Appendix 13

Final Void Assessment

BYERWEN COAL PROJECT

Final Void Assessment

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Revision History

Revision	Date	Comment	Signatures		
			Originated by	Checked by	Approved by
A	19/10/12	Issue for Client Review	B. Nichol	C. Gimber	D. Nevin
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CONTENTS

Summary

This report provides an assessment of the four voids that will remain as permanent depressions following mining activities within the Project area. This assessment forms part of a wider study which will be input into the Environmental Impact Statement (EIS) for the Project. The Project is located in central Queensland around 130 km west of Mackay within the headwaters of the Burdekin Basin.

The primary objective of this study was to evaluate the risk of discharge from the voids and to predict the void water quality. This required a water balance to capture the steady state water level conditions within the voids as well as modelling to predict the salinity concentrations within the voids over time. An assessment of the voids in terms of limnology and potential for eutrophication was also carried out along with the predicted storage capacity of void water during a range of storm events. These tasks help to predict the quality of void water during potential release events, predict impacts on the environment caused by the release of any void water and determine whether the final void water would meet the rehabilitation criteria (being safe, stable and non-polluting).

Pit lakes will form within the final voids as a result of groundwater inflows (from predominantly the coal measure aquifers), surface water runoff from immediate areas surrounding the pit (and from the pit walls) and from incident rainfall. In the case of one of the pits (South pit) a small surface water catchment that cannot to be re-directed also contributes to inflows into this void. The water level within the pits will rise over several hundred years until a steady state water level is reached. The steady state water levels within the pits are under most scenarios lower than the regional groundwater table. The difference in hydraulic gradient between the pit lake and the surrounding groundwater table elevation results in groundwater flowing down gradient towards the pit. This effectively precludes water from within the pit moving off-site via groundwater flow. It is noted that there is a remote chance that one or more pit lakes may eventually stabilise at or above the regional groundwater table as a result of higher than expected groundwater inflows or a significant change in climate.

Water quality data (assumed and observed) of the void inflow sources was used to predict void water quality in the long term as well as the stratification and eutrophication potential of the lakes. At steady state water level conditions, a prominent layer of dense water is expected to form in the lower section of the lake. This water will have a higher salinity than the upper layer of the lake. Nutrient concentrations within the lakes could at times be sufficiently high to cause

eutrophication and support algal growth, however, additional data needs to be captured before a reliable prediction can be made.

Currently it is anticipated that the pit lakes which form within the final voids will not reach surface level and will not require any ongoing maintenance. Some effort will be required in the early stages of pit lake establishment to promote biological activity and ecological development which can have significant benefits.

Data is to be collected over the life of the mining operation which will provide key indictors to the likely quality of the water that will ultimately contribute to the pit lakes. This qualitative and quantitative data will be used to support a refined strategy for the Byerwen final voids which will aim to ensure the voids are safe and stable, minimising risk of environmental and health impacts from the final voids.

Glossary of terms, abbreviations and acronyms

Incident rainfall	Water that falls directly onto a water body or surface without passing through any land phase of the runoff cycle.
Datadrill	A service provided by the Queensland Government that produces continuous patched-point meteorological datasets for any given location in Australia
EC	Electrical Conductivity
Eutrophic	A eutrophic lake is a lake with high nutrient content. These lakes are subject to excessive algal blooms, resulting in poor water quality.
Goldsim	A generic, dynamic simulation program, widely used for water and mass transport modelling.
Monte Carlo	A class of computational algorithms used in Goldsim that rely on repeated random sampling to compute their results. Monte Carlo analysis is used when there is uncertainty in defining the system or the system inherently varies.
Patched Point	Continuous climate record developed by interpolated (using splining and kriging techniques) point observations from the Bureau of Meteorology
Pycnocline	The layer that separates water of two different densities.
Relisation	A single model run, which represents one possible path the system could follow through time
Redfield ratio	A widely used indicator of the algal species composition in lakes
TDS	Total Dissolved Solids
AWBM	Australian Water Balance Model
mAHD	metres Australian Height Datum
mbgl	metres below ground level
SD	Standard Deviation
ARI	Average Recurrence Interval. The average or expected value of the periods between exceedances of a given rainfall total accumulated over a given duration.
PMP	Probable Maximum Precipitation

Limnology	The scientific study of the life and phenomena of inland waters.
SAR	Sodium Adsorption Ratio
ANC	Acid Neutralising Capacity
Emerson Class	A measure of the dispersive characteristics of a soil when exposed to water.
µS/cm	Micro-Siemens per centimetre. A measure of the electrical conductivity of a sample.
Thermocline	A separation between two layers in a water body brought about by differences in temperature.
Chemocline	A separation between two layers in a water body brought about by differences in chemical properties (salinity, oxygen etc).
DYRESM	A Dynamic Reservoir Simulation Model commonly used to predict the vertical distribution of the key stratification indicators being temperature, salinity and density.
Hypolimnium	The dense bottom layer of a water body under stratified conditions.
Epilimnium	The less dense upper layer of a water body under stratified conditions.
Mesotrophic	An intermediate system with respect to biological production.
Oligotrophic	A system with limited biological production.
TN	Total Nitrogen
TP	Total Phosphorus
PHREEQC	A geochemical modelling package produced by the USGS.
USGS	United States Geological Survey
SI	Saturation Index with respect to mineral geochemistry.
NTU	Nephelometric Turbidity Units. A common measurement of turbidity.
TSS	Total Suspended Solids

1 Introduction

1.1 BACKGROUND

Kellogg Brown & Root Pty Ltd (KBR) has been commissioned by Byerwen Coal Pty Ltd (‘the proponent’) to undertake an assessment of the risk of discharge and prediction of water quality within the final voids left by the Byerwen Coal Project (herein referred to as the ‘Project’). The Project is located in central Queensland around 130 km west of Mackay within the headwaters of the Burdekin Basin.

