Chapter 11

Final Voids

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11. FINAL VOIDS

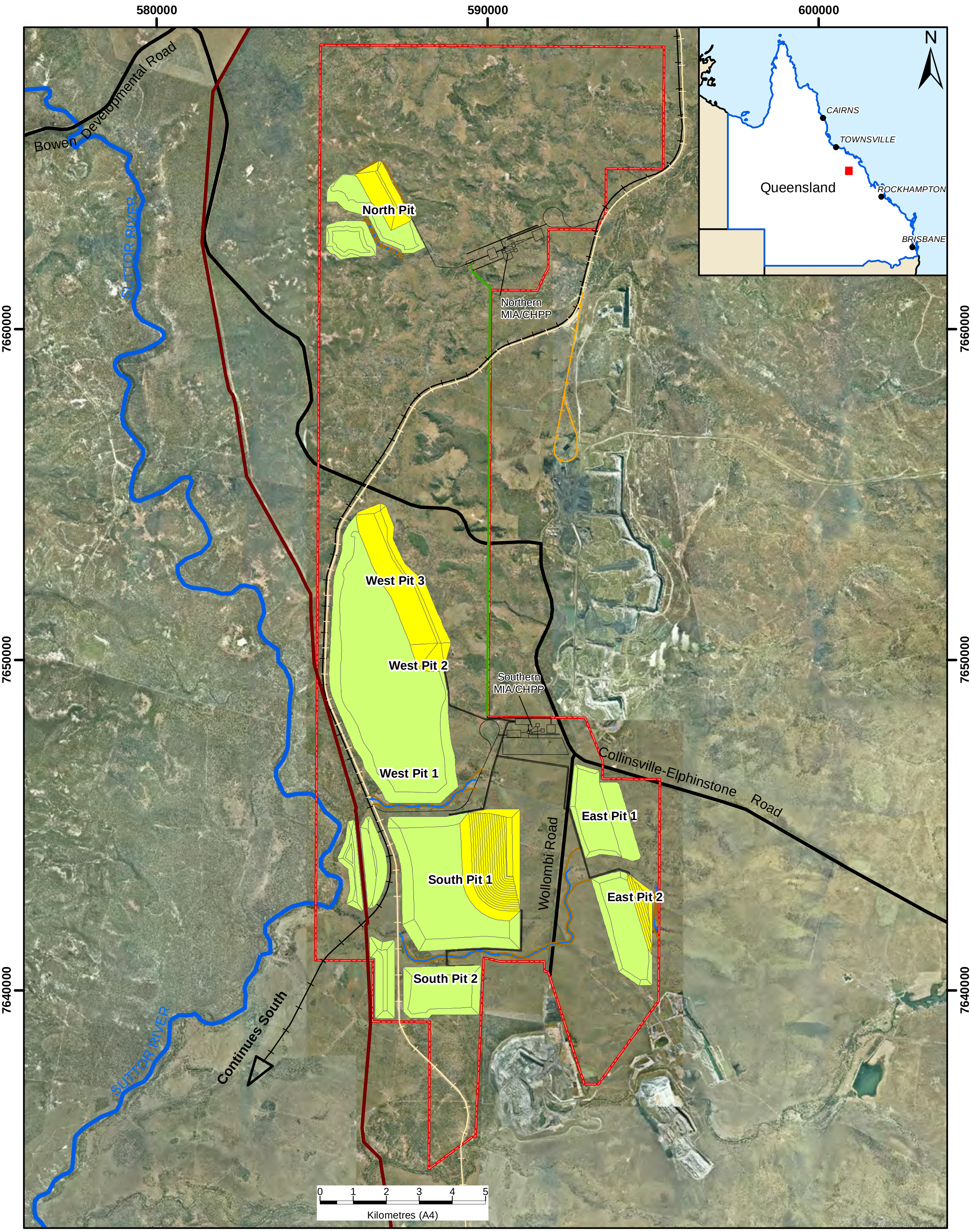
11.1 Introduction

This chapter provides an assessment of the voids that will remain as permanent depressions following the completion of mining operations within the project area, including an evaluation of the risk of discharge to the environment and the prediction of the water quality within the final voids. It is based on the technical report, Final Void Assessment, provided in **Appendix 13**.

11.1.1 Final Void Extent and Location

Four final voids will be created by the project associated with North Pit, the West Pits complex (predominantly in West Pit 3), South Pit 1 and East Pit 2. The location of the voids is shown on **Figure 11-1**.

Pit lakes will form within the final voids as a result of groundwater inflows (predominantly from coal measures), surface water runoff from walls immediately surrounding the pit (i.e. high and low pit walls), seepage through waste rock dumps and direct rainfall. A surface water catchment of approximately 290 ha (as described in **Chapter 8**) that cannot be re-directed will contribute to inflows to South Pit 1. All four pit lakes will increase in depth and area slowly, over several hundred years, until a steady state condition is reached where water losses (evaporation) are equivalent to water inputs.



Legend

- Project Area
- Completed Rehab
- Final Void
- Drainage Bund
- Drainage Diversion
- Suttor River
- Burdekin to Moranbah Pipeline
- Haul Road
- GAP Rail line
- Newlands Mine Rail Loop
- Alpha Coal Project Rail Line
- Formed Roads
- Mine Infrastructure
- Central Infrastructure Corridor

Location of Final Voids

QCOAL GROUP

Figure 11-1

Byerwen Coal Project

environmental and licensing professionals pty ltd

Date: *28/02/2013*

Author: samuel.ferguson

Map Scale: 1:150,000

Revision: R1

Coordinate System: GDA 1994 MGA Zone 55

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11.2 Final Void Design Strategies

11.2.1 Final Void End Use

A range of options have been considered for the final void end-use, including the following:

- The final voids could be backfilled with waste rock from the out of pit waste rock dumps. This would require these dumps to be left unrehabilitated during mining or the disturbance of a previously rehabilitated area. There is potential that any remaining resource would be sterilised.
- The final voids could be used for water storage. However, the quality of the void water is likely to be brackish due to groundwater inflows and long term evapo-concentration.
- The final voids could be used as wetland/wildlife habitat. The final voids will be depressions in the landscape and have a higher depth to width ratio and contain brackish water.
- The final voids could be used for waste disposal. The voids that will be formed in the project area will be a small addition to the existing and proposed final voids in the region. The main waste produced in the region is mining waste (waste rock and coal rejects). However, there are no plans to utilise final voids for post operational placement of mining waste. The voids could be used for solid municipal waste. However, this is not currently planned for the project area.
- Restrict access and ensure public safety. This option involves re-contouring and restricting / deterring access to the final voids to ensure public safety. This option allows a progressive rehabilitation approach and requires minimal works to implement following the conclusion of mining at the site. Additionally, minimal maintenance will be required.

