Strategies to Manage Environmental Impacts

The currently proposed closure strategy for Cells 1 and 2 is based on the strategy developed for the closure of the existing cell. However, as closure of the proposed TSF will be approximately 25 years away, the results of monitoring from the performance of the closure of the existing cell will be incorporated into the final closure strategy, which will be modified to incorporate ongoing monitoring and trial work as appropriate.

Key features of the proposed closure strategy developed for the existing cell include:

- Stop placing tailings into the cell – this will limit the gradually increasing head of water within the stored tailings
- Re-profile the tailings surface to provide a well graded surface that promotes surface runoff and prevents ponding
- Construct a low permeability cap across the final landform surface. This cap will limit the infiltration of water, control oxidation of the tailings surface that may generate acidic seepage, and provide a suitable medium for establishing vegetation across the tailings surface.
- Construct a surface water management system across the TSF to collect rainfall and discharge this clean water to the surrounding environment in a controlled manner. The surface water management system would include graded drains and rock lined chutes, with flows routed through sediment ponds during the establishment phase. Water would be discharged to the surrounding environment only after water quality monitoring had confirmed that discharge standards had been reached. Prior to that, water will be discharged to the water management dam. After mine closure, water not suitable for discharge would be disposed of in the decommissioned mine pit.
- Maintain the recovery bores until the seepage head within the TSF has been lowered to the design level. After mine closure, this may require the use of solar or wind powered pumps should the power supply to the site be decommissioned.

- Monitor the groundwater levels around the perimeter of the TSF for a period of five years after the recovery bores have been decommissioned, to ensure that the ongoing seepage performance meets the design expectations.

The cost of an unplanned closure of the mine site is used to estimate the security that is held by the Department of Primary Industries Fisheries and Mines (DPIFM) as required by the *Mining Management Act (2001)*. The security is based on the costs of implementing the environmental requirements to achieve the agreed closure criteria and are presented annually in the Mining Management Plan. The current security bond relates to the underground operation. As the Open Cut Project introduces different environmental liabilities (including the requirement for long-term dewatering of the TSF), MRM will enter into discussion with DPIFM about a new security bonding arrangement for the project.

7.5 Long-Term Stability

7.5.1 Overview

To ensure that the TSF remains stable in the long-term, and will not pose an ongoing threat to the surrounding environment, particular attention has been given to the provision of a competent and long lasting embankment and cover to encapsulate the stored tailings against air or water intrusion.

The embankment design is described in Section 7.2.2, and engineering analysis of the rock-filled embankment has shown that it will be stable in the long-term. This section provides design details of the cap that will be placed over the tailings at closure.

It is important to note that the TSF cover will not be designed in detail and installed until nearer to mine closure, in 25 years time. By that time considerable operational experience and monitoring data will be available to guide the design. This section outlines the design concepts as currently proposed, however it is noted that the design concepts could change as more monitoring and operational information becomes available.

7.5.2 Cover Design

Approach

The design of a TSF cover can include a range of materials and different layers, depending upon the local site conditions and the potential environmental risks that are considered acceptable after rehabilitation. A review of selected literature on the design of covers indicates that the number of layers within a cover may vary from one to five layers. There is also a significant variation in the specified thickness of the various layers.

A summary of the cover layers and their thickness, sourced from selected reference material, is provided in Table 7.5. It is evident from the data presented that there is considerable variation in the thickness of the various layers used, dependent on the climate and other factors.

Table 7.5

Cover Layer Thicknesses

	Aubertin *et. al.* (1997)	Aziz and Ferguson (1997)	Lundgren (1997)	Ayres *et. al.* (2003)	Garvie *et. al.* (2003)	Mylona *et. al.* (2003)	Williams, D.J. *et. al.* (1997)	MRM Concept Design
Climate	Temperate	Temperate	Temperate	Temperate	Semi-Arid	Semi-Arid	Semi-Arid, Sub-Tropical	Tropical Monsoonal
Topsoil (mm)					300	400		200
Protection (mm)		300	2,000	300	1,000	300	1,500	1,000
Drainage (mm)	400							
Barrier (mm)	600	500	500	500		600	500	500
Capillary Break (mm)	1,000					300		300
Total Thickness (mm)	2,000	800	2,500	800	1,300	1,600	2,000	2,000

The conceptual design for the TSF cover at MRM includes a four-layered system, which is considered necessary to provide long-term stability in a tropical monsoonal climate with wet and dry seasons. These layers are described below:

- The first layer to be placed directly on to the surface of the tailings would be a 'capillary break' layer comprising coarse gravel material. This material would have a low fines content, be resistant to attack by potentially acid waters, and have sufficient pore or void size to reduce the rise of salts above the surface of the tailings into the cover and limit evapo-concentration.
- The second layer would be the 'barrier layer' comprising a low permeability, fine-grained material that would be compacted in place to increase its efficiency to act as a barrier to both moisture inflow and oxygen ingress into tailings materials.
- The third layer would be the 'protection layer' and comprise an uncompacted fine-grained material suitable for root growth and would provide some protection to the underlying barrier layer from seasonal variations in moisture content.
- The final layer would be topsoil to provide a growth layer for vegetation.

These proposed four layers are described in more detail below.

Capillary Break Layer

A capillary break layer is required to limit the potential for salts to rise from the tailings surface into the cover and evapo-concentrate at the surface. Should this occur, the salts could have a detrimental impact on the sustainability of vegetation and may also be leached from the cover into surface runoff.

The capillary break layer will be placed at least at the lower third of the perimeter of the cover system, where capillary salt rise potential is likely to be greatest. The capillary break material will comprise a coarse-sized gravel material with minimal fines.

The thickness of the capillary break layer will be dependent upon the nature of the surface of the tailings material at the time of construction of the rehabilitation works. Typically a thickness of 600 mm of material is required. However, given that the tailings will be placed to form a cone, drainage of the tailings surface may enable this thickness to be reduced. A minimum thickness of 300 mm may be achievable.

Barrier Layer

The barrier layer will comprise a fine-grained material with high clay content. This material will be compacted in place to obtain a low permeability layer to act as a barrier to water infiltration and oxygen ingress into the tailings.

Based on the results of laboratory testing in previous studies, the available sandy clay materials that could be sourced from suitable borrow area near the TSF have a permeability of between $2x10^{-8}$ and $5x10^{-8}$ m/sec, if compacted to achieve a density ratio of 98% of the Standard Maximum Dry Density. These tested permeability values are towards the upper range of recommended permeability limits for barrier materials.

Protection Layer

The protection layer will comprise a fine-grained material suitable for the growth of vegetation. Depending on the availability of suitable material at the time, it could be augmented by the clay material identified for use as a barrier layer. In this case it may need to be conditioned with additives (e.g. gypsum and fertiliser) to ensure that sufficient sources of nutrients are available to establish a vegetative cover, and that the materials do not cement or erode with time.

The objectives of the protection layer are:

- To protect the underlying barrier layer from degradation during extreme drying events
- To minimise the potential degradation of the barrier layer due to penetration of roots, cracking due to drying or differential settlement, animal activity including native and stock animals
- Limit the potential impacts of surface erosion due to wind and surface water runoff, which may reduce the effective thickness of this layer in the long term.

Topsoil

The mine area has been mapped to describe general soil types and this mapping indicates that the soils vary according to terrain; ranging from lithosols on hill and ridge tops, to grey and brown cracking clays in gullies and depressions. More detailed discussion of the various soil types available is presented in the Draft EIS (URS, 2005a). Topsoil will be stripped during the construction phase and stockpiled for subsequent rehabilitation activities. This will include adequate topsoil resources for covering the TSF.