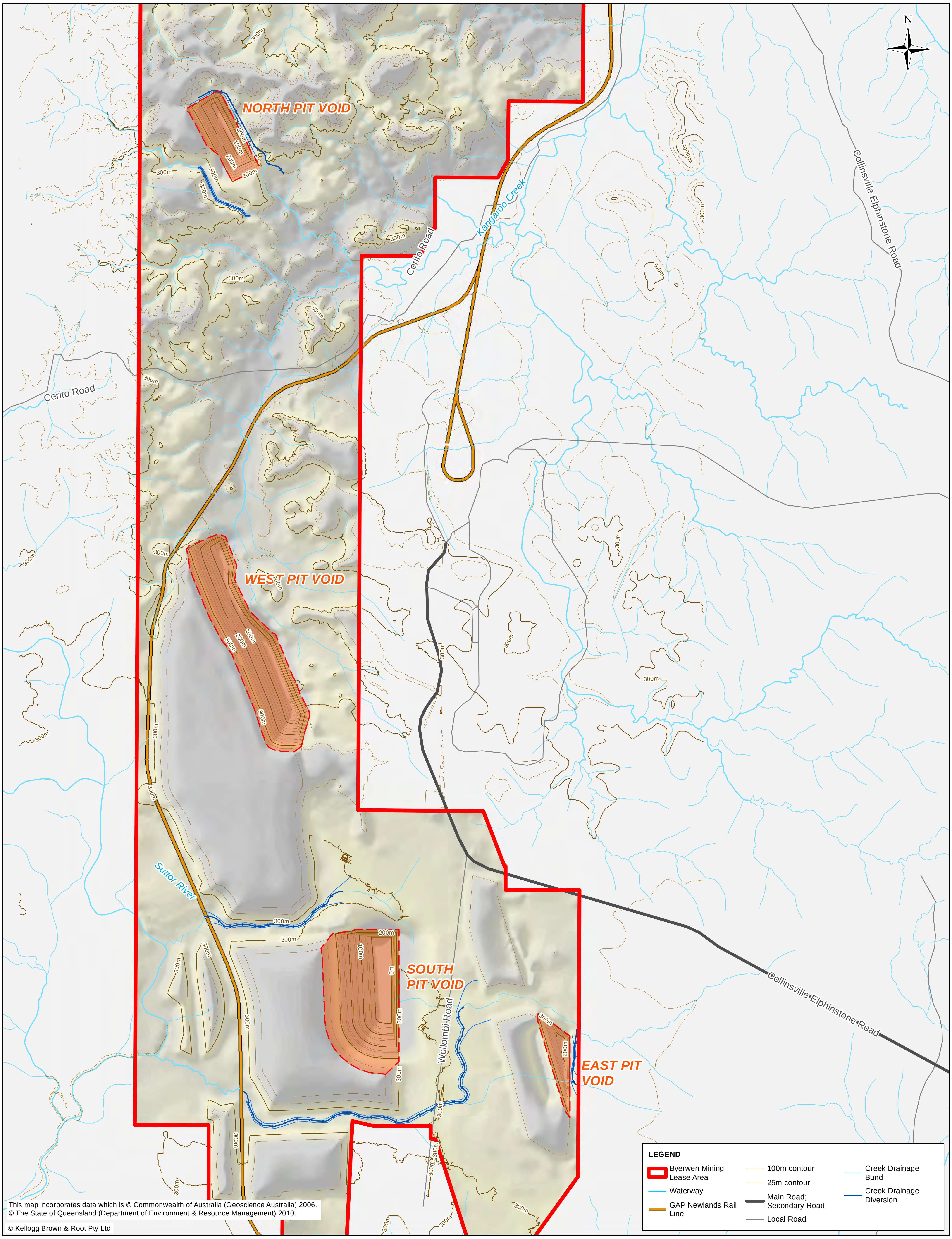
This final void assessment forms part of a wider Environmental Impact Statement (EIS) for the Project and provides technical information which addresses the final void component of the EIS Terms of Reference (ToR).

Four final voids will be created by the Project. These are identified as North Pit, West Pit, South Pit and East Pit which are shown in Figure 1.1.

1.2 SCOPE

The scope of this assessment reflects the ToR which requires an evaluation of the risk of discharge and prediction of water quality within the final voids. Specifically, these requirements include:

- 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 storage dams (includes 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 1000 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.



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COORDINATE SYSTEM GDA 1994 MGA Zone 55

DATE 14 Nov 2012

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TITLE

Byerwen Coal Project
Final Landform

Figure 1.1

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1.3 STUDY APPROACH

The approach adopted in this study involves:

- Assessment of final void geometry with respect to final land use within the Project area.
- Assessment of key model input factors such as climate and hydrological considerations (surface water and groundwater).
- Water balance assessment to capture the range of possible water level conditions that may develop within the voids.
- Mass balance (coupled with the water balance) to predict salinity changes over time.
- Assessment of void water quality including salinity, stratification potential, biological succession, trace metals, geochemical behaviour and water quality evolution.
- Overview of void management principles that should be considered.

1.4 REPORT STRUCTURE

This report contains the following chapters:

- Rehabilitation approach
- Surface and groundwater hydrology
- Water level prediction
- Pit lake water quality
- Management Strategy
- Conclusions
- References
- Appendices.

2 Rehabilitation approach

2.1 MINE REHABILITATION

The areas disturbed by mining will be rehabilitated as per a rehabilitation management plan and specific rehabilitation details are specially addressed in the EIS. Spoil will be graded and a shedding-type cover provided to direct water away from the spoil and minimise infiltration. There may also be opportunities for grazing in sections of the site. Further details of the rehabilitation strategy are provided in the EIS.

2.2 FINAL VOID END-USE

A range of options were considered for the final void end-use based on the former Department of Mines and Energy Technical Guidelines for Environmental Management of Exploration and Mining in Queensland (DME, 1995) on open pit rehabilitation. These options include:

- Backfilling: The proposed mining process involves limited out-of-pit dumping of waste rock in the early stages of mining, with the remainder being dumped in-pit. Backfilling the final void will require waste rock from the out-of-pit dump to be transported to the final void. This will require either the out-of-pit dumps to be left in an unrehabilitated state during mining, or disturbance of a previously rehabilitated area. It will also require additional earthworks after the saleable product has been exhausted and will sterilise any remaining resource. While it is financially viable to backfill some of the pits which have become available for backfilling during operation of other pit areas, the backfilling of all pits is not considered viable.
- Water storage: Final voids could be used for water storage. However the quality of water in the voids is likely to be brackish due to groundwater inputs and evapo-concentration effects. Use of the final voids for water storage may be undertaken on an opportunistic basis, but will not be the primary end-use.
- Wetland/wildlife habitat: The final voids will be depressions in the landscape, have a much higher depth to width ratio than natural lakes and as noted above are likely to contain brackish water. Use of the final voids for wetland/wildlife habitat may be undertaken opportunistically by birds, but will not be the primary end-use.
- Waste disposal: Final voids proposed as part of the Project are a small addition to the existing and proposed final voids that exist in the region. The main waste produced in the region is mining wastes (e.g. waste rock and rejects). There are no current plans to utilise the proposed final voids for post operational placement of mining waste. The final voids could be used for municipal solid waste if economics and environmental considerations are favourable, however this is not currently planned or catered for in this study.

- Restrict access and ensure public safety: This option involves making the final voids safe by re-contouring and preventing or deterring access. This option allows for a progressive rehabilitation approach and requires minimal works to implement once mining has concluded on the site. This option also allows for minimal maintenance and ongoing inspection of elements and is complemented by the remote location of the site.

An assessment of the above options determined that restricting access and ensuring public safety is the preferred option for dealing with final voids. There area a number of impracticalities arising from the remote location of the site and relative costs associated with some of the other final void options. The potential brackish nature of the water collected in the pits limit the use of the final voids for water storage (though this will be undertaken on an opportunistic basis). Similarly, the conditions of the final void structures will not be complimentary to a wetland habitat. Economic factors limit the use of the final void structures for municipal waste disposal (due to the remoteness of the site) and backfilling has been prepared for 4 of the 8 pits where this was financially viable.

2.3 FINAL VOID DESIGN

The primary objective of final void design is to make the voids safe to ensure public safety. This may involve re-contouring batters and discouraging public access.

The other considerations in final void design are the catchment extent, void location and access arrangements. These variables affect the movement of water into and from the void. There are three general approaches as follows:

- 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 in situations where the void water quality is expected to be poorer than surface water systems and the void can be configured to avoid overflows. In situations of high groundwater inflows or large catchment extents, this may not be a feasible option.
- Intermittent flushing void: This approach aims to isolate water in the void from surface water systems until there is a very large flow in the receiving environment. During large flows the void overflows and relies on dilution to minimise water quality impacts. The flushing arrangement is normally achieved by configuring weirs at the inlet and outlet of the void.
- Regularly flushed void: This approach aims to regularly flush water from the void. This approach is well suited to situations of high groundwater input or when the risk of overflow of isolated void water (subject to evapo-concentration effects) to the environment is unacceptably high.

Consideration was given to each of these approaches, however the isolated void was selected as the lowest risk option for reasons described further throughout this report.

2.4 FINAL VOID GEOMETRY

The final void geometry used in this report is based on the final landform profile as defined by the mine plan generated by Minserve in 2012. The void designs are indicative of the final levels and shape, but are subject to change in the future in response to future mine planning, as well as resource and economic factors.