An assessment of these options determined that restricting access and ensuring public safety is the preferred option for dealing with final voids. The other void options have a number of impracticalities associated with them, relating to the remote location of the site and relative costs involved. The potential brackish nature of the void water will limit the use of the voids for water storage and as a wetland/wildlife habitat. These uses may be may be undertaken on an opportunistic basis, but will not be the primary end-use. Economic factors limit the use of the final void structures for municipal waste disposal and backfilling of mine pits been designated for four out of the eight pits.

11.2.2 Final Void Design

The main objective of the final void design is to make the voids safe to ensure public safety. Other considerations for the final design include the catchment extent, void location and access arrangements, which affect the flow of water into and out of the void.

Three general approaches to final void design were assessed including:

- isolated void – This approach aims to isolate the void from surface water and groundwater systems by minimising the catchment extent and creating a permanent groundwater sink. This is the preferred approach where void water quality is expected to be poorer than surface water systems, and the void can be configured to avoid overflows.
- intermittent flushing void – This approach aims to isolate water in the void from surface water systems until there is a large flow in the receiving environment. The void will overflow during large flows and relies on dilution to minimise water quality impacts. Flushing is usually achieved by the configuration of weirs at the inlet and outlet of the void.

- regularly flushing void – This approach aims to regularly flush water from the void. This option is well suited in situations where there is a high groundwater input or when there is an unacceptably high risk of overflow of isolated void water to the environment.

Final void water depth is unlikely to be at a depth where it can be accessed safely by fauna or livestock. Water quality is unlikely to be suitable for stock use or as a source of aquatic ecosystem habitat. Therefore the primary objectives of final void design will be to:

- isolate the void from surface water and groundwater systems by minimising the catchment extent and creating a permanent groundwater sink
- exclude humans, fauna and stock from the final voids.

This is the preferred approach as the void water quality is expected to be poorer than surface water systems and the void can be configured to avoid overflows. These objectives can be achieved by:

- constructing permanent self-sustaining bunds around final voids (nominally minimum 2 m high with 4 m base and located 10 m beyond the area potentially affected by any instability of the pit highwall)
- limiting access to the final void through bund walls, tree planting, fencing, signage and landholder and community awareness.

11.3 Hydrology of Final Voids

11.3.1 Surface Water Hydrology

Several catchment types exhibiting different runoff characteristics will drain into the final voids. The catchments can be divided into three broad categories with associated runoff characteristics as follows:

- rehabilitated waste rock dumps
- pit wall (or direct rainfall)
- external catchment.

A summary of the catchment area for each pit lake is presented in **Table 11-1**.

Table 11-1 Catchment Areas for each Final Void

Catchment	North Pit	West Pit	South Pit	East Pit
Rehabilitated waste rock^	100 ha	965 ha	531 ha	178 ha
Pit Wall	0 – 163 ha	0 – 548 ha	0 – 542 ha	0 – 88 ha
Pit Lake	0 – 163 ha	0 – 548 ha	0 – 542 ha	0 – 88 ha
External	0 ha	0 ha	290 ha	0 ha

^ Rehabilitated waste rock will be contoured to drain away from the final void. Some infiltration into the cover is predicted, forming a groundwater mound within the waste rock. It is assumed that the mound will be highest in the centre of the waste rock, causing approximately half of the area to drain towards the pit. The catchment area presented represents the area over which infiltration could flow towards the final void.

11.3.1.1 Rehabilitated Waste Rock Dumps

Rehabilitated waste rock dumps will be contoured to direct surface runoff away from the pit lakes, effectively eliminating the surface runoff component of flow from this catchment. It is predicted however, that base flow from this catchment will, in part, flow towards the pit lakes. Base flow describes the fraction of rainfall which permeates into the soil (as opposed to forming surface runoff). As the rehabilitated dumps are not natural landforms, the base flow is not likely to flow to the groundwater, rather it is expected that a base flow mound will develop within the rehabilitated dumps. It has been assumed that half of the base flow will drain towards the pit lakes and half to the surface water system in the form of toe seepage from the dumps. The model was not sensitive to changes in the size of this catchment. For each pit, half of the adjacent waste rock dump area was used to determine the inflow to the pit from the rehabilitated dump catchment.

11.3.1.2 Pit Wall

The primary source of inflow by volume is from pit wall rainfall surface runoff, from exposed walls of the pit lakes. The pit wall area has been calculated for each pit using a model of the final void landform. The area of each of these catchments will vary with time as the increasing elevation of each pit lake reduces the potential for runoff from the exposed walls. As the volume of water in the pit increases, the pit wall area will decrease at an inverse rate. The pit wall runoff is a function of pit wall area and incident (or direct) rainfall.

11.3.1.3 External Catchment

South Pit 1 final void is the only void predicted to have an external catchment component of inflow due to the shape of the final landform and the location of the creek diversions.

11.3.2 Groundwater Hydrology

Groundwater inflows are a contributor to the water within the final voids and are based on the inflow calculations described in **Chapter 17** and **Appendix 18**. It is expected that groundwater flow into the pit lakes will predominantly be associated with the groundwater from the coal measures.

11.4 Water Level and Quality Assessment Methodology

An assessment was undertaken to evaluate the water level conditions within the voids, predict the quality of void water during potential release events and any potential impacts on the environment, and determine whether the final void water would meet the rehabilitation criteria.

The assessment included the following elements:

- water balance to capture the steady-state water level condition within the voids and to determine the risk of environmental discharge
- modelling and assessment of practicable management measures to mitigate contaminant increases in final voids (including salinity and nutrient predictions)
- qualitative assessment of void water limnology
- the predicted storage capacity of void water during annual exceedance probability 1 in 25, 50, 100, 200 and 1,000 year rainfall events including potential for discharge
- the predicted quality of void water during potential release events
- the predicted impact on the environment caused by the release of any void water
- the ability of the final void water to meet the rehabilitation criteria – being safe, stable and non-polluting.

The methodology and results of the assessment are summarised below. Full details are provided in the specialist report in **Appendix 13**.

11.5 Void Water Level

11.5.1 Modelling Methodology

A water balance model of the final voids was developed using Goldsim software, a package commonly adopted for mine site water balance studies. This included the use of the contaminant transport module to track salt movement and accumulation. Water level predictions were made using a water balance approach involving:

- Incident Rainfall (I)
- Catchment Runoff (R)
  - external catchments
  - pit walls
- Groundwater Seepage (G)
- Evaporation (E).

The change in water storage = I + R + G – E.

The model was based on a daily time step, and is therefore capable of addressing the impact of individual storm events or longer term climatic variations. The model was run for 500 years. The model was run 100 times (realisations) for each scenario to generate water level probability distributions. Full details of the modelling methodology are provided in the specialist report in **Appendix 13**.