It is proposed that further testing and analysis of potential topsoil materials would be completed as part of the detailed design in order to assess the need for additional treatment, such as the addition of gypsum and fertiliser, to promote vegetative growth across the rehabilitated surfaces.

7.5.3 Long-Term Performance Modelling

Approach

The Visual HELP program (version 2.2, Waterloo Hydrogeologic, 2000), which is based on the Hydrologic Evaluation of Landfill Performance (HELP) program, was used to assess the water balance for a range of possible cover designs for maximum long-term performance.

The HELP model was developed by the United States Environmental Protection Agency (USEPA) to assist landfill designers and regulators in evaluating the hydrologic performance of proposed landfill designs. The HELP model is a quasi-two-dimensional, deterministic, water-routing model for evaluating water balances. The water-balance method evaluates:

- Water moving into the TSF (e.g. infiltrating rainfall)
- Changes in the amount of water stored in the TSF elements (TSF cover and tailings material)
- Water moving out of the TSF (e.g. evaporation from the TSF cover, drainage flows, or seepage from the base of the TSF).

Cover Options

Five options were developed for the conceptual cover design to assess the environmental effectiveness of varying layer thicknesses. Details of the five options considered are presented in Table 7.6.

Table 7.6
Summary of Cover Options

Layer No	Layer Description	Layer Thickness (m)				
		Option 1	Option 2	Option 3	Option 4	Option 5
1	Topsoil – vegetated with local grasses	0.2	0.2	0.2	0.2	0.2
2	Protection - sandy clay	0.5	0.5	0.5	0.8	0.5
3	Sand drain		0.3			-
4	Barrier layer - compacted clay (permeability of $2x10^{-8}$ m/s)	0.5	0.2	0.6	0.5	1.0
5	Capillary break layer	0.3	0.3	0.3	0.3	0.3
	Total Thickness	**1.5**	**1.5**	**1.6**	**1.7**	**2.0**

The HELP model was used to simulate the performance of five cap designs for the TSF, using the historic rainfall and evaporation records. Cover performance was assessed on the predicted long-term seepage rates through each cap option. Each of the model runs simulated 100 years of climatic conditions, which were generated from Bureau of Meteorology data for the McArthur River site, localised to relevant climatic conditions using mean monthly rainfalls and temperatures.

The average rainfall for the site area is about 760 mm (predominantly as summer rainfall), while mean annual pan evaporation is about 2,450 mm. This climatic setting results in minor recharge to groundwater through the soil profile. The predicted infiltration rates for each of the cover options is presented in Table 7.7.

Table 7.7
Predicted Cover Infiltration

Description	Predicted Infiltration				
	Option 1	Option 2	Option 3	Option 4	Option 5
Seepage as mm/annum	74	93	72	70	65
Seepage as % annual rainfall	10	12	9	9	8

The modelling results indicate that Option 5 has the least infiltration. Option 5 has the following features:

- The diversion of approximately 16% of rainfall as runoff
- Interception and storage of about 76% of rainfall, which would be removed subsequently from the cap by evapo-transpiration
- Approximately 8% of annual rainfall (65 mm) could infiltrate through the cap. This would assist in reducing the risk of cracking of the cover profile. In the event of extremely dry conditions, cracking could occur, but this is expected to be self healing as summer rains rewet the cover profile.

The figure of 65 mm of annual seepage through the cap has been included in the long-term seepage modelling for the TSF.

7.5.4 Vegetation Cover

It is proposed that the surface of the TSF cover would be protected against long-term erosion by the establishment of a self-sustaining vegetative cover. The vegetation to be established across the covered surface of the TSF will comprise a mixture of native and exotic grasses and shallow rooted tree species such as suitable Acacias. The exotic grasses will be used to quickly establish a vegetation cover while the slower growing native species become established.

The recommended grass species and planting rates for the revegetation program are outlined in Table 7.8. Silk Sorghum is proposed as the dominant initial cover crop species, because it is suitable for rapid and aggressive establishment for erosion control, and mulching of perennial species in the pasture mix.

Table 7.8

Recommended Grass Species Mix

Species	Planting Rate (kg/ha)
Silk Sorghum	20
Rhodes Grass	10
Buffel Grass	10
Indian Couch	8
Purple Pigeon Grass	8
Bambasti Panic	8
Siratro	5
Stylo	5

The topsoil surface of the cover will be susceptible to erosion from wind and rain immediately after construction and during the vegetation establishment period. Erosion protection will be provided to minimise erosion and the loss of seed and fertiliser from the surface of the cover. A range of options is available to provide erosion protection including a number of proprietary surface mat products, straw mulching or hydro-mulching.

Hydro-mulching is a technique that involves mixing a slurry containing, for example, selected seed varieties, fertiliser, hay mulch, water and an adhesive. The slurry is pumped from a large tanker through a high-pressure spray, over the area to be treated. The seed generally adheres to the mulch, which improves the microclimate for germination and establishment.

Hay mulch in the slurry provides cover for the soil to improve pasture growth, modifies the soil surface to assist in erosion control, and improves moisture availability to establishing pasture. The mulch protects the soil surface against raindrop impact, improving the micro-environment for seed germination/establishment by reducing evaporation loss and assisting in the control of surface erosion caused by raindrop impact and overland water flow.

The final land use for the top of the TSF will be confirmed in the Life of Mine Completion Plan which will include rehabilitation strategies developed from experience to be gained from the closure of the existing TSF cell. The current expectation is that it will be retained as an area of stable self-sustaining native vegetation. It is not expected that the area will be used for cattle grazing due to the difficulty in providing access for cattle.

7.5.5 Stormwater Management

Design Objective

The overall design objective of surface water management strategies is to limit erosion of the rehabilitated TSF surface in high intensity rainfall events. This will be achieved by ensuring that:

- Drainage works are designed to convey flows safely from the TSF
- Unlined catchment areas of the drainage system are limited
- Drainage layout and drain types are compatible with their respective capacity to limit erosion and the slopes that the drains traverse.

It is proposed that the drainage works will cater for peak flow conditions, particularly for unlined components of the drainage system. In this respect the design criterion for unlined revegetated drains, rock lined drains, and rock chutes that form the permanent drainage system is for adequate erosion resistance for large storms with up to 1 in 100-year ARI rainfall intensity.

Contour Drains

It is proposed that regularly spaced contour drains will be provided as the primary design mechanism against sheet flow causing rilling and gully erosion of the crest and outer slopes of the TSF.

Across the crest of the TSF, the longitudinal gradient of contour drains will be no flatter than 1 in 200. As such, these contour drains may be susceptible to siltation, however, the general gradient of the crest of the TSF is expected to generate only minor quantities of sediment.

The contour drains will be formed by small embankments as opposed to drains cut into the slope as this ensures that adequate cap depth will remain beneath the drains. The drains will be V-shaped with relatively flat side slopes. Such drains have similar performance to wide drains in terms of limiting peak velocity, but are less prone to siltation when flow is less than the design capacity.

It can be expected that the base of the V-shaped contour drains will eventually silt up and form a parabolic shaped cross-section. Such sediment will not be removed unless an excessive depth of sediment substantially reduces the flow capacity of the contour drain.

It is desirable to retain minor silt deposits (say up to 150 mm thick) in the drains as this greatly assists in maintaining moisture in the soil profile and maximising the success of vegetation growth along the contour drains.

In lesser storm events the deposition of silt promotes shallow flow hydraulics and assists in limiting flow energy. In more intense storm events, the silt deposits erode and consume flow energy.

The contour drains will be spaced to limit the velocity of sheet flow across the surface of the TSF. Under bare earth conditions, the surface of the TSF with an alluvial silt or silt loam cover should be able to resist sheet flow velocities up to 0.6 m/s (IEAust, 1996). Under revegetated conditions, the surface should be able to resist flow velocity up to 1.0 m/s depending on uniformity and condition of the vegetation.