Refinement to the geometry of final voids is unlikely to have a significant impact on the management approach or findings of this study given the large footprint and storage capacities of the voids. A summary of the elevation-area-volume relationship of the four voids is provided in Figure 2.1

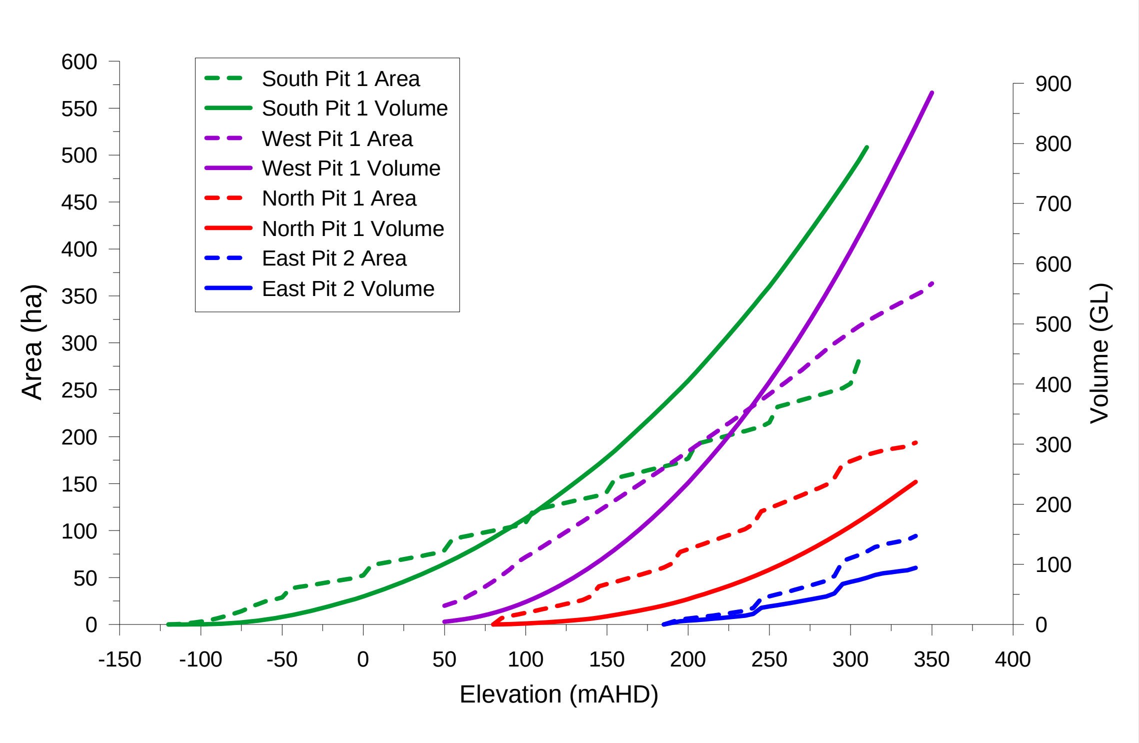


Figure 2.1
AREA-ELEVATION-VOLUME RELATIONSHIP OF EACH FINAL VOID

3 Surface and groundwater hydrology

3.1 CLIMATE

3.1.1 Rainfall and evaporation

Rainfall and evaporation data has been collected from the Data Drill database which provides patched point data over a period of 123 years (1889-2012). The grids of data were interpolated (using kriging and splining techniques) from Bureau of Meteorology point observations (Queensland Government, 2011).

The site is located in a semi-arid zone where on average annual evaporation rates are greater than annual rainfall. The relationship between pan evaporation and rainfall is presented in Figure 3.1. The long term rainfall record from Data Drill (Queensland Government 2011) is presented in Figure 3.2.

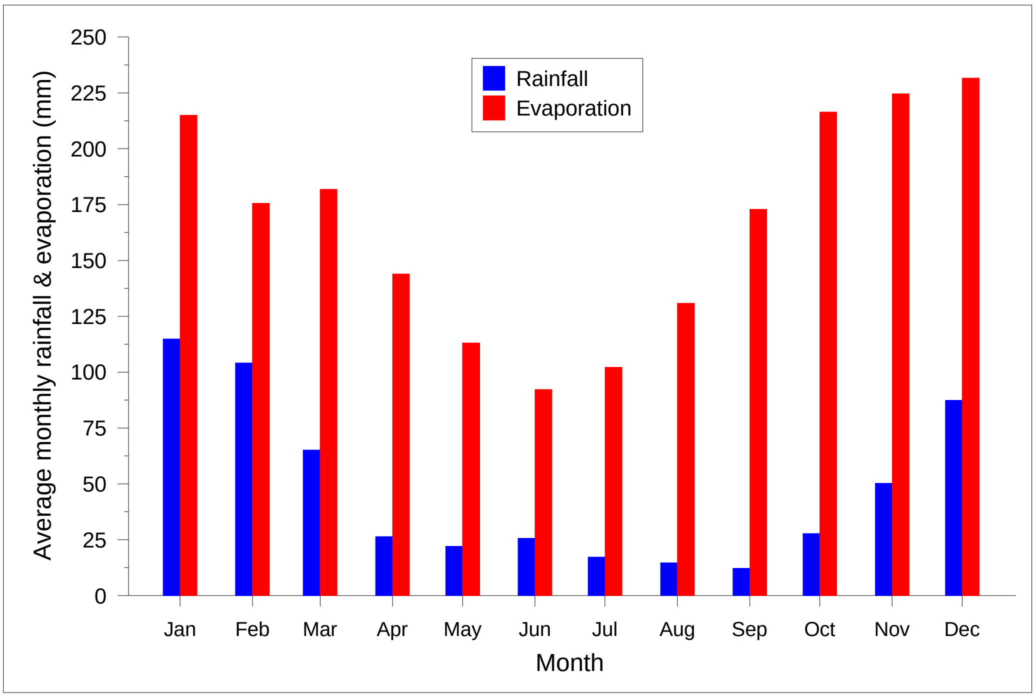


Figure 3.1
MONTHLY AVERAGE RAINFALL AND EVAPORATION

Due to the long term prediction timeframes required for this assessment, stochastic rainfall data was generated based on the Data Drill record. Stochastic rainfall data is synthetic data that has the same statistics as the historical record, but provides alternative realisation of the historical record that are equally likely to occur.