Four key scenarios were modelled including:

- Base case scenario
- Higher hydraulic conductivity scenario – used to test the sensitivity of the pits to changes in hydraulic conductivity as described in **Chapter 17**.
- Climate change scenario 1 – based on a high greenhouse gas emissions scenario (A1F1 scenario from IPCC (IPCC, 2007)) 90th percentile prediction for 2070.
- Climate change scenario 2 – based on the low greenhouse gas emissions scenario 10th percentile prediction for 2070 (IPCC (2007) scenario B1).

11.5.2 Assessment of Void Water Level

11.5.2.1 Base Case Scenario

The model predicts that a lake will form in all of the final voids over a period of approximately 120 to 390 years depending on the void. The lakes will have a steady state depth in the range of 50 to 194 m. The elevation of the lakes is indicated to be depressed in the landscape, below the adjacent groundwater level. The results are summarised in **Table 11-2** and discussed in the following sections.

Table 11-2 Base Case Scenario Mean Results

Final void pit	Ground level (mAHD)	Groundwater level (mAHD)	Evolution phase	Steady state		
			Evolution period (year)	Mean Water level (mAHD)	Lake depth (m)	Fluctuation range (m)
North Pit	290	270	260	175	94	± 5
East Pit 2	305	260	120	235	50	± 3
South Pit 1	300	250	390	65	194	± 5
West Pit 3	305	125	250	110	99	± 3

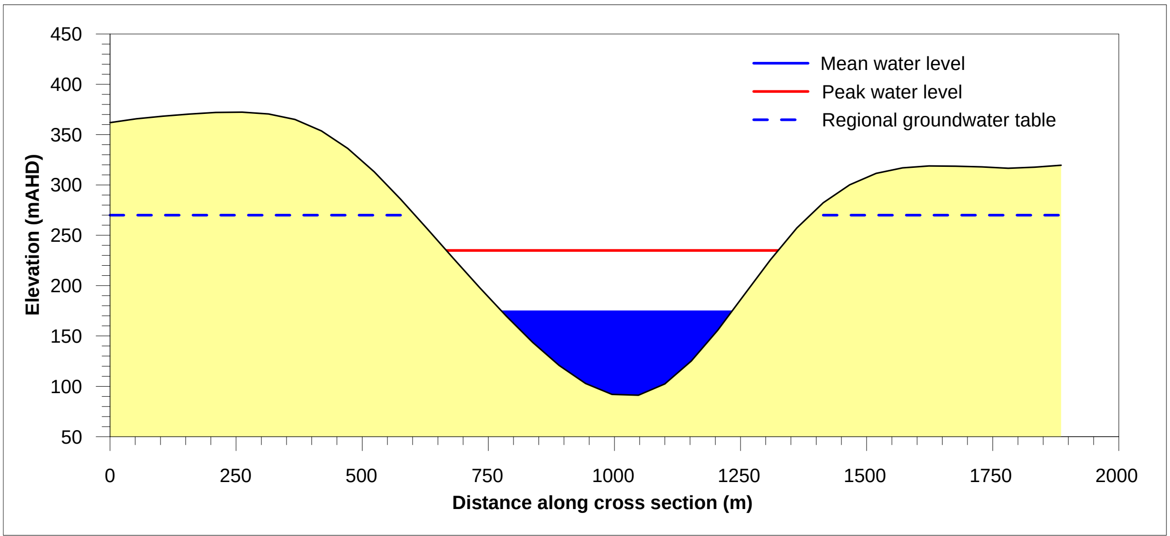
North Pit

The model indicates that the water level within the final void will be below the level of the expected regional groundwater (270 mAHD) in this area. The mean water level predicated at steady state for this void is 175 mAHD, which is indicated to be within 260 years following the completion of mining. The peak water level (99^{th} percentile of all model realisations) is 235 mAHD for the North Pit and is predicted to occur approximately 340 years following completion of mining. This is 35 m below the regional groundwater level. Further details are provided in **Table 11-3** and **Figure 11-2.**

Table 11-3 North Pit Results Summary - Base Case Scenario

Parameter	Results	Metres below ground level (mbgl)
Pit depth	210m	
Assumed ground level	290 mAHD	
Regional groundwater level	270 mAHD	20
Mean steady state water level	175 mAHD	115
Peak water level (highest of 100 realisations)	235 mAHD	55
Freeboard at peak	55m	
Peak water level to groundwater	35m	

Figure 11-2 North Pit Base Case Scenario Cross Section



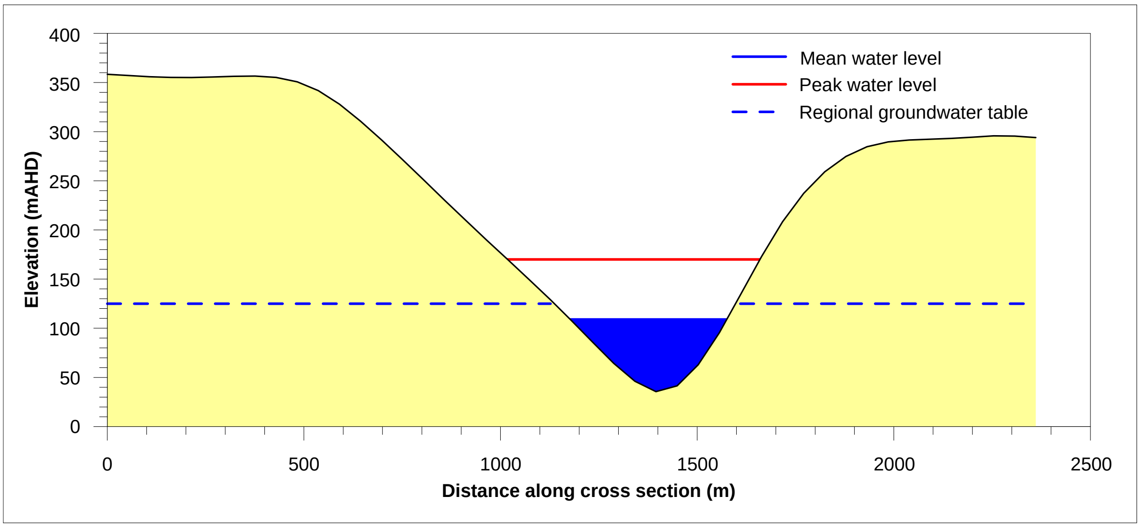
West Pit 3

The model predicts that there is a 15% chance that the water level within the void will reach a level above the expected regional groundwater table of 125 mAHD. The peak water level within the void is 170 mAHD, which is well below the top of the void which lies at 305 mAHD (135 m above the peak water level). The mean water level predicated at steady state for this void is 109 mAHD. The period at which the void will reach a steady state is uncertain, but is indicated to be approximately 250 years following the completion of mining. Further details are provided in **Table 11-4** and **Figure 11-3**.