The crest contour drains will discharge into rock-lined channels. Where the channel gradient needs to be steeper than 1 in 20 (5%), rock chute structures will be used. The channel design is discussed further below.

Rock-Lined Channels and Chutes

It is proposed that rock-lined channels and rock chute drop structures will be provided to convey flow from the contour drains safely to the toe of the TSF. Unlined drains are not suitable, because the amount of flow discharging from the contour drains may result in flow velocities exceeding maximum permissible velocities during more intense rainfall events.

Rock-lined channels will be used for drains where the longitudinal gradient is at 1 in 20 (5%) or less.

For steeper drains, the combination of flow forces and gravity forces acting to destabilise the rock armouring are too high to utilise simple rock lined channels, and engineered rock chute drop structures will be used.

The rock-lined channels will be sized as wide shallow V-shaped drains with 1 in 10 side slopes and armoured with 200 mm (D_{50}) rock, laid 500 mm deep. The relatively shallow side slopes of the drain will ensure that flow velocities are adequately limited for the specified rock size, and will allow passage of off-road vehicles across the drains and hence eliminate the need to construct formal access road crossings.

The dimensions of the rock chute drop structures depend on peak flows, slope of the chute, height of the chute, and grading (size) of the rock. The rock chute drop structures are likely to use a rock grading D_{50} of 300 mm. The flow down the rock chute drop structures will have high velocity and energy, and outlet aprons will be provided to dissipate flow energy at the toe of the chute. The rock chute drop structures will be constructed of durable rock, as these structures are required for the long-term stability of the TSF.

7.5.6 Long Term Erosion Protection

Closure Strategy

The proposed TSF rehabilitation design is consistent with current best practice and provides multiple levels of protection against erosion. Continual improvement in the TSF rehabilitation design will be developed during the life of the mine. Furthermore, data from the performance monitoring of the early rehabilitation of the existing TSF cell will be used to adapt the rehabilitation design and to confirm the integrity of the rehabilitation works prior to mine closure. MRM will use the monitoring data and erosion modeling to verify that the rehabilitation design has adequate protection to sustain the integrity of the TSF against erosion in the long term.

Progressive results will be reported to the Northern Territory Government during the mine life through the Mine Management Plan process and agreed measurable mine closure criteria will be defined in the Life of Mine Closure Plan. This approach ensures that adequate objectives and prescriptive rehabilitation processes are provided as commitments for project approval, whilst ensuring mechanisms and commitments are in place for continual improvement and implementation of best practice during the mine life and prior to mine closure.

Rehabilitation Monitoring

Monitoring of the early rehabilitation works for the existing TSF cell will include the performance of capping materials and depth, topsoil cover (i.e. evidence of topsoil erosion and loss), vegetation cover species and resilience, integrity of constructed drainage, erosion and silt accumulation in constructed drainages, net sediment loss rates (tonnes/ha/year), sediment quality, and runoff quality. These monitoring data will be used to review the performance of the rehabilitation works implemented for the existing cell and any deficiencies will be remediated including all relevant aspects and causes of poor performance. For example, if erosion is identified due to insufficient vegetation growth indirectly caused by inadequate topsoil cover, topsoil replenishment and protection against topsoil depletion would be key requirements to remediate the TSF rehabilitation.

Progressive rehabilitation monitoring is a key requirement to adapt and implement remedial and contingency works to achieve the objective of a stable and sustainable landform. The knowledge and experience gained from performance monitoring of the early rehabilitation works will then be applied and adapted to the overall rehabilitation design for closure of the remainder of the TSF.

At the end of mine life, and prior to relinquishment of the mine lease, MRM will provide detailed post-rehabilitation monitoring reports to the Northern Territory Government to demonstrate that the rehabilitated landform is stable and that performance criteria agreed in the Life of Mine Completion Plan have been achieved.

Erosion Modelling

Consideration has been given to the potential to undertake long-term erosion modelling of the proposed landform design for rehabilitation of the TSF to ensure that it provides adequate protection against erosion for long-term integrity after mine closure.

Erosion modelling, also known as landscape evolution modelling, is a newly-developing science that attempts to model the integrated processes and influences of rainfall, runoff, landform geometry and materials, cover protection, and sediment transport to estimate the long-term evolution of landforms due to erosion. Application of erosion modelling (such as SIBERIA software) has been tested in some case studies in the Northern Territory on abandoned mine sites and requires extensive data collection on erosion, hydrology, and sediment transport to ensure adequate model calibration and accuracy in the long-term predictions. To date, the application of erosion modelling has not been adequately tested on vegetated constructed landforms or on landforms with engineered drainage systems. Hence, the technological capabilities and accuracy of erosion-modelling science are not adequate at this stage to improve the proposed rehabilitation design for the TSF particularly as it includes added levels of erosion protection that are not present in the disturbed lands where erosion modelling has been tested to date.

MRM will continue to review the limitations and potential application of erosion modelling technology, and monitor new developments and improvements in the future. When erosion modelling science is sufficiently developed to provide reliable estimates of long-term erosion from engineered rehabilitation landforms, MRM will undertake erosion modelling with the monitoring data gained from early rehabilitation of the existing TSF cell. The modelling results will be used to verify and adapt the future TSF rehabilitation strategy for the Life of Mine Completion Plan.

7.6 Risks to the Receiving Environment

As discussed in the preceding sections, a risk identification and mitigation approach has been adopted to ensure that the design, operational and closure criteria for the TSF will have minimal risk of impacts to the receiving environment.

The low risk rating will be achieved because of the "multiple lines of defence" approach that has been taken to TSF management. Risk minimisation aspects include:

- The predicted long-term seepage volumes are generally low and are of the order of 30 to 40 L/day/m width of the TSF wall. The primary reason for the low seepage volumes is the relatively low permeability of the embankment core, the tailings and the underlying dolomitic siltstone material
- Decant water will be stored at the centre of the TSF, rather than on the periphery thereby reducing the potential for seepage under the embankment
- The tailings will be deposited sub-aerially in thin layers which maximises the density of the tailings beach against the embankment, which provides a low permeability layer between the decant water pond and the perimeter embankment
- The perimeter spigot discharge system maintains an appropriate level of saturation/moisture within the tailings beach during the cycling between the spigots, which limits the potential for oxidation of tailings that could generate sulphates/acidic water
- Geochemical testing indicates that the tailings have an inherent acid neutralising capacity (ANC) which reduces the risk of the tailings oxidising and generating acidic conditions
- The underlying basement sequence has significant buffering capacity, should acidic seepage be generated
- Any seepage that does occur will be contained by a combination of measures including the low permeability clay core and cut-off key in the TSF embankment, the geopolymer cut-off barrier, and the network of recovery bores
- OPSIM modelling has shown that the TSF water management dam will comply with its target overflow probability of a 1 in 500-year annual exceedance probability. Should such a large rainfall event occur, any discharge from the TSF would be into a significant flood flow with dilutions of greater than 1,000 times
- Capping and revegetating the TSF after closure of the mine will limit the potential for future oxidation of the stored tailings, and enable clean runoff to be discharged to the surrounding environment
- Ongoing operation of the recovery bores after mine closure will reduce the groundwater head within the TSF, so that expression of ongoing seepage will not occur on the surface
- A comprehensive monitoring program will be maintained over the life of the TSF and will include the following components:
  - Piezometric levels within the embankment

  - Surface water management
  - Groundwater management
  - Water quality
  - Decant pond water
  - Decant pond water quality
  - Embankment condition

- MRM will continue to be responsible for post mine closure monitoring, and maintenance of the recovery system, until closure criteria have been met and it is demonstrated that recovery wells are no longer required.