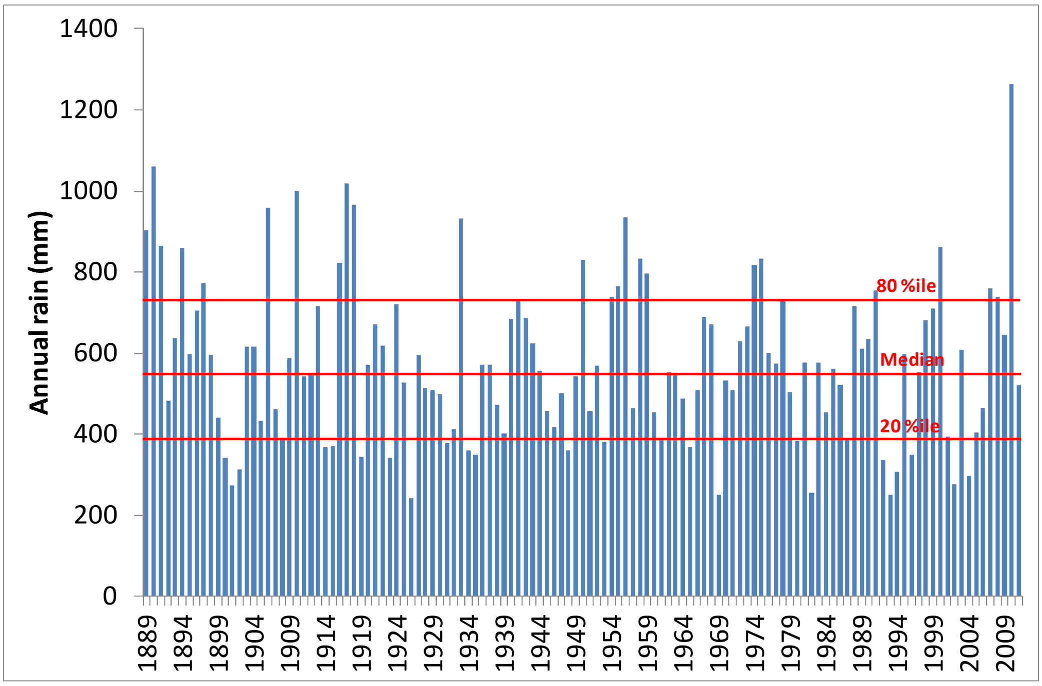


Figure 3.2
ANNUAL RAINFALL DERIVED FROM DATA DRILL

Evaporation is also an important input to the water balance models that predict pit lake formation. Various approaches are available to estimate evaporation from the lake surface. A common method, Morton's lake evaporation equation, is not considered appropriate as the pit lake is not a conventional lake. The pit lake will be affected by shading from pit walls and reduced wind penetration which Morton's Lake evaporation cannot account for.

An alternative approach is to apply a pan factor to the measured evaporation to obtain a more accurate value for lake evaporation. The pan factor applied accounts for the difference between measured "pan evaporation" and actual evaporation from an open water body which is susceptible to reduced wind penetration (which increases localised humidity) and shading from pit walls. The small dish which is used to measure pan evaporation takes extra heat through the sides of the pan which can also contribute to an over-estimation of actual evaporation.

There are no guidelines and very little research of appropriate pan factors for pit lakes which therefore introduces a large degree of uncertainty into water level predictions. An upper and lower bound of 0.4 and 0.8 was considered reasonable, and is consistent with assumptions adopted for various other long term pit lake models. This was implemented in the stochastic model using a normal distribution curve with a median value of 0.6 and a standard deviation of 0.1. The distribution remained constant for each given time series, but was re-sampled for each new realisation.

3.1.2 Climate change

The observed climatic data collected for the past 123 years may not be representative of the future conditions due to anthropogenic causes of climate change. In Australia, average temperatures have increased by almost 1 degree Celsius since 1950 (CSIRO 2007).

The most widely recognised scientific findings on atmospheric change and the potential for human induced changes in the Earth's climate have come from the Intergovernmental Panel on Climate Change (IPCC). The summarised findings of the 2007 study are that it is very likely that there will be changes in the global climate system in the centuries to come, larger than those seen in the recent past. Future changes have the potential to have a major impact on human and natural systems throughout the world including Australia (IPCC, 2007).

Algorithmic climate change data was sourced from the CSIRO (2007) and IPCC (2007) studies. These algorithms provide scenarios to quantify the impacts that climate change will have on rainfall and evapotranspiration.

Climate change scenarios investigated have been restricted to the most sensitive parameters of the water balance model, rainfall and evaporation.

Rainfall

The IPCC predicts that anthropogenic change will impact the average rainfall, as well as the magnitude and frequency of rainfall extremes. CSIRO have compiled the outcomes of the fourth assessment report of the IPCC, and built on a large body of climate research that has been undertaken for the Australian region in recent years to provide climate change predictions for the different regions of Australia.

Regional projections are available for low, mid-range and high greenhouse gas emission scenarios. The scenarios were developed by the IPCC, and are based on multiple assumptions regarding factors such as the economy, technology and demographic factors which could influence future emissions. Emission scenarios from the IPCC report presented were scenario B1 for low emissions, and scenario A1FI for high emissions (CSIRO, 2012).

Table 3.1 below summarises the predicted climate change parameters for the Byerwen mining lease area for the year 2070. The 10^{th} percentile was selected to model the smallest climate change for the Low emission scenario (IPCC emissions scenario B1), while the 90^{th} percentile high emission scenario (IPCC emissions scenario A1F1) was selected to depict the worst case scenario. This approach should identify the bounds of potential changes resulting from anthropogenic climate change

Table 3.1 Rainfall and evaporation change prediction adopted for Byerwen (2070)

Year	Season	Percentile	Emission	Rainfall	Potential Evapotranspiration
2070	Autumn	10	Low	-20 to -40%	2 to 4%
2070	Spring	10	Low	-20 to -40%	2 to 4%
2070	Summer	10	Low	-10 to -20%	2 to 4%
2070	Winter	10	Low	-20 to -40%	2 to 4%
2070	Autumn	90	High	20 to 40%	16 to 20%
2070	Spring	90	High	10 to 20%	12 to 16%
2070	Summer	90	High	20 to 40%	16 to 20%
2070	Winter	90	High	20 to 40%	16 to 20%

Adapted from CSIRO, 2012.

Evaporation

The IPCC predicts that potential evaporation is likely to increase as a result of climate change (IPCC, 2007). The changes predicted for the project area are presented in Table 3.1. These values are based on two of the scenarios developed by the IPCC, where low emissions are derived from scenario B1 and high emissions are derived from scenario A1FI.

The 10^{th} percentile was adopted for the Low emissions scenario as this gives the most conservative estimate of climate change predicted for 2070. This scenario shows a uniform 2 - 4% increase in potential evaporation for the area. For the high emissions scenario, the 90^{th} percentile prediction was adopted as it would provide the most extreme prediction of climate change impact on the site.

By comparing the two selected scenarios, both predict an increase in evaporation by the year 2070, however the rate of change is significantly different between the two models. As evaporation is the major outflow point for the final void model, changes to this factor can have significant impacts on both the depth of the pit lake and the associated salt concentration.

3.2 SURFACE WATER HYDROLOGY

3.2.1 Catchment areas

Several catchment types exhibiting different runoff characteristics drain into the final voids. The catchments have been divided into three broad categories with associated runoff characteristics:

- rehabilitated spoil
- pit wall (or direct rainfall)
- external catchment.

The external catchment area for each pit was determined using Catchment Sim model of the site which predicts catchment areas based on contours of the area. For most of the pits considered, it was assumed that bunding around the perimeter of the pit would divert surface runoff away from the pit. Only south pit final void is predicted to have an external catchment component of inflow due to the shape of the final landform and the location of the creek diversions.

Rehabilitated spoil catchment areas are derived from the spoil mounds in the final landform prediction provided by the proponent. The mounds 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 lake. Base flow describes the fraction of rainfall which permeates into the soil (as opposed to forming surface runoff). As the rehabilitated spoil 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 spoil. The framework of the spoil dump, its construction, the spoil characteristics and the volumetric content of the dump will all play a factor in determining the hydrology of the waste rock dump (Smith. et. al, 1995). As the textural properties of the rehabilitated spoil dump will be unknown until they have they have undergone the rehabilitation process, it has been assumed that half of the base flow will drain towards the pit lake and half to the surface water system in the form of toe seepage from the spoil. The model did not appear to be sensitive to changes in the size of this catchment. For each pit, half of the adjacent spoil mound area was used to determine the inflow to the pit from the rehabilitated spoil catchment.