Table 11-4 West Pit 3 Results Summary - Base Case Scenario

Parameter	Results	Metres below ground level
Pit depth	295 m	
Assumed ground level	305 mAHD	
Regional groundwater level	125 mAHD	180
Mean steady state water level	110 mAHD	195
Peak water level (highest of 100 realisations)	170 mAHD	135
Freeboard at peak	135 m	
Peak water level to groundwater	-45 m	

Figure 11-3 West Pit 3 Base Case Scenario Cross Section



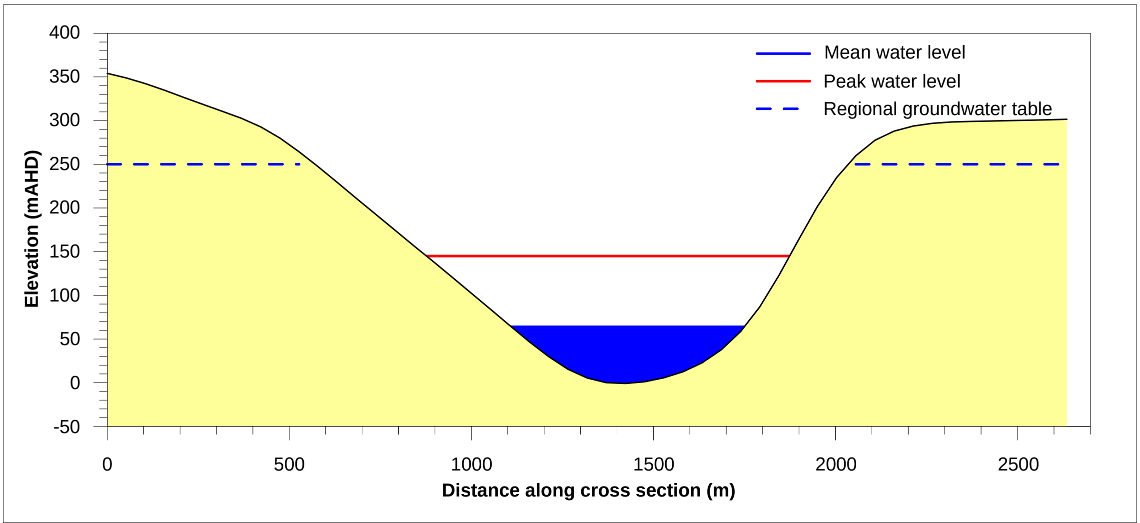
South Pit 1

The model indicates that the water level within the final void will be below the level of the expected regional groundwater (250 mAHD) in this area. The peak water level (145 mAHD) for the South Pit 1 is indicated to occur 375 years following completion of mining. This is 105 m below the regional groundwater level. The mean water level predicated at steady state for this void is 65 mAHD. The period at which the void will reach a steady state is uncertain, but a plateau in pit level is indicated approximately 360 to 400 years following the completion of mining. The model for South Pit 1 includes runoff from an external surface catchment area of approximately 290 ha and therefore the inclusion of this catchment in modelling did result in the void water level reaching the regional groundwater level or the ground level. Further details are provided in **Table 11-5** and **Figure 11-4**.

Table 11-5 South Pit 1 Results Summary - Base Case Scenario

Parameter	Results	Metres below ground level
Pit depth	430 m	
Assumed ground level	300 mAHD	
Regional groundwater level	250 mAHD	50
Mean steady state water level	65 mAHD	235
Peak water level (highest of 100 realisations)	145 mAHD	155
Freeboard at peak	155 m	
Peak water level to groundwater	105 m	

Figure 11-4 South Pit 1 Base Case Scenario Cross Section



<u>East Pit 2</u>

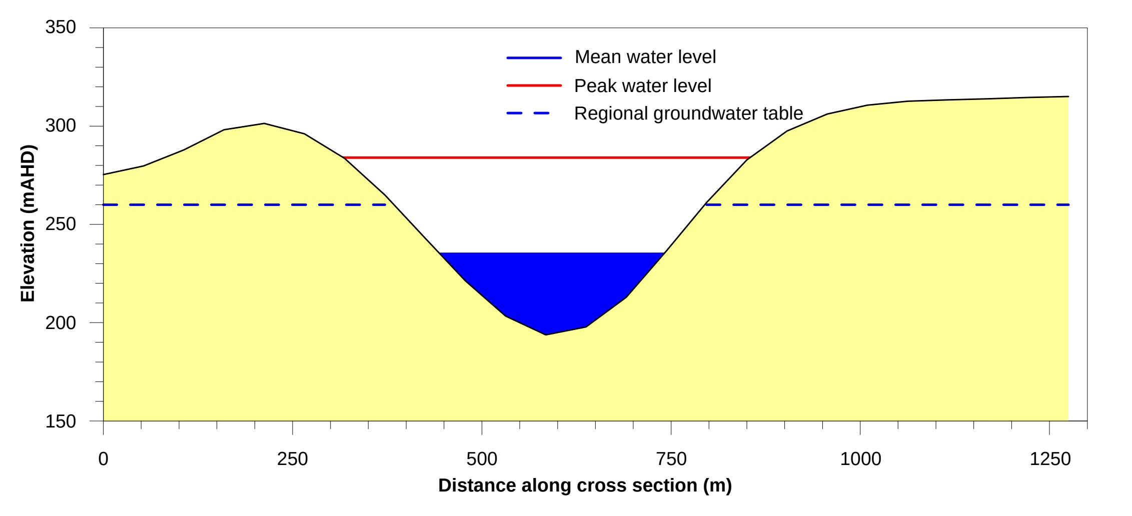
The mean water level predicated at steady state for this void is 235 mAHD, which is indicated to be within 120 years following the completion of mining. The peak water level (284 mAHD) for the East Pit is indicated to occur approximately 340 years following completion of mining, which is well below the top of the void which lies at 305 mAHD. The water in the void is not predicted to reach ground level. However, there is a 15% chance that the water level within the void will reach a level above the expected regional groundwater table of 260 mAHD. Further details are provided in **Table 11-6** and **Figure 11-5.**

Table 11-6 East Pit 2 Results Summary - Base Case Scenario

Parameter	Result	Metres below ground level
Pit depth	120 m	
Assumed ground level	305 mAHD	
Regional groundwater level	260 mAHD	45
Mean steady state water level	235 mAHD	70
Peak water level (highest of 100 realisations)	285 mAHD	20

Parameter	Result	Metres below ground level
Freeboard at peak	20 m	
Peak water level to groundwater	-25 m	

Figure 11-5 East Pit 2 Base Case Scenario Cross Section



Summary for Base Case Scenario

The two smaller pit voids (East Pit 2 and North Pit) are both predicted to reach a steady state relatively quickly, 120 and 260 years post mine closure respectively. The model also predicts that the larger West Pit 3 void will reach a steady state in approximately 250 years post mine closure which can be attributed to the low regional groundwater level expected in the area. South Pit 1 is predicted to take longer to reach a steady state condition, around 400 years post mine closure.