7.7 Alternative Seepage Control Measures

A range of alternative seepage control measures were considered during the design of the TSF. These include:

- **Clay lining the base of the TSF** – Seepage modelling indicates that, based on the likely permeability of a compacted clay liner which could be achieved using the materials available at the site, a clay liner in itself would not be able to adequately control seepage from the TSF

- **A deep cut-off barrier around the perimeter of the TSF** – Seepage modelling indicates that, while a cut-off barrier could provide some level of seepage control, the nature of the underlying dolomitic siltstone would limit its effectiveness in the long-term

- **A perimeter cut-off drain around the perimeter of the TSF** – Seepage modelling shows that a perimeter cut off drain would be effective in controlling seepage flows from the TSF, however the depth of drain required would be difficult to construct and to drain under gravity. The proposed recovery bore seepage controls described in Section 7.3.3 replicate the performance of the perimeter cut-off drain while resolving the problem of construction and gravity outflow from the drain.

For the above reasons, none of these alternative control measures is preferred.

7.8 Modelling of Recovery Bore Performance

Modelling of the effects of the recovery bores on seepage levels within the TSF was undertaken as part of the design, and the results were presented in Section 7.4.7 of the Draft EIS (URS, 2005a). Since then, additional modelling of the seepage performance of the TSF has been undertaken using the following mathematical models:

- MODFLOW – a three-dimensional block-centred finite-difference modelling to assess the potential impacts on the regional groundwater levels. A detailed description of the MODFLOW modelling undertaken is presented in Appendix N

- SEEP/W – a two dimensional seepage modelling to assess the seepage performance of the TSF embankment section and seepage controls.

7.8.1 TSF Operation

MODFLOW modelling of the proposed recovery bores was undertaken to assess their impact on the regional groundwater regime. The modelling was undertaken assuming that a total of 32 recovery bores are installed around the perimeter of the TSF. The number and depth of bores actually installed may vary depending upon the results of further detailed design studies. A summary of the modelling results is presented below, and further details are given in Appendix N.

- Pumping the recovery bores over a 10 year period using an average pumping rate of approximately 60 kL/day/bore is effective in limiting seepage impacts typically to the immediate vicinity of the TSF footprint. The model results, shown in Figure 7.3, indicate that, at the modelled pumping rate, groundwater levels will rise within the footprint of the TSF and to the south-west for about 1km. Increasing the pumping rate of the bores along the southern boundary of the TSF would reduce the groundwater rise in the south-west of the TSF.

- Continuing the pumping at the same rate for 25 years of operations shows similar results as indicated on Figure 7.4. While the model result indicates a groundwater level increase of 1 -2 m south-west of the TSF, this can be reduced by increasing the pumping rate of the bores along the southern boundary of the TSF.

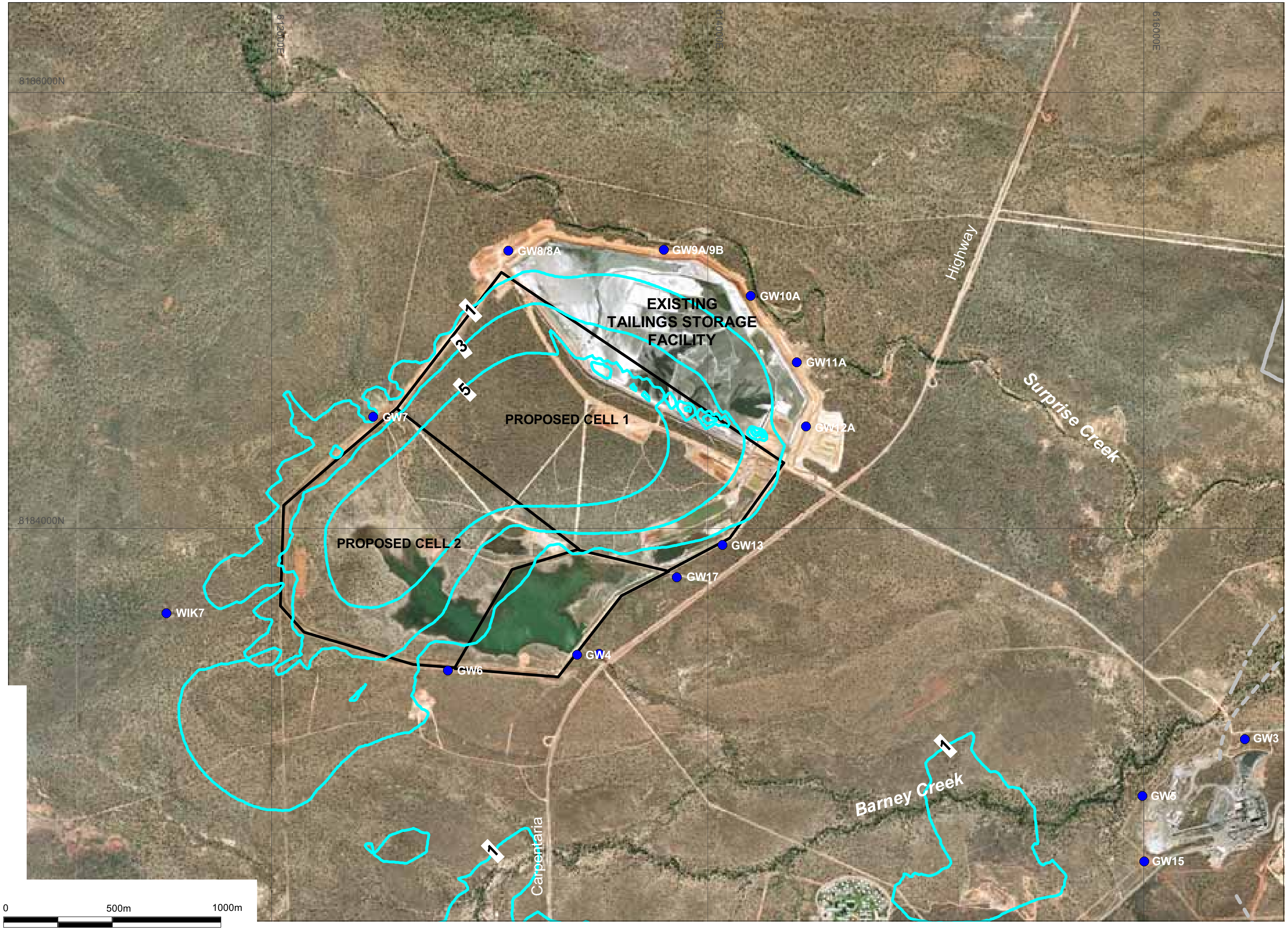
The modelling has shown that judicious variation of the recovery bore pumping rates, which can be determined by using an observational approach, will result in no significant drawdown or mounding of groundwater levels surrounding the TSF during the operational life of the project.

7.8.2 TSF Closure

SEEP/W modelling has been undertaken to assess the long-term performance of the TSF embankment design and seepage controls. The following comments are provided based on the results of the SEEP/W modelling:

- The recovery bores gradually lower the head of water within the TSF with time, as presented in Figure 7.5, and the volume of seepage pumped from the bores also decreases with time, as presented in Figure 7.6. Figure 7.5 shows that between 30 and 50 years after closure, the groundwater level will have reached the pre-TSF levels. By this time there will be no more TSF seepage as there will be no hydraulic head in the TSF. By then the recovery bore pumping can cease and seepage will no longer require management.