The pit wall area has been calculated for each pit using a 12D model of the final void landform provided by the proponent. The area of each of theses 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 rainfall. A summary of the catchment area for each pit lake is presented in Table 3.2.

Table 3.2 Catchment areas for each final void

Catchment	North Pit	West Pit	South Pit	East Pit
Rehabilitated Spoil^	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 spoil will be contoured to drain away from the final void. Some infiltration into the cover is predicted, forming a groundwater mound within the spoil. It is assumed that the mound will be highest in the centre of the spoil, 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.

3.2.2 Incident rainfall

Incident rainfall directly to the pit lake was assumed to contribute directly to the water levels (i.e. no losses). In the model, surface area of the lake was multiplied by the rainfall to determine the volume of incident rainfall.

3.2.3 Catchment runoff

Catchment hydrology was modelled using the Australian Water Balance Model (AWBM) (Boughton, 1993). AWBM is a partial area saturation overland flow model. The partial area method separates the catchments into regions that produce runoff (contributing areas) during a rainfall-runoff event and those that do not. These contributing areas can be modelled to vary within a catchment according to pre-defined catchment conditions, allowing for the spatial variability of surface storage in a catchment. The use of partial area saturation overland flow approach is simple, and provides a good representation of the physical processes occurring in most Australian catchments (Boughton, 1993).

Derivation of AWBM model input parameters is described in the Mine Water Management Strategy (KBR, 2012b).

As discussed above, the catchment area for each pit is derived from the rehabilitated spoil area adjacent to the pit. The surface runoff will be directed away from the pit lake, however, the base flow component of approximately half of the rehabilitated spoil mound will enter the pit lake. As such, only the base flow component of the AWBM model was used to calculate catchment runoff.

3.3 GROUNDWATER HYDROLOGY

The groundwater equations used were described by Marinelli and Niccoli in their 2000 paper *Simple analytical equation for estimating groundwater inflow to a mine pit*. As discussed above, two separate zones of flow were considered. Zone 1 flow considers steady-state, unconfined, horizontal and radial flow. Zone 2 considers steady-state flow to one side of a circular sink of constant uniform drawdown.

The analytical model uses interpolation to derive the radius of influence from the centre of the pit lake. Once the radius of influence is known, Zone 1 inflow is calculated. Zone 2 uses a slightly different approach, where a number of assumptions regarding the hydraulic head of the pit lake define the rate of flow from the circular sink. A summary of the model parameters is shown in Figure 3.3.

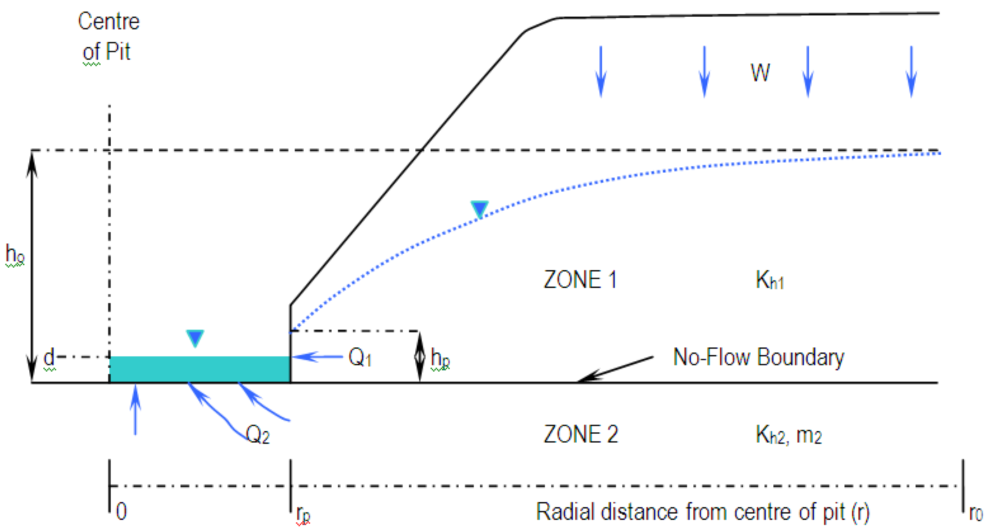


Figure 3.3
PIT INFLOW ANALYTICAL MODEL (AFTER MARINELLI AND NICCOLI, 2000)

The equations used for the groundwater flow estimates are:

Equation 1: Extent of drawdown

$$h_o=\sqrt{(h_p^2+(W/K_{h1})[r_o^2\ln(r_o/r_p)-\{(r_o^2-r_p^2)/2\}]}$$

h_o - Saturated thickness of aquifer

h_p - Height of aquifer seepage face

W - Rainfall recharge rate

K_{h1} - Hydraulic conductivity

r_o - Radius of influence

r_p - Equivalent radius of mine pit as a cylinder

By applying interpolation to Equation 1, the radius of influence could be estimated. This provides a key input to the inflow equation for Zone 1.

Equation 2: Zone1 inflow

$$Q_1 = W\pi(r_o^2 - r_p^2) \quad m^3/day$$

Zone 2 inflow could be calculated when considering the relative vertical and horizontal hydraulic conductivities.

Equation 3: Zone2 inflow

$$Q_2 = 4r_p(K_{h2}/ m_2) \quad m^3/day$$

m_2 = $\sqrt{(K_{h2}/ K_{v2})}$

Kv_2 - Vertical hydraulic conductivity

Inputs to the model such as regional groundwater level and hydraulic conductivity were provided by Rob Lait and Associates (2012).

In the case where the water level in the pit was to rise above the regional groundwater level, Zone 1 and Zone 2 would cease to flow into the pit. Under these conditions the rate at which water would discharge from the pit to the surrounding groundwater system was estimated by applying Darcy's equation.

4 Water level prediction

4.1.1 Model platform

A water balance model of the final voids was developed using Goldsim software. 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)

Where, Δstorage= I + R + G - E

The Byerwen final void Goldsim model includes:

- Uncertainty analysis using Monte Carlo techniques.
- Consideration of climate change.
- The relationship between pit water level and regional groundwater level and the associated affects on groundwater seepage.
- Modification of pit wall catchment area based on pit lake area.
- Modification of evaporation rates due to increasing salinity in the pit.

4.1.2 Time step

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.

4.1.3 Uncertainty

Not all variables of the Goldsim model are measured values. As such there is some inherent uncertainty in the selection of appropriate values for certain variables. The water balance was constructed using probabilistic simulation, which involves explicitly representing this uncertainty by specifying inputs as probability distribution functions and specifying random events that could affect the system. The probability distributions are either assumed based on the range of expected values, or derived based on analysis of available datasets.

Goldsim uses advanced Monte Carlo techniques to propagate the uncertainty in model inputs to model outputs.

Since the inputs describing the water balance are uncertain, the water level predictions in the voids are also approximations. That is, the result of any analysis based on inputs represented by probability distributions is itself a probability distribution. This type of result is typically more useful for understanding risks than avoiding traditional deterministic simulation, which provides a single result based on "the best guess" or "worst case" values, without providing context of the likelihood of this scenario actually occurring.

The model was run 100 times (realisations) for each scenario in order to generate water level probability distributions.

4.1.4 Scenarios

Four key scenarios were modelled. The scenarios were designed to address key factor and uncertainties in the model. The scenarios included:

- Base case scenario.
- Higher hydraulic conductivity scenario.

  A higher hydraulic conductivity value was used to test the sensitivity of the pits to changes in hydraulic conductivity. The values selected were chosen based on the technical paper produced by Rob Lait (2012).

- Climate change scenario 1

  Climate change variations applied to rainfall and evaporation based on the climate change predictions from CSIRO (2012). The factors were applied to each month for the high emission scenario (A1F1 scenario from IPCC (2007)) 90th percentile prediction for 2070.