There is approximately a 15% chance that the East Pit 2 and West Pit 3 will exceed the regional groundwater level and result in a scenario where they are no longer acting as a sink feature but rather contribute to the regional groundwater.

The model did not predict any scenario where the water level in any of the pits would reach the surface level. The closest of any of the pit lakes to reach the surface was East Pit 2 which had a freeboard of 21 m at the peak predicted level.

11.5.2.2 Higher Hydraulic Conductivity Scenario

The hydraulic conductivity of the ground changes spatially and within each aquifer unit. For selected voids, a higher hydraulic conductivity scenario was used to test the sensitivity of the final voids scenarios to changes in hydraulic conductivity. The hydraulic conductivity values applied to the scenarios were based on the higher hydraulic conductivity described in **Chapter 17** and **Appendix 18**. The results for each void are summarised in the following sections.

North Pit

The hydraulic conductivity used in the base case scenario for North Pit represents a higher hydraulic conductivity scenario based on the groundwater monitoring data available in the northern project area. Hence no additional modelling of a higher hydraulic conductivity scenario is required for North Pit.

West Pit 3

The hydraulic conductivity changes in the West Pit 3 produced a 5m increase in the mean depth of the final void water levels (115 mAHD) in comparison to the base case scenario (110 mAHD). Peak water levels were indicated to decrease from those predicted in the base model by 30 m to 140 mAHD. The peak water level is predicted to be 165 m below the ground level, but is predicted to be 15 m above the regional groundwater level. The amount of time to reach a steady state condition was also decreased by 60 years to 190 years following completion of mining.

South Pit 1

The hydraulic conductivity changes in the South Pit 1 produced a significant (120m) increase in the mean depth of the final void water levels (185 mAHD) in comparison to the base case scenario (65 mAHD). Peak water levels were indicated to increase from those predicted in the base model (145 mAHD) by 105 m to 250 mAHD. The peak water level was indicated to be close to the regional groundwater level. However, the model did not predict any scenario where the water level exceeded the groundwater table. The peak water level is predicted to 50 m below the ground level. The amount of time to reach a steady state condition decreased slightly to 330 years following completion of mining.

East Pit 2

The hydraulic conductivity changes in the East Pit 2 produced a 15m increase in the mean depth of the final void water levels (250 mAHD) in comparison to the base case scenario (235 mAHD). Peak water levels were indicated to decrease from those predicted in the base model by 10 m to 275 mAHD. The amount of time to reach a steady state condition was similar to that predicted in the base model, around 100 to 120 years following completion of mining. This scenario predicted a 5% chance that the water level within the void would reach a level above the expected regional groundwater table of 260 mAHD.

Summary for Hydraulic Conductivity Scenario

This scenario had varied effects on the final void water levels. East Pit 2 and West Pit 3 recorded only minor changes to the predicted water levels and time to reach a steady state. All pits showed an increase in the mean steady state water level. This was particularly visible in South Pit 1, which had a 120 m increase in the mean water level at steady state. South Pit 1 also showed an increase in peak water level from the base scenario, compared to the East and West Pits which showed a decrease in peak water levels. No modelled scenarios showed peak water levels exceeding the ground level.

11.5.2.3 Climate Change Scenario 1

This scenario is based on a high greenhouse gas emissions scenario (A1F1 scenario from IPCC (2007)[1]) 90th percentile prediction for 2070 and included a 10-40% increase in rainfall and 12-20% increase in potential evapotranspiration. This climate change scenario is expected to provide a 'worst case' climate change outcome for the final void model. The results for each void are summarised in the following sections.

North Pit

In this scenario, steady state water levels in the North Pit were indicated to decrease by 5m to 170 mAHD. Peak water levels were indicated to increase by 5 m to 240 mAHD, but are 30 m below the regional groundwater level. The amount of time to reach a steady state condition was similar to that predicted in the base model, with a variation of 30 years. The peak water level is predicted to 50 m below the ground level.

[1] IPCC 2007, Climate Change 2007: Synthesis Report, Fourth Assessment Report, Intergovernmental Panel on Climate Change

West Pit 3

This scenario produced only minor changes in West Pit 3 water levels compared to the base scenario. Steady state water levels were indicated to decrease by 5 m to 105 mAHD. Peak water levels were indicated to increase by 5 m to 175 mAHD. The amount of time to reach a steady state condition was similar to that predicted in the base model, with a variation of 30 years. This scenario predicted a 15% chance that the water level within the void would reach a level above the expected regional groundwater table. The peak water level is predicted to 130 m below the ground level.

South Pit 1

This scenario produced only minor changes in South Pit 1 water levels compared to the base scenario. Steady state water levels were indicated to decrease by 5 m to 60 mAHD. Peak water levels were indicated to increase by 10 m to 155 mAHD. The amount of time to reach a steady state condition was the same as that predicted in the base model (390 years following completion of mining operations). The water in the void is not predicted to exceed the expected regional groundwater table. The peak water level is predicted to 145 m below the ground level.

East Pit 2

In this scenario, steady state water levels in East Pit 2 were not indicated to change, remaining at 235 mAHD. Peak water levels were indicated to increase by 5 m to 290 mAHD. The amount of time to reach a steady state condition was similar to that predicted in the base model, with a variation of 60 years. This scenario predicted a 15% chance that the water level within the void would reach a level above the expected regional groundwater table. The peak water level is predicted to 15 m below the ground level.

Summary

This scenario had minimal impacts on the final void water levels. The greatest change was a 10m increase predicted in the peak water level of South Pit 1. The overall effect of the climate change scenario was an increase in uncertainty in each of the models.

11.5.2.4 Climate Change Scenario 2

This scenario is based on the low greenhouse gas emissions scenario 10th percentile prediction for 2070 (IPCC (2007) scenario B1) and included a 10-40% decrease in rainfall and 2-4% increase in potential evapotranspiration. Due to the minimal changes produced by the high emissions climate change scenario, it was considered repetitive to model this scenario for all voids. West Pit 3 was selected to be modelled for this scenario, as it showed some receptiveness to the high climate change scenario and was considered to be fairly representative of the changes in all the voids.

This scenario produced only minor changes in West Pit 3 water levels compared to the base scenario. Steady state water levels were indicated to decrease by 15 m to 95 mAHD. Peak water levels were also indicated to decrease by 20 m to 150 mAHD. This scenario predicted a 5% chance that the water level within the void would reach a level above the expected regional groundwater table. These outcomes indicate that further modelling is not required to validate the scenario.