- The rate of lowering of the head of water within the TSF and the volume of seepage pumped does not vary significantly for sandy clay or sandy soils in the upper horizons. This demonstrates that the seepage performance is controlled by the nature of the underlying dolomitic siltstone material.



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Horizontal Datum: AGD84, Zone 53

Date of Aerial Photography, 2001

● Groundwater Monitoring Bore

—5— Groundwater Level Change (m)

URS

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McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

Drawn: VH

Approved: CMP

Date: 27-06-2006

Job No: 42625552

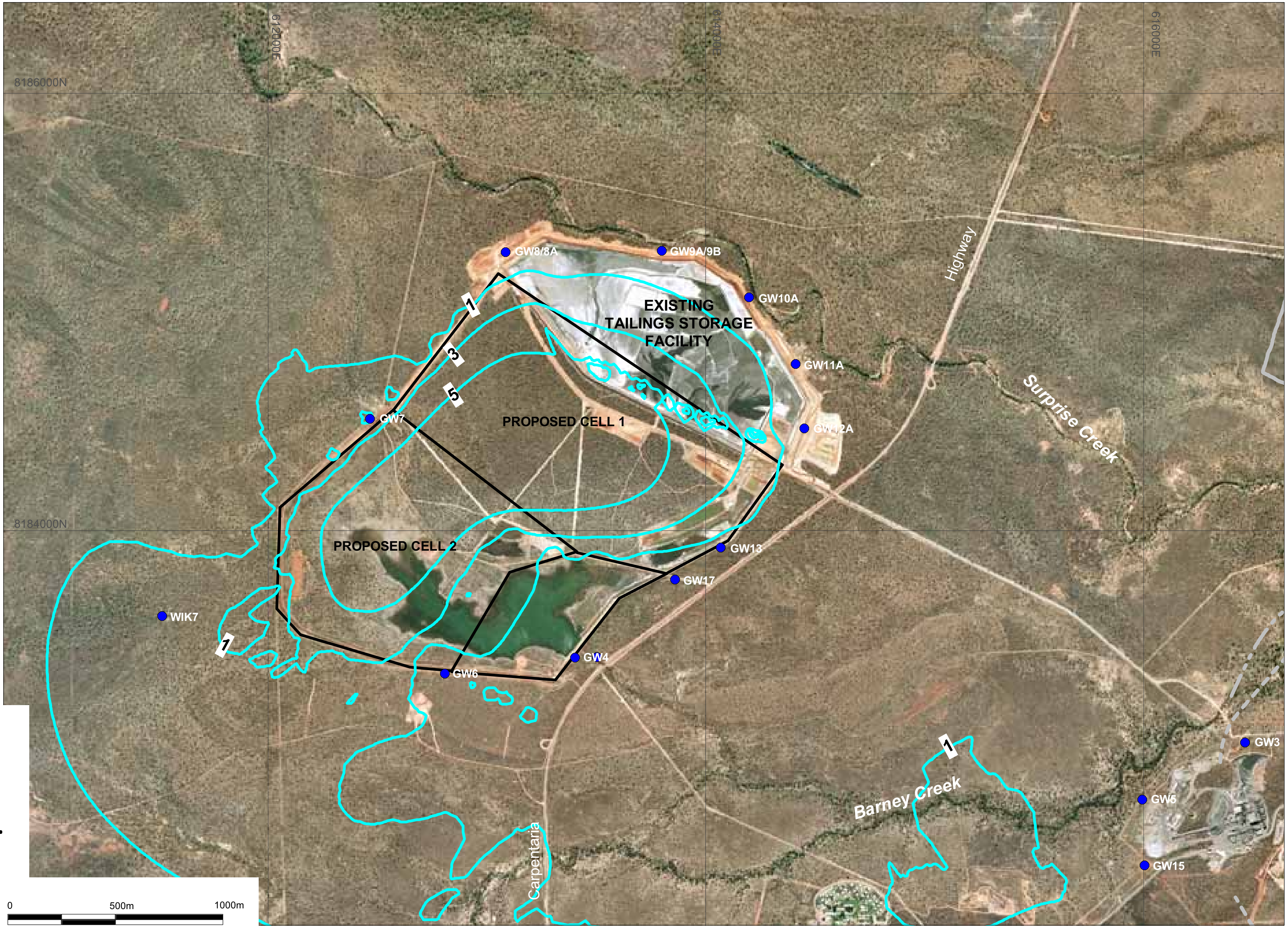
File No: 42625552-g-192b.wor

PREDICTED GROUNDWATER LEVEL CHANGE FROM RECOVERY BORES - 10 YEARS OF OPERATION

Figure: 7.3

Rev: B

A4



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Scale 1:25 000 (A4)

Horizontal Datum: AGD84, Zone 53

Date of Aerial Photography, 2001

● Groundwater Monitoring Bore

—5— Groundwater Level Change (m)

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Job No: 42625552 | File No: 42625552-g-193b.wor