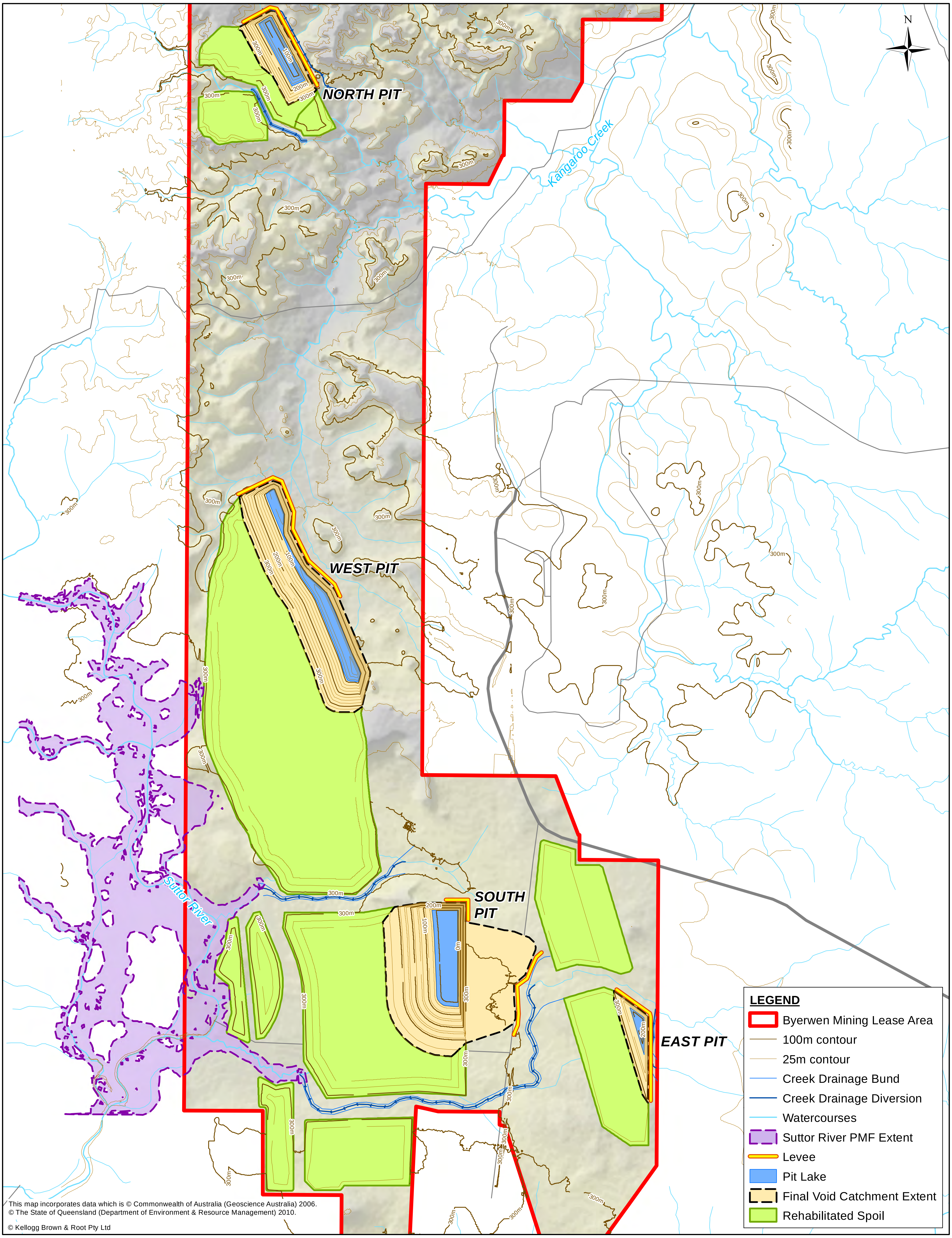
- Climate change scenario 2

  Climate change variations applied to rainfall and evaporation based on the climate change predictions from CSIRO (2012). The factors were applied to each month for the low emission scenario 10th percentile prediction for 2070 (IPCC (2007) scenario B1).

4.2 WATER BALANCE MODEL RESULTS

This section provides a discussion of the water balance model results. More detailed model output including minimum, maximum and 5th, 25th, 50th, 75th, 95th percentile results is provided in the following appendices:

- East Pit – Appendix A
- South Pit – Appendix B
- North Pit – Appendix C
- West Pit – Appendix D.



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DATE 14 Nov 2012

KBR

Kellogg, Brown & Root Pty Ltd ABN 91 007 660 317
Level 11, 199 Grey Street, South Bank Qld 4101

Created by EM

TITLE

FINAL VOID LAYOUT

FIGURE 4.1

Rev A

4.2.1 Base case

The model predicts that a pit lake will develop in all of the final voids. The results are summarised in Table 4.1 and displayed in Figure 4.1. These suggest that pit lakes will form over a period of approximately 120–390 years depending on the void and lakes will have a steady state depth in the range of 50 to 194 m. The pit lake elevation will be depressed in the landscape, well below the adjacent ground level. A diagram showing these water levels is provided in Table 4.1.

Table 4.1 Mean results

Final Void Pit	Ground Level (mAHD)	Groundwater Level (mAHD)	Evolution phase	Steady State		
			Evolution period (yr)	Water level (mAHD)	Lake depth (m)	Fluctuation range (m)
North	290	270	260	175	94	± 5
East	305	260	120	235	50	± 3
South	300	250	390	65	194	± 5
West	305	125	250	109	99	± 3

There is a high degree of uncertainty and variability in the model input parameters, which have been represented in the model. It is therefore important to consider the range of results (difference between the higher and lower percentiles). A discussion on these is included in the following sections.

North pit

The model indicates that the water level within the pit lake will be below the level of the (expected) regional groundwater (270 mAHD) in this area. The peak water level predicted is the greatest value predicted by any of the 100 realisations of the data. Statistically it represents the 99^{th} percentile for the highest water level. The mean steady state water level is representative of the mean (of all realisations run) water level which the model predicts once the water level has reached a steady state. The peak water level of all realisations in the North pit occurred 340 years post mine closure, the water level predicted was 235 mAHD, some 35 m below the regional groundwater level (see Figure 4.2). The mean water level predicted at steady state for the model is 175 mAHD

The period at which the model reaches a steady state condition is near 260 years post mine closure. The model predicts that there will be a definitive plateau of pit water level from around year 325 in all scenarios.