11.5.3 Extreme Event Impacts

11.5.3.1 Extreme Rainfall

The impact of high and extreme rainfall events on the water balance was assessed for each void, including the impact of 25, 50, 100, 200 and 1,000 year ARI design storm events and probable maximum precipitation (PMP). The rainfall depths associate with the storm events are summarised in **Table 11-7**. A 72 hour duration storm was adopted for the assessment, as it resulted in the largest amount of total rainfall.

Table 11-7 Extreme Rainfall Intensity–Duration–Frequency Relationship

ARI (year) (72 hour storm duration)	Intensity (mm/hour)	Rainfall depth (mm)
25	3.6	259
50	4.0	288
100	4.7	338
200	5.3	382
1,000	6.8	490
PMP	22.4	1,613

The runoff generated by storm events ranging from 25 year ARI to PMP was modelled for each void. The water level change resulting from the runoff was calculated by comparing the runoff volume to the stage-storage relationship in the final void.

The runoff volume for the pits was small in comparison to the capacity of the final voids and the resulting changes in water level were therefore minimal, ranging from 5 m in the North Pit to 11 m in South Pit 1 for the PMP storm event.

11.5.3.2 Flooding

The impact of flooding from the Suttor River during a Probable Maximum Flood (PMF) event was assessed for the final voids. Flooding from the Suttor River during a PMF event was not indicated to affect the final voids and these flood waters would not interact with any of the final voids. This is further described and illustrated in **Chapter 16**.

Floodwaters from local tributaries have the potential to enter the final voids, which would substantially change the pit lake water quality and water level. This risk will be mitigated by the construction of levees around the perimeter of the final voids at these locations.

The proposed levees around the pits will be designed to cope with a 1:1,000 year storm event with appropriate geotechnical safety factors. The structures will be permanent self-sustaining features and will not require any monitoring or maintenance. With levees in place around the final voids there is no opportunity for floodwaters to enter the final voids.

11.6 Void Water Quality

An assessment was undertaken to predict the quality of void water, potential impacts on the environment, and determine whether the final void water would meet the rehabilitation criteria of being safe and non-polluting. As described in **Section 11.5** final void water levels are not predicted to release to the environment under any modelled rainfall or climate scenarios and therefore there will no impact from release of final void water.

11.6.1 Physical Factors Affecting Pit Lakes

The final voids are expected to operate as groundwater sinks. The regional groundwater table surrounding the voids is expected to be elevated above the pit lake water level, therefore drawing groundwater towards the void.

A water balance analysis was undertaken for South Pit 1 to determine the relative sources of inflow into the void under steady state water level conditions. South Pit 1 was selected for the water balance analysis, as it was considered to be fairly representative of the system dynamics in all the voids. Results from the analysis are summarised in **Table 11-8**.

Table 11-8 Average Inflow Relationship for South Pit at 400 years Post Mine Closure

Inflow Source	Rate of Flow (ML/yr)	% of Total Inflow
Direct rainfall	254	24
Groundwater	134	12
Pit wall runoff (high wall and low wall)	658	61
Waste rock dump seepage	36	3
Total	**1,082**	**100**

Although the annual average rate of evaporation is almost four times greater than that of annual average rainfall, inflows from other sources are predicted to match losses through evaporation when the pit water levels are at steady state. The highest percentage of the inflow into the voids is expected to come from pit wall runoff, with less coming from direct rainfall and groundwater inflows.

11.6.2 Source Water Quality

The quality of inflow sources can have a significant impact on the water quality within the pit voids. Data from groundwater monitoring bores and from waste rock samples were assessed to determine the quality of the water flowing into the final voids.

11.6.2.1 Groundwater

Data from groundwater monitoring bores were assessed to determine the quality of the groundwater flowing into the final voids. Groundwater quality for various water quality parameters is presented in **Chapter 17**.

The water within the coal measures is indicated to be slightly alkaline, brackish groundwater with generally low concentrations of nutrients and is considered to be of moderate to poor quality. This water is expected to have some bearing on the water quality within the pit lakes during inflows.

11.6.2.2 Waste Rock Characterisation

Waste rock analysis results provide an indication on the quality of water that is expected to enter the voids both via seepage from rehabilitated waste rock dumps and as surface runoff from the exposed walls of the pit lake. As the void represents an area where coal resource and waste rock have been mined, the characteristics of the pit lake walls are expected to be generally consistent with the waste rock data.

Waste rock characterisation for various parameters is presented in **Chapter 9**. Waste rock geochemistry testing suggests that there is a very low risk of acid generation and that the water quality entering the voids from the pit walls (as surface runoff or waste rock dump seepage) would not adversely affect void water quality.

11.6.2.3 Waste Rock Seepage

Seepage from rainfall percolating through the rehabilitated waste rock dump is indicated to be alkaline, slightly saline with low concentrations of total metals and metalloids. Inflows from waste rock dump seepage are expected to be relatively minor when compared with other inflow sources. Therefore, the quality of this water is expected to have a limited influence on pit lake water quality.

11.6.2.4 Surface Runoff

Surface water runoff will include runoff from rehabilitated waste rock dumps, pit walls and external catchments (in the case of South Pit 1). Surface runoff from the waste rock dump is expected to be alkaline, slightly saline with low concentrations of total metals and metalloids. Surface runoff from rainfall on the exposed faces of the voids is expected to be of similar quality to the water from seepage from the waste rock dumps.

South Pit 1 final void is the only void predicted to have an external catchment (approximately 290 ha) component of inflow. The water quality from this catchment will be typical of surface waters in the region, as described in **Chapter 15**.

11.6.2.5 Direct Rainfall

Direct rainfall onto the pit lake will have a lower salinity than the other sources of inflow and is likely to remain in the upper section of the water column due to the density effect of the low salinity rainwater. Although there will be some degree of dilution from rainfall within the pit lake, the effects of the other inflows which are predominantly brackish to saline is expected to offset the benefits in water quality received from direct rainfall.

11.6.3 Final Void Water Salinity Prediction

Salt will be present in water inflows in the final voids. The major outflow of water from each pit is evaporation. Salt does not evaporate and the salinity in the pit water will increase following evaporation. As the water evaporates and salinity within the pit increases, a partial reduction in evaporation potential will be observed.

11.6.3.1 Modelling Methodology

The contaminant transport module was adopted as part of the Goldsim water balance model to predict the movement and accumulation of salt within the system. The model couples salts associated with water inflows to determine the change in salt mass and associated concentration over time.

Three salinity profiles were generated for the model, assigned to the catchment types entering the final void, as follows:

- rehabilitated waste rock dumps
- pit wall (or direct rainfall)
- external catchment

Water quality data used for the salinity profiles was collected from surface water monitoring (refer **Chapter 15**), waste rock geochemical investigations (refer **Chapter 9**) and groundwater monitoring (refer **Chapter 17**). **Table 11-9** provides the observed salinity data (measured as total dissolved solids) and the salinity profiles (probability distribution) adopted for modelling purposes for the various water types.