PREDICTED GROUNDWATER LEVEL CHANGE FROM RECOVERY BORES - 25 YEARS OF OPERATION

Figure: 7.4

Rev: B

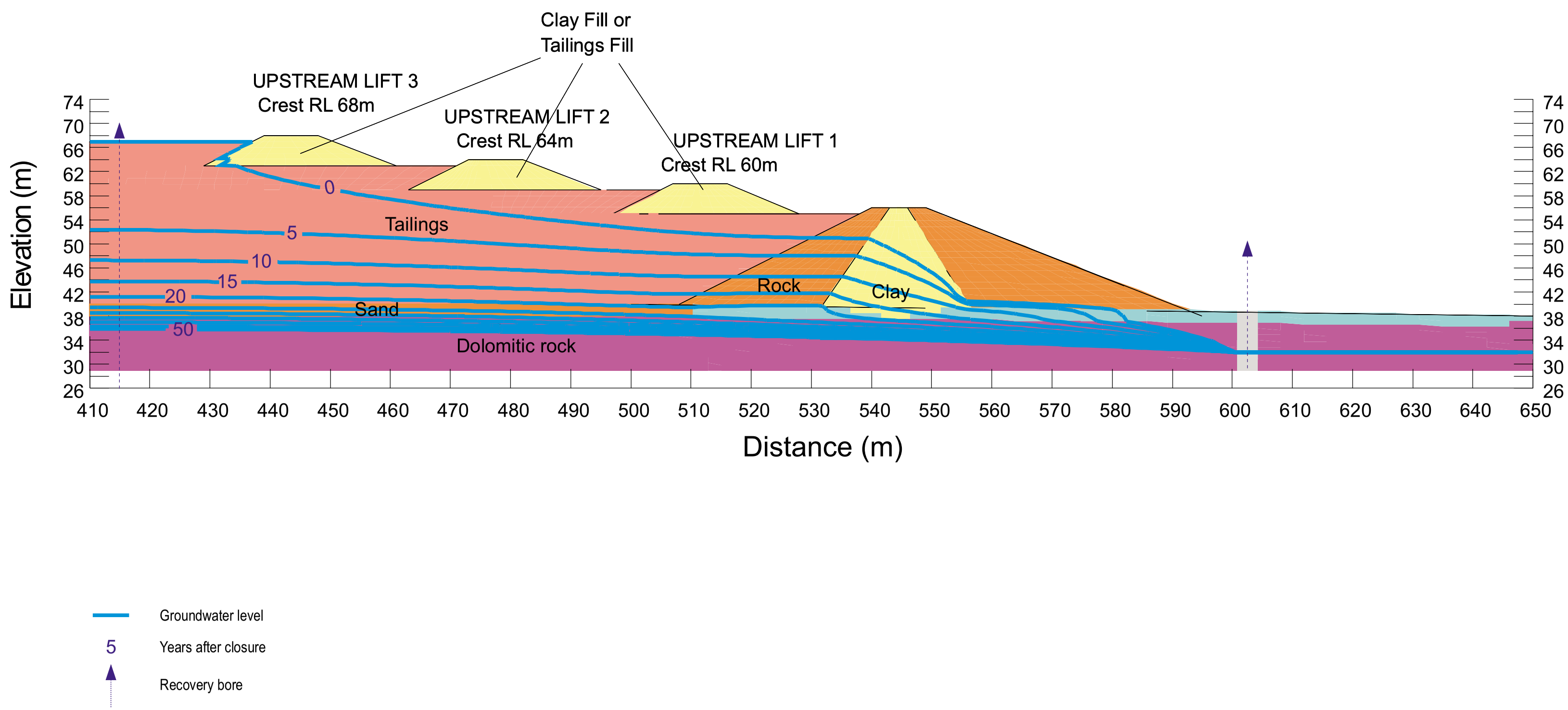
A4

K dolomitic rock=10-6 m/s

Description: McArthur River Mine
Comments: Seepage Analysis for Long Term Condition
File Name: MRM017a.sez
Last Saved Date: 29/05/2006
Last Saved Time: 2:08:21 PM
Analysis Type: Transient
Analysis View: 2-D

Case 17a - AFTER CLOSURE
Drain well in operation for 50 years after closure
Sand overlying dolomotic rock

dam material kh=1x10-8 m/s ; kv/kh=0.5
tailings material kh=1x10-7 m/s (short term) kv/kh=0.5
sand and rock kh=1x10-6 m/s kv/kh=0.5
dolomitic rock kh=1x10-6 m/s kv/kh=0.5
Initial Conditon - Water Table in 2039 (end of Case 8a-3-Lift 3)



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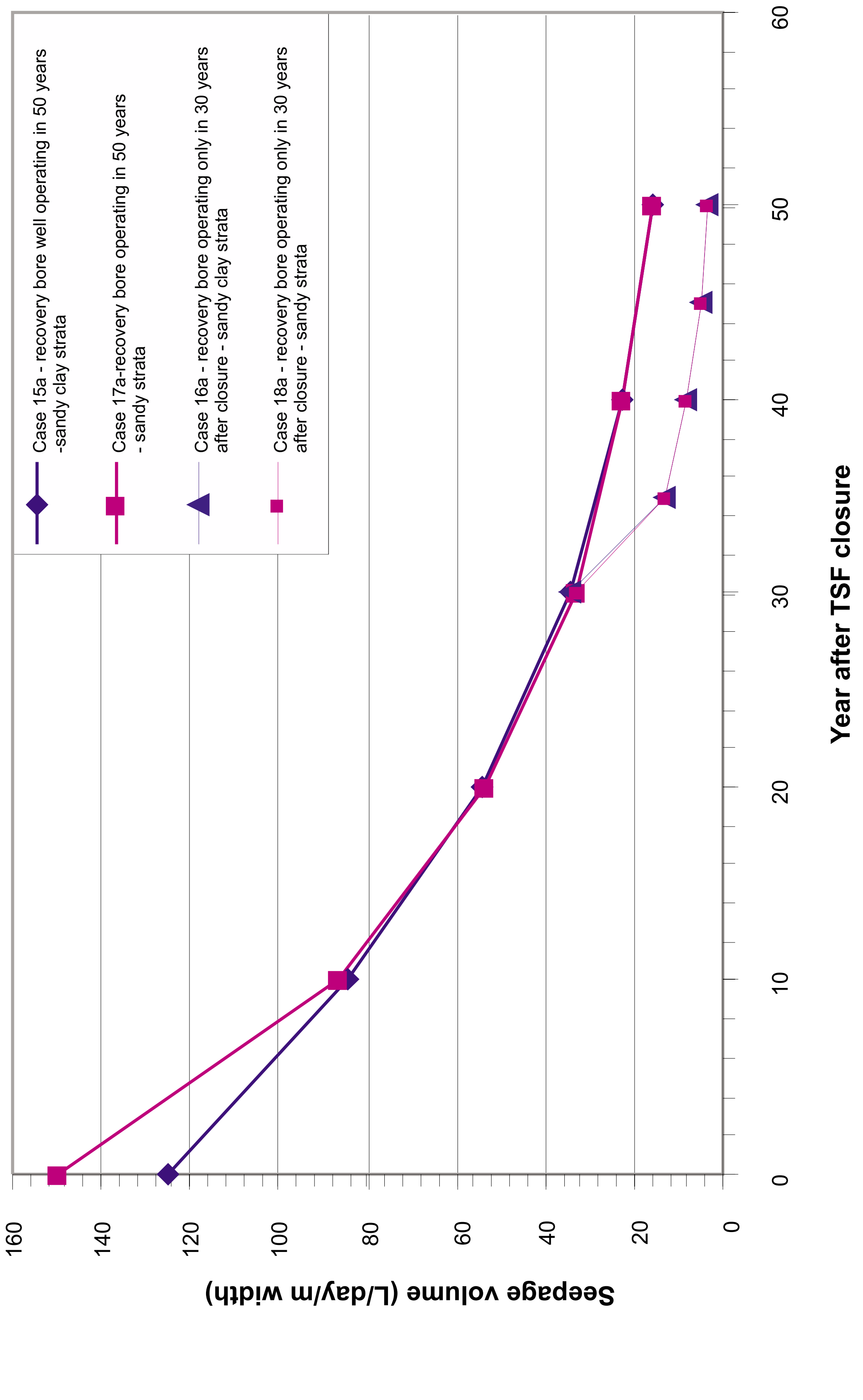
MODELLED PHREATIC SURFACE
50 YEARS POST CLOSURE

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **7.5**	Rev. A
Job No.: **42625552**	File No. 42625552-g-194.cdr			A4



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MODELLED SEEPAGE VOLUMES 50 YEARS POST CLOSURE

Drawn: VH	Approved: CMP	Date: 27-06-2006	Figure: **7.6**	Rev. A
Job No.: **42625552**	File No. 42625552-g-195.cdr			A4

- A sensitivity analysis was carried out to assess the impact of a lower permeability base rock. Lowering the permeability of the base rock shows that the seepage rates are generally lower and the time taken to lower the head of water within the TSF is increased. The result of modelling this worst case scenario is shown in Figure 7.7. However there is considerable evidence that the underlying dolomitic siltstone has a higher permeability than this 'worst case' scenario.

MODFLOW modelling of the proposed recovery bores has been undertaken to simulate the performance of the TSF with respect to impacts on the regional groundwater regime following its closure. The modelling has been undertaken assuming that a total of 32 recovery bores are installed around the perimeter of the TSF. Again, the number and depth of bores actually installed may vary depending upon the results of further detailed design studies.

A summary of the MODFLOW modelling results is presented below. Further details are provided in Appendix N.

- Pumping the recovery bores over a 10 year period after TSF closure using flow rates of approximately 12 kL/day/bore is effective in drawing down the elevated groundwater levels that have built up during operations, with the seepage impacts confined typically to the immediate vicinity of the TSF footprint as shown in Figure 7.8. The model results show a slight (1 to 2 m) mounding of groundwater levels to the south of the TSF. This mounding can be reduced by increasing the pumping rate beyond that assumed in the model for the bores along the southern boundary of the TSF.

- Pumping the recovery bores over a 25 year period after closure, using the same assumed flow rates, is effective in managing seepage impacts over the longer term. Seepage impacts are confined typically to the immediate vicinity of the TSF footprint, as shown in Figure 7.9, again with a slight mounding to the south.