Table 4.2 North pit results summary - scenario 1

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

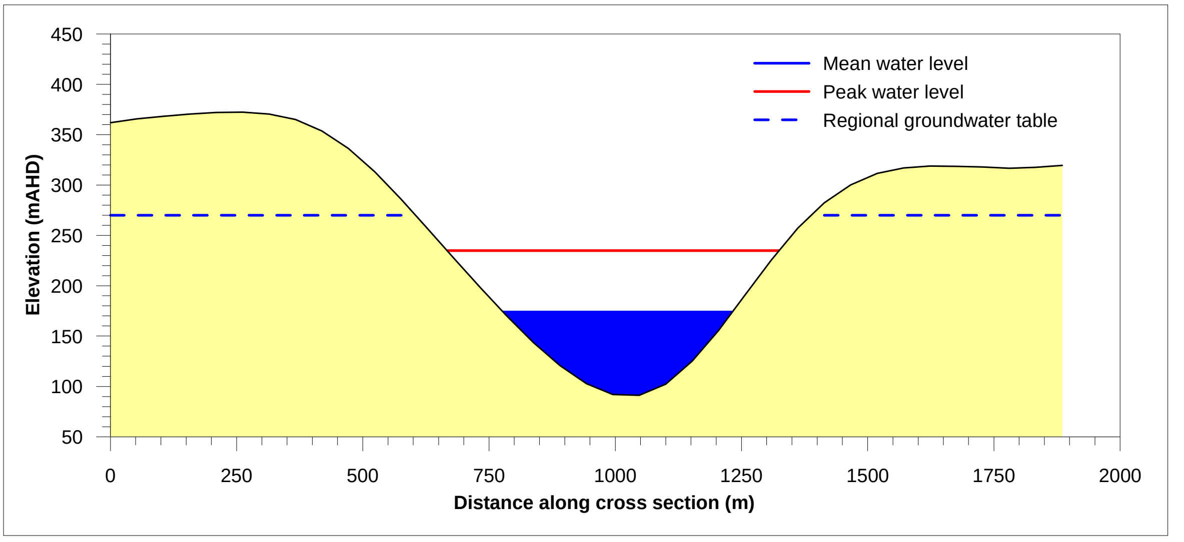


Figure 4.2
NORTH PIT BASE CASE SCENARIO CROSS SECTION

West pit

The model predicts an approximately 15% chance that the water level within the pit lake will reach a level above the (expected) regional groundwater level of 125 mAHD. From all scenarios (100 realisations) run by the model the peak water level within the pit is 170 mAHD. This is still well below the top of the pit which lies at approximately 305 mAHD (135m above the peak water level).

The duration required to reach a steady state condition is uncertain, but the mean steady state is reached at approximately 250 years after mine closure.

Table 4.3 West pit results summary – scenario 1

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

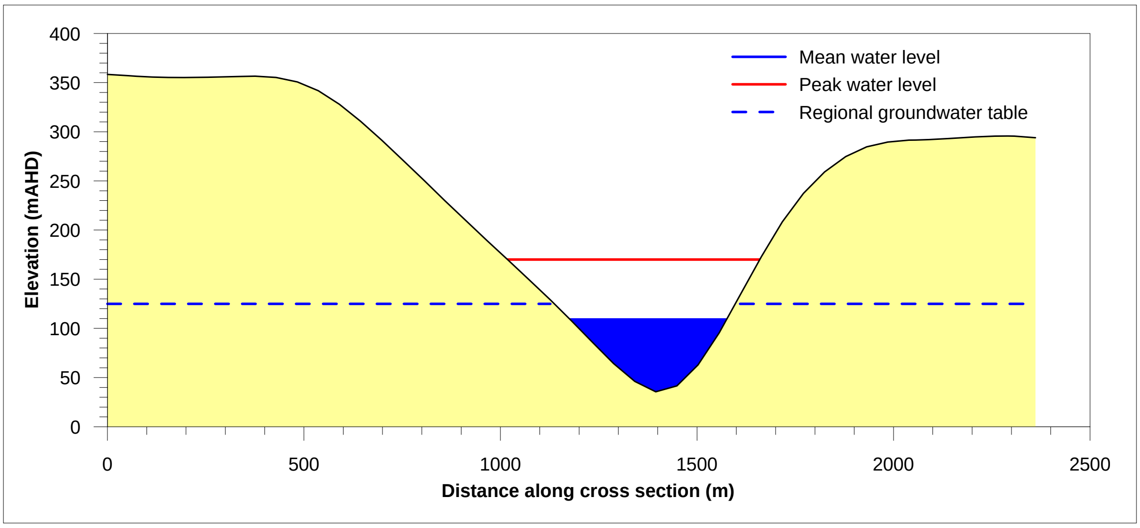


Figure 4.3
WEST PIT BASE CASE SCENARIO CROSS SECTION

South pit

The model indicates that the water level within the pit lake will stabilise at a level well below the (expected) regional groundwater level of 250 mAHD in this area. The ground level around the south pit lies at approximately 300 mAHD. The peak pit water level from all realisations was 145 mAHD. This occurred approximately 375 years post mine closure.

The period at which the model reaches a steady state condition is uncertain, but appears to plateau at close to the 400 years post mine closure mark. The model predicts that there may be cases where steady state will not be reached with 400 years passed mining closure, however there is a plateau of the pit level by approximately 360 years.

Table 4.4 South pit results summary – scenario 1

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

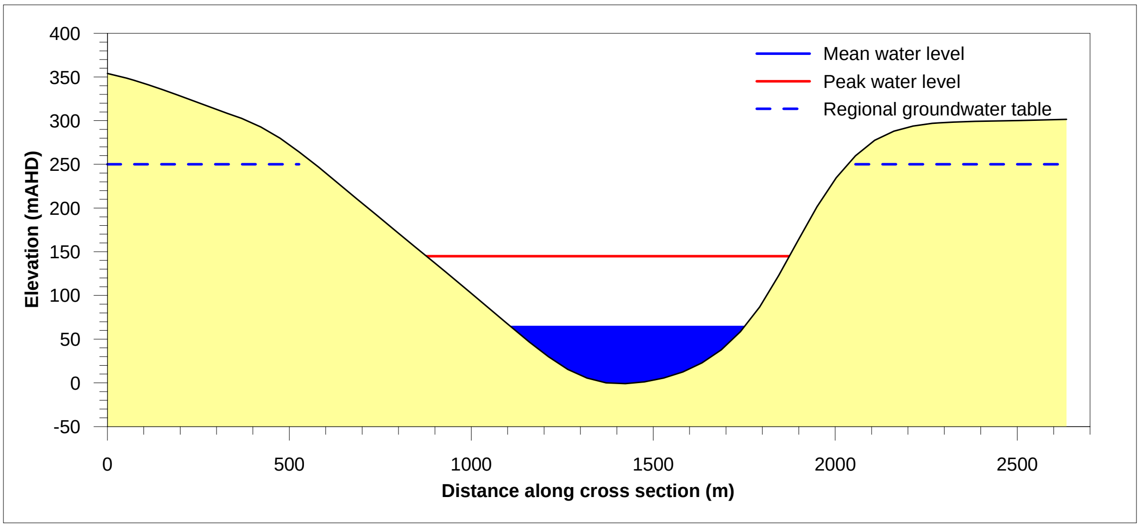


Figure 4.4
SOUTH PIT BASE CASE SCENARIO CROSS SECTION

East pit

The predicted (mean) steady state water level for the east pit lake under this scenario is 235 mAHD. The model predicts that the east pit will reach steady state within 120 years. The peak level of water in the pit from all realisations is 284 mAHD which occurred at approximately 340 years post mining. The ground level around the east pit lies at approximately 305 mAHD. The model does not predict a scenario where the water level in the pit will reach the ground level, however, there is a 15% chance that the water level in the pit will exceed the expected groundwater level (260 mAHD).