Table 11-9 Salinity Profiles

Percentile	TDS Waste Rock (mg/L)		TDS Groundwater (mg/L)		TDS Suttor River Catchment (mg/L)	
	Raw Data	Probability Distribution	Raw Data	Probability Distribution	Raw Data	Probability Distribution
0.1	140	130	1,000	820	130	90

Percentile	TDS Waste Rock (mg/L)		TDS Groundwater (mg/L)		TDS Suttor River Catchment (mg/L)	
	Raw Data	Probability Distribution	Raw Data	Probability Distribution	Raw Data	Probability Distribution
0.25	200	210	1,210	1,480	210	150
0.5	340	360	2,130	2,570	250	290
0.75	580	610	4,910	4,600	450	540
0.9	1,210	930	6,970	5,840	910	920
0.95	1,560	1,270	7,310	6,980	1,830	1,230
0.99	2,120	1,940	7,600	8,910	1,970	1,790
Mean		495		3,100		470
Standard deviation		742		2,200		580

Total dissolved solids (TDS) values for surface runoff and seepage from the waste rock catchment may be slightly underestimated at the upper and lower extremes of the dataset, but there is a good fit of the median values. Groundwater concentrations of TDS have a slightly longer "tail" of data at both ends of the probability distribution as well as a higher median value. The TDS distribution for the Suttor River catchment underestimates the concentrations at both "tails" of the data slightly, while overestimating the peak of the median concentration. This is not considered to significantly skew the salinity predictions.

11.6.3.2 Salinity Prediction Results

Salinity was modelled for the four scenarios described in **Section 11.5.1**.

Base Case Scenario

The predictions of salinity for the base case are summarised in **Table 11-10** and discussed below. The peak salinity prediction is an unlikely scenario representing the 99th percentile of salinity values from model realisations.

Table 11-10 Salinity Predictions Base Case Scenario

Final Void	Mean Salinity (mg/L)			25th to 75th percentile salinity predictions (mg/L)	Peak salinity prediction - (mg/L)
	Year 100	Year 200	Year 400	Year 400	
North Pit	3,500	5,500	10,000	3,500 – 15,000	27,000
East Pit 2	1,750	3,000	6,500	750 – 7,000	42,000
South Pit 1	1,250	1,500	2,000	800 – 4,500	6,750
West Pit 3	1,100	1,500	3,000	1,500 – 11,500	66,000

The model confirmed that salinity will increase over time due to evapo-concentration effects. The final voids will act as sinks in the majority of scenarios predicted and under these conditions, are expected to gradually accumulate salts over time.

As time increased, so did uncertainty in the model. At 400 years post mine closure, peak values were often well in excess of 10,000 mg/L (with the exception of South Pit 1), but none of the pit lakes became hyper-saline. Spikes in the peak values had limited effect on the mean values predicted, however the range (25th to 75th percentile) was considerably increased by spike predictions.

Higher Hydraulic Conductivity Scenario

The higher hydraulic conductivity scenario resulted in a large increase in the mean salinity of the pit lakes, but a reduction in the predicted peak values (refer **Table 11-11** in comparison to **Table 11-10**). An increase in salinity over time was predicted in all of the pit lakes, other than North Pit where a high hydraulic conductivity scenario was not modelled. As per the base case scenario, uncertainty in the model also increased with time.

Table 11-11 Salinity Predictions High Hydraulic Conductivity Scenario

Final Void	Mean Salinity (mg/L)			25th to 75th percentile salinity predictions (mg/L)	Peak salinity prediction - (mg/L)
	Year 100	Year 200	Year 400	Year 400	
North Pit	3,500	5,500	10,000	3,500 – 15,000	27,000
East Pit 2	5,500	9,000	16,000	1,500 – 10,000	24,000
South Pit 1	3,000	3,500	4,500	2,500 - 8,000	10,000
West Pit 3	2,250	3,250	6,000	4,000 – 25,000	42,000

Climate Change Scenario 1

The high emission climate change scenario did not result in any unusual changes in the mean salinity prediction for any of the pit lakes. However, there were large increases to the peak values predicted by the model. This suggests that there is a significant increase in the uncertainty in the model.

Climate Change Scenario 2

The low emission climate change scenario had little effect on the salinity concentration trends. However, the concentration of salinity predicted was generally higher than the base case predictions. Similar to the high emission climate change scenario, there were a number of 'spikes' in concentration during the first 100 - 200 years post mine closure. This is an uncertainty of the modelling but is likely attributed to the decrease in rainfall (less dilution) and increase in evaporation.

11.6.4 Stratification and Mixing

Stratification refers to the separation of a water body into multiple layers which is brought about by the different properties of the water body which can occur at different depths. Mixing throughout the profile can impact on pit lake water quality.

Stratification is influenced by the depth of the void, the slope of the void walls and other physical characteristics which can influence temperature, salinity and oxygen. Variations in meteorological conditions (wind, temperature and rainfall) over the seasons can also influence the stratification and mixing potential of the final voids. Although meteorological drivers can have an effect on the stratification and mixing potential of open water bodies, the geometry of the voids is predicted to significantly reduce its influence.

An assessment of the stratification and mixing potential of the pit lakes was undertaken using the one-dimensional Dynamic Reservoir Simulation Model (DYRESM version 2). South Pit 1 was selected for assessment, as the potential for stratification was considered more likely in this deeper void, than the voids with a shallower water depth. Four scenarios involving South Pit 1 were simulated to determine the variation in pit lake behaviour under different conditions.

In the early filling of the void (30 to 50 years) and at steady state water level conditions, South Pit 1 lake is predicted to behaviour similarly under the two different conditions. The stratification potential and mixing processes within the pit lake are expected to involve the development of chemoclines (salinity, oxygen or other chemical separation between layers) in the form of dissolved oxygen and salinity. A layer of dense water (hypolimnium) will form in the lower section of the lake. This water will have a higher salinity than the upper layer of the lake. The surface layer (the epilimnion) of the water column (upper 15 m at year 30 or upper 30 m at year 500) will undergo seasonal mixing from the warming and cooling of the surface layers. As the pit lakes mature, the salinity is expected to gradually increase causing strong and permanent stratification to occur.

Due to the depth of the final voids, a prominent thermocline (temperature separation between layers) is also expected to develop during the warmer seasons due to the stratification potential and mixing processes within the pit lake. A less distinct thermocline is expected during the cooler winter months.

Full details of the assessment are provided in **Section 5.5** of the specialist report in **Appendix 13**.

11.6.5 Biological Succession

An assessment of the expected nutrient concentrations within the pit lakes indicates that they may be sufficiently high on occasions to cause eutrophication and support algal growth. However, additional data for the inflow sources would be beneficial to allow more reliable predictions to be made.