The modelling has shown that judicious variation of the recovery bore pumping rates, which can be determined by using an observational approach, will result in no significant drawdown or mounding of groundwater levels surrounding the TSF following its closure. Once the hydraulic head within the TSF is removed within 30 to 50 years after closure, no further seepage will be generated and no further pumping of the recovery bores will be required.

7.8.3 Drawdown Impacts to Surrounding Groundwater Resources

Results of the modelling described above show that the proposed recovery bores can effectively capture the seepage from the TSF and contain potential seepage impact to within the TSF footprint area both during operations and following mine closure. The proposed observational approach will enable pumping rates to be varied across the recovery bore network, and to adapt to potential variations between the actual and modelled seepage performance. On this basis, no significant environmental impact is expected from TSF seepage or from the operation of the recovery bore network on the regional groundwater system.

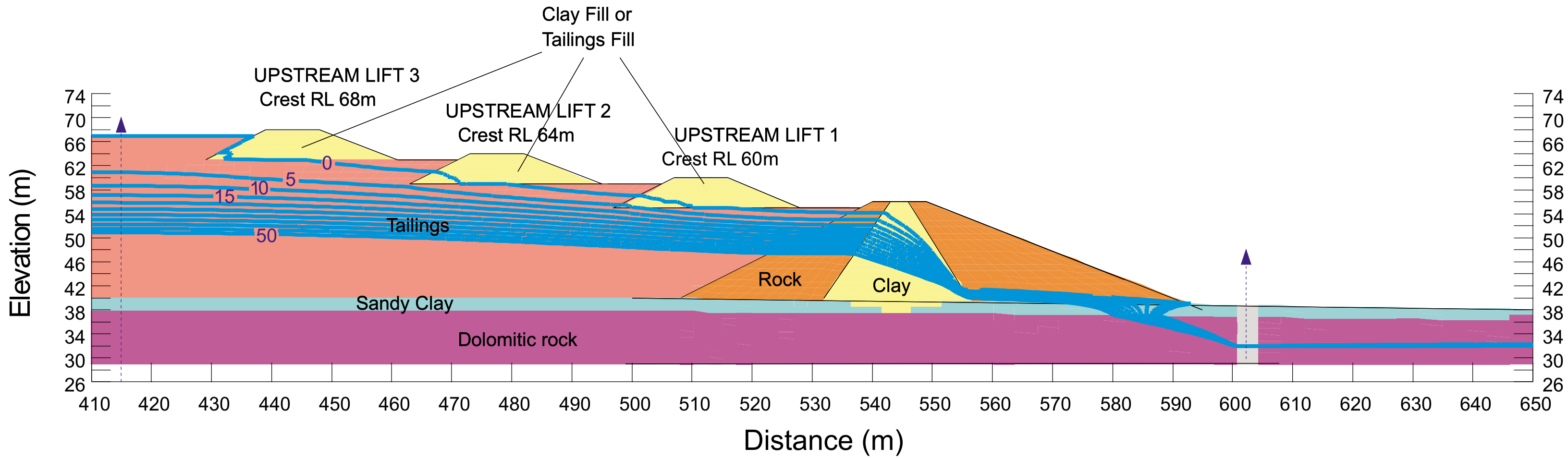
The geopolymer wall that is proposed below the eastern embankment of Cells 1 and 2 will provide an additional line of defence for containing seepage from the TSF. However, following decommissioning of the recovery bore network, this geopolymer wall may cause a build-up of groundwater upstream of the

K dolomitic rock=10-7 m/s

Description: McArthur River Mine
Comments: Seepage Analysis for Long Term Condition
File Name: MRM015.sez
Last Saved Date: 31/05/2006
Last Saved Time: 1:08:53 PM
Analysis Type: Transient
Analysis View: 2-D

Case 15 - AFTER CLOSURE
Drain well in operation for 50 years after closure

dam material kh=1x10-8 m/s ; kv/kh=0.5
tailings material kh=1x10-7 m/s (short term) kv/kh=0.5
sandy clay kh=1x10-8 m/s kv/kh=0.5
dolomitic rock kh=1x10-7 m/s kv/kh=0.5
Initial Conditon - Water Table in 2039 (end of Case 10-3-Lift 3)



Groundwater level
5 Years after closure
Recovery bore

xstrata
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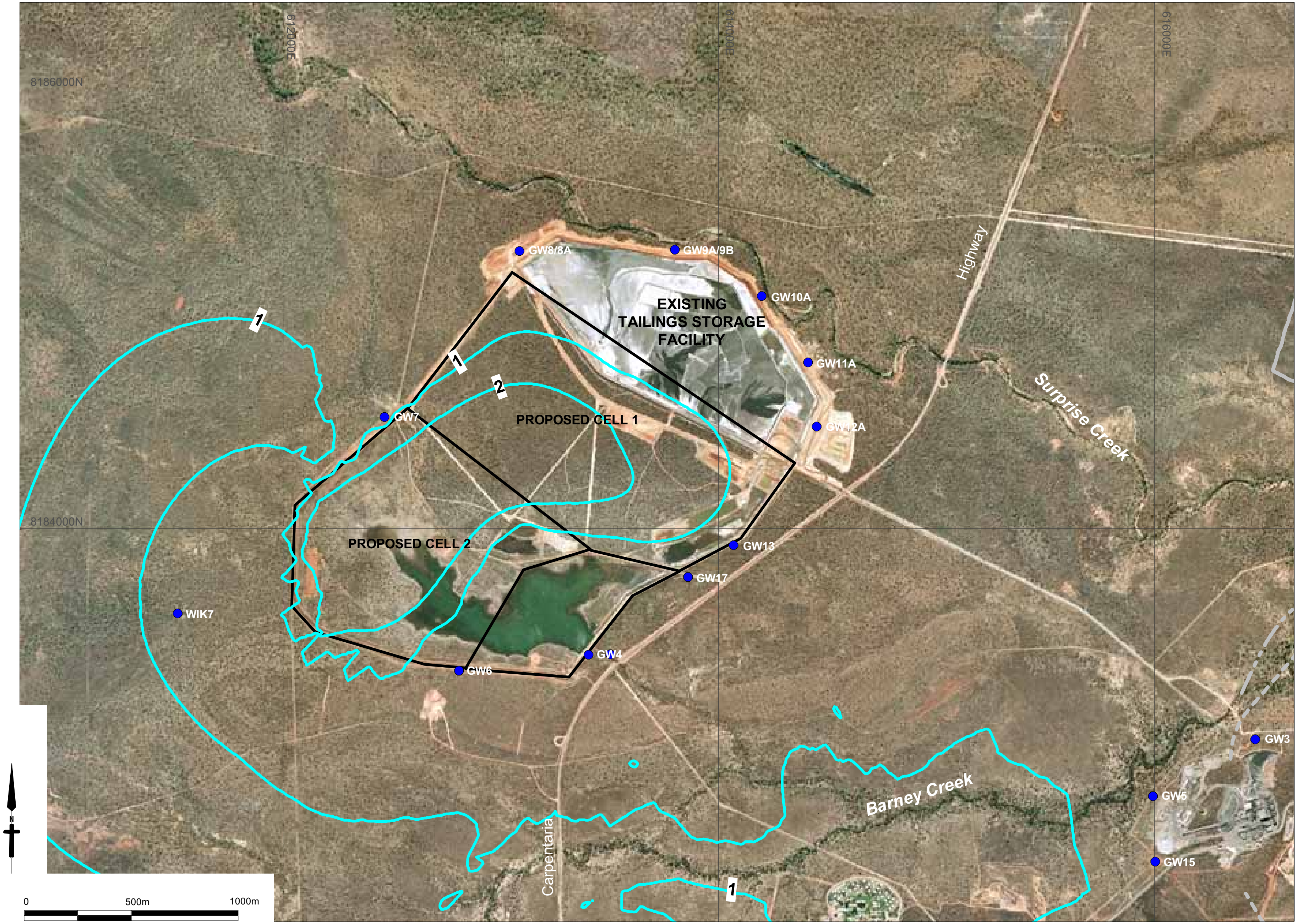
McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