The salinity of near surface water is expected to be much lower that at depth, with high dissolved oxygen, neutral to slightly alkaline with low to very low dissolved metal concentrations. These conditions should support an aquatic ecosystem that can function independently of the poorer quality water below.

The final voids will have sides where access prevention has been a consideration and will be fenced/bunded around the perimeter to minimise the potential for stock access to voids. The pit lake will incorporate deep zones and areas of shallow water. Mosquito populations are expected to colonise within the pit lakes. However, due to the characteristics of the lake, these populations are not anticipated to develop into plague like proportions.

Further details are provided in **Section 5.6** of the specialist report in **Appendix 13**.

11.6.6 Trace Metals and Geochemical Behaviour

There are three main inflow sources to the final voids; direct rainfall, groundwater inflow and runoff from pit walls. Direct rainfall typically has very low solutes and the main influence on water geochemistry is to lower the ionic strength of the water through dilution. This can be significant in the near surface layers of the lake, causing density differences. The main source of solutes into the pit lakes will be from groundwater and pit wall runoff. Several groundwater systems would be intersected by the pits and would mix within the void. Seepage from waste rock dumps may eventually report to the pit lake, and carry solutes derived from the waste rock.

An assessment of the water quality in groundwater and waste rock was undertaken using the geochemical modelling package, PHREEQC, produced by the United States Geological Survey.

The assessment indicates that metal concentrations will be low in the near surface layers (the epilimnion). This is attributed to the alkaline conditions and the oxidising conditions in this zone, which will promote precipitation of mineral phases. This is further supported by the fact that acid forming materials have not been identified in the geochemical characterisation studies.

Full details of the assessment are provided in **Section 5.7** of the specialist report in **Appendix 13**.

11.6.7 Other Water Quality Considerations

11.6.7.1 Dissolved Oxygen

The surface area to depth ratio for the voids will be lower than in natural open water bodies. Meteorological effects on the void water are therefore expected to be limited, which will reduce the potential for dissolved oxygen to mix throughout the void water profile. Oxygen is expected to be limited to the upper layers of the void water column.

11.6.7.2 Turbidity

Turbidity is a measure of the finer particles within a water body and is an important indicator of the health of an aquatic system as light penetration (and the subsequent processes which require light) can be reduced due to even moderate levels of turbidity.

During the early filling of the void when the surface area of the pit wall is greatest, turbidity within the pit lake is expected to be higher than the average turbidity levels under steady state water level conditions. As the majority of the final voids are not influenced by external surface water runoff, the sources of turbidity are likely limited to runoff from the pit wall.

11.6.8 Limnology Changes During Pit Lake Evolution

The final water quality of the voids is dependent on a number of key factors, including void water pH, oxygen status, hydrogeological flow, void wall composition, evapo-concentration potential, rate of biological activity and hydrothermal inputs. Although steady state is predicted within the voids, many of the biological and chemical processes occurring within the void may continue to evolve with time, which may impact on the routine physical changes which occur during the different seasons.

11.7 Final Void Rehabilitation

The strategy for the finals voids will be refined over the life of the mining operation prior to closure. The strategy will aim to:

- ensure the voids are safe and stable over the long term and require no ongoing management
- ensure that bunding and levees are permanent, self-sustainable and require no ongoing management
- minimise the potential for environmental impacts from the voids
- minimise the potential for health risks from the voids
- maximise (where practicable) the future usage potential of the voids
- develop an overall approach that requires no ongoing management inputs.

Data will be collected over the life of the mining operation to provide key indicators to the likely quality of the water that will contribute to the pit lakes. This data will be used to prepare a strategy for the final voids which will aim to ensure that they are safe and stable and to minimise the risk of impacts to the environmental and human health.

It is currently anticipated that the pit lakes will not require ongoing maintenance; however as part of the mine closure process biological activity and ecological development in the pit lake should be promoted.

Further details in relation to the final void design and rehabilitation are provided in **Chapter 10.**

11.8 Conclusion

The project will create four final voids that will remain as permanent depressions following the completion of the mining operations. Pit lakes will form within the final voids as a result of groundwater inflows, seepage from waste rock dumps, surface water runoff from the pit walls and land surrounding the pit and direct rainfall. The pit lakes will increase in depth and area slowly, over several hundred years, until a steady state condition is reached where water losses are equal to water inputs.

A water balance model was used to evaluate the water level conditions within the voids. There were no modelled scenarios where the level of the pits lakes reached the ground level (void rim) with a freeboard between peak probability lake level and ground level of 55 m for North Pit, 135 m for West Pit 3, 155m for South Pit 1 and 20 m for East Pit 2.

The model indicated that it is likely that the steady state water level within all the pits will be lower than the regional groundwater table, which will create a permanent groundwater sink. As the voids will form a regional sink, water from the pit will be prevented from moving off-site via groundwater flow. It is therefore not expected that environmental discharge to surrounding groundwater will occur.

There is a remote chance (5 to 15%) that if higher than expected groundwater inflows occur, or anthropogenic climate change results in higher rainfall and lower evaporation, then one or more pit lakes may eventually stabilise above the regional groundwater table. Discharges to the groundwater system could occur under these conditions, however the assessment suggests there is a very low probability (5 to 15%) of this occurring. No modelled scenarios predicted that lake levels would reach ground levels under higher than expected groundwater inflows or anthropogenic climate change.

The salinity of all water inflows to the voids was modelled. Salinity is expected to increase over time and mean salinity ranges between 1,000 mg/L and 10,000 mg/L over time. Pit wall runoff is expected to be the primary source of void water inflow. Waste rock geochemistry testing suggests that there is a very low risk of acid generation, and the water quality entering the voids from the pit walls would not adversely affect void water quality.

The salinity of near surface water is expected to be much lower that at depth, with high dissolved oxygen, neutral to slightly alkalinity, with low to very low dissolved metal concentrations. These conditions should support an aquatic ecosystem that can function independently of the poorer quality water below surface water.

The stratification potential and mixing processes within the pit lake are expected to involve the development of chemoclines (salinity, oxygen or other chemical separation between layers) in the form of dissolved oxygen and salinity. As the pit lakes mature, the salinity is expected to gradually increase causing strong and permanent stratification to occur.

Due to the depth of the voids, a prominent thermocline is expected to develop during the warmer seasons. A less distinct thermocline is expected during the cooler winter months.

Flooding from the Suttor River during a PMF event was not predicted to affect the final voids and these flood waters would not interact with any of the final voids. Floodwaters from local tributaries have the potential to enter the final voids, which would substantially change the pit lake water quality and water level. This risk will be mitigated by the construction of levees, designed to cope with a 1:1,000 year storm event, around the perimeter of the final voids at these locations.

Final voids will be safe and stable over the long term. Bunding and levees that are permanent, self sustaining and requiring no ongoing management, will limit access to the voids by humans and fauna.