MODELLED PHREATIC SURFACE
50 YEARS POST CLOSURE
"WORST CASE"

Drawn: VH	Approved: CMP	Date: 27-06-2006
Job No.: **42625552**	File No. 42625552-g-196.cdr	

Figure: **7.7** Rev. A A4



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Scale 1:35 000 (A4)

Horizontal Datum: AGD84, Zone 53

Date of Aerial Photography, 2001

● Groundwater Monitoring Bore

5 Groundwater Level Change (m)

URS

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McARTHUR RIVER MINE
OPEN CUT PROJECT
PUBLIC ENVIRONMENTAL REPORT

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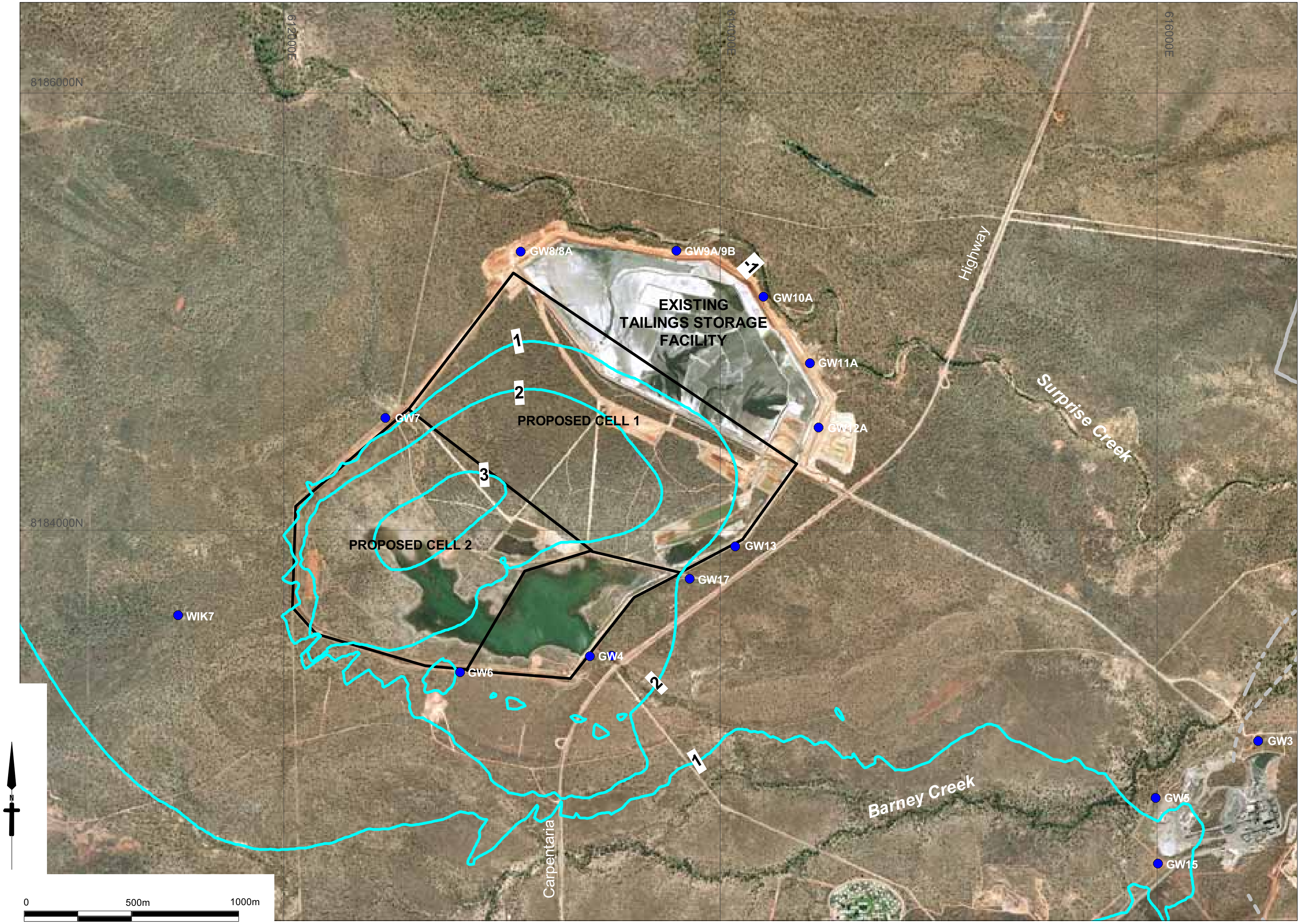
PREDICTED GROUNDWATER LEVEL CHANGE FROM RECOVER BORES - 10 YEARS OF POST CLOSURE

Figure: **7.8**

Rev: B

A4



0 500m 1000m

Scale 1:25 000 (A4)

Horizontal Datum: AGD84, Zone 53

Date of Aerial Photography, 2001

● Groundwater Monitoring Bore

—5— Groundwater Level Change (m)

URS

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PREDICTED GROUNDWATER LEVEL CHANGE FROM RECOVERY BORES - 25 YEARS OF POST CLOSURE

Figure: 7.9

Rev: B

A4

wall (beneath the TSF). This build-up will be from uncontaminated naturally-occurring groundwater flowing from upstream of the TSF. However, given the limited length of the geopolymer wall (along the eastern embankment only), any localised build-up of groundwater under the TSF footprint is not expected to be significant. It will remain below the ground surface and will not move into the TSF. Any such build-up of groundwater would be identified and reported in the post-closure monitoring (described in Section 7.4) and appropriate action taken if necessary. Such action could include drilling holes through the geoploymer wall or providing by-pass trenches.

7.9 Contaminated Sludge

The PER guidelines have asked for details of the proposed disposal of contaminated sludge to the TSF.

MRM currently disposes of wastes such as rags, gloves, wooden pallets, crates, bags, soil or other materials that have been contaminated by oil, ore, concentrate or process water to the TSF. There is a designated and signposted location at the TSF to receive this contaminated waste. These wastes eventually become buried in the tailings.

There is no contaminated sludge disposed of in the TSF. In previous years sludge from the on-site sewage treatment plant was disposed of in the TSF. However this practice has since ceased and the sludge is now trucked to the sewage treatment plant at Borroloola for disposal.

No effects have been detected to date from the disposal of contaminated waste at the TSF. In this respect the tailings provide an ideal low permeability encapsulated environment for the disposal of this material. The quality of seepage from the TSF has not shown any significant sign of contamination from the wastes.

As discussed in the Draft EIS (URS, 2005a), seepage was discovered in Surprise Creek adjacent to the TSF in 1997. Water in the creek was found to contain elevated sulfate concentrations, which is a positive indication of tailings origin, however only background levels of lead and zinc were measured. Regular monitoring of the water in Surprise Creek has indicated minimal to no transport of lead and zinc in the seepage from the TSF.

As discussed above, any ongoing seepage from the proposed TSF will be managed by a combination of the geopolymer barrier and recovery bores. If any seepage from the TSF was to be contaminated by the waste disposal activities, it would be recovered by the recovery bores and returned to the water management dam.

Likewise, any surface runoff from the waste disposal area of the TSF would flow to the water management dam. All water in this dam is retained within the site's water management system and re-used in the process plant. Thus it is considered that there will be no risk to the receiving environment from the disposal of wastes to the TSF.