Table 4.5 East pit results summary - scenario 1

Parameter	Result	
Pit depth	120 m	
Assumed ground level	305 mAHD	
Regional groundwater level	260 mAHD	45 mbgl
Mean steady state water level	235 mAHD	70 mbgl
Peak water level (highest of 100 realisations)	285 mAHD	20 mbgl
Freeboard at peak	20 m	
Peak water level to groundwater	-25 m	

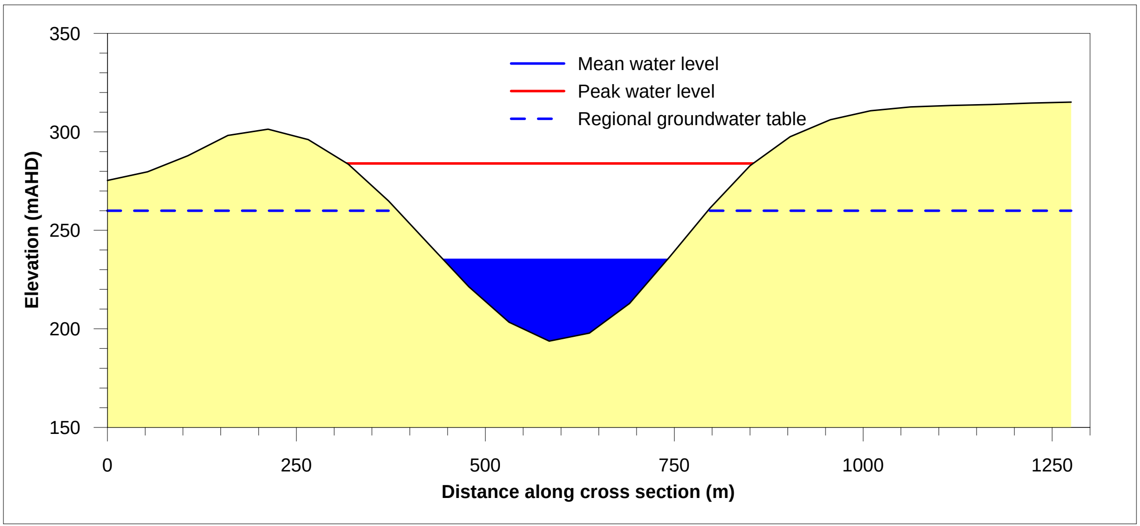


Figure 4.5
EAST PIT BASE CASE SCENARIO CROSS SECTION

Scenario 1 summary – Base case

The two smaller pits (East pit 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 will reach a steady state in approximately 250 years most mine closure which can be attributed to the low regional groundwater level expected in the area. South pit 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 and West pits 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 the east pit which had a freeboard of 21m at the peak predicted level.

4.2.2 Higher hydraulic conductivity scenario

The hydraulic conductivity of the ground will change spatially and with each aquifer unit the groundwater moves through. The current information regarding hydraulic conductivity at the site is covered in a technical paper by Rob Lait and Associates (2012). In the technical paper two hydraulic conductivity scenarios are proposed, a low and high hydraulic conductivity case. The most likely scenario according to the technical paper is the low hydraulic conductivity scenario, and the predicted values for this scenario have been applied to the final void modelling. In order to assess the sensitivity of the predicted final void scenarios to the hydraulic conductivity of the in-situ groundwater the higher hydraulic conductivity scenario proposed by Rob Lait and Associates (2012) was adopted and input to the model. The results follow.

North pit

A higher hydraulic conductivity value was not used to test the sensitivity of the North pit. The hydraulic conductivity remained constant at 1.28 x 10^{-7} m/s. This assumption was based on the technical paper produced by Rob Lait (2012). As such, no change was recorded in the north pit lake water levels from the base case scenario.

West pit

The base case hydraulic conductivity value applied to the west pit was 2.45 x 10^{-8} m/s. The higher hydraulic conductivity case applied for sensitivity analysis was 7.81 x 10^{-7} m/s which was derived from the technical paper produced by Rob Lait and Associates (2012).

The mean steady state water level for the west pit lake was 114 mAHD, while the peak predicted water level was 142 mAHD.

The hydraulic conductivity brought about a 5 m increase in the mean depth of the lake compared to the Base Case. The model predicted a decrease of 60 years to the amount of time required for the pit lake to reach steady state condition (190 years post mine closure). The peak water level predictions were more muted in the higher hydraulic conductivity scenario suggesting slightly less uncertainty in the model.

Table 4.6 West pit results summary - scenario 2

Parameter	Result		Change from Scenario 1
Pit depth	295 m		
Assumed ground level	305 mAHD		
Regional groundwater level	125 mAHD	(180 mbgl)	
Mean steady state water level	115 mAHD	(190 mbgl)	+ 5 m
Peak water level (highest of 100 realisations)	140 mAHD	(165 mbgl)	- 30 m
Freeboard at peak	165 m		+ 30 m
Peak water level to groundwater	-15 m		+ 30 m

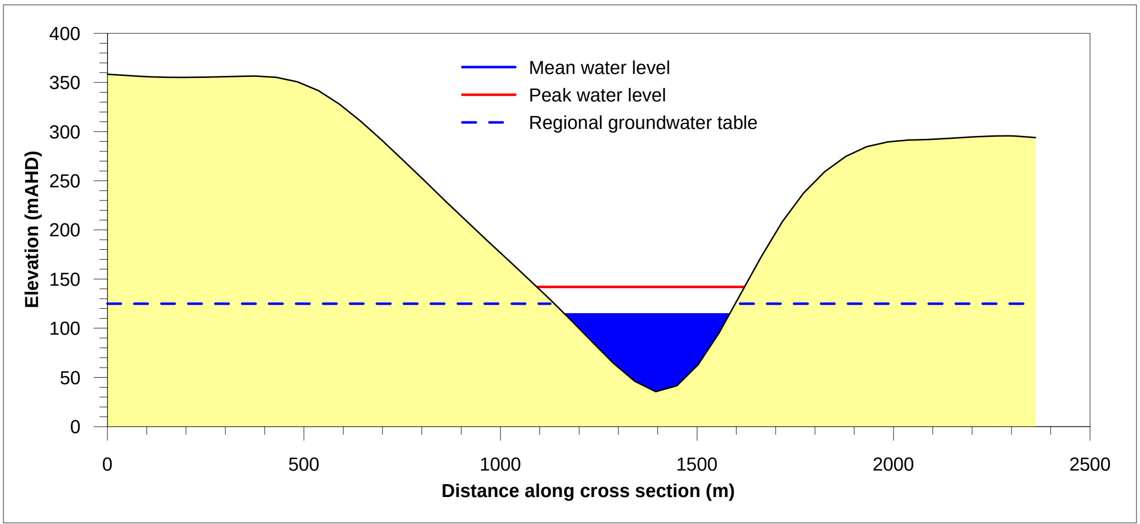


Figure 4.6
WEST PIT HIGH HYDRAULIC CONDUCTIVITY SCENARIO CROSS SECTION

South pit

The hydraulic conductivity applied to the south pit in the base case scenario was 2.45 x 10^{-8} m/s. The higher hydraulic conductivity case applied for sensitivity analysis was

7.81 x 10^{-7} m/s which was derived from the technical paper produced by Rob Lait and Associates (2012).

The higher hydraulic conductivity brought about a significant increase in the depth of the lake. The high hydraulic conductivity increased the mean steady state water level to 186 mAHD. The model predicted the amount of time required for the pit lake to reach steady state would decrease slightly to 330 years post mine closure, with a noticeable plateau in the rise of the pit lake water level between 150 and 200 years post mine closure. The peak predicted water level of the south pit lake was 248 mAHD across the 100 realisations the model ran and occurred 340 years post mine closure.

The model did not predict any scenario where the water level in the pit exceeded the regional groundwater level (250 mAHD), however the peak water level was very close to that level.

Table 4.7 South pit results summary – scenario 2

Parameter	Result		Change from Scenario 1
Pit depth	430 m		
Assumed ground level	300 mAHD		
Regional groundwater level	250 mAHD	(50 mbgl)	
Mean steady state water level	185 mAHD	(115 mbgl)	+ 120 m
Peak water level (highest of 100 realisations)	250 mAHD	(50 mbgl)	+ 105 m
Freeboard at peak	50 m		- 105 m
Peak water level to groundwater	0 m		- 105 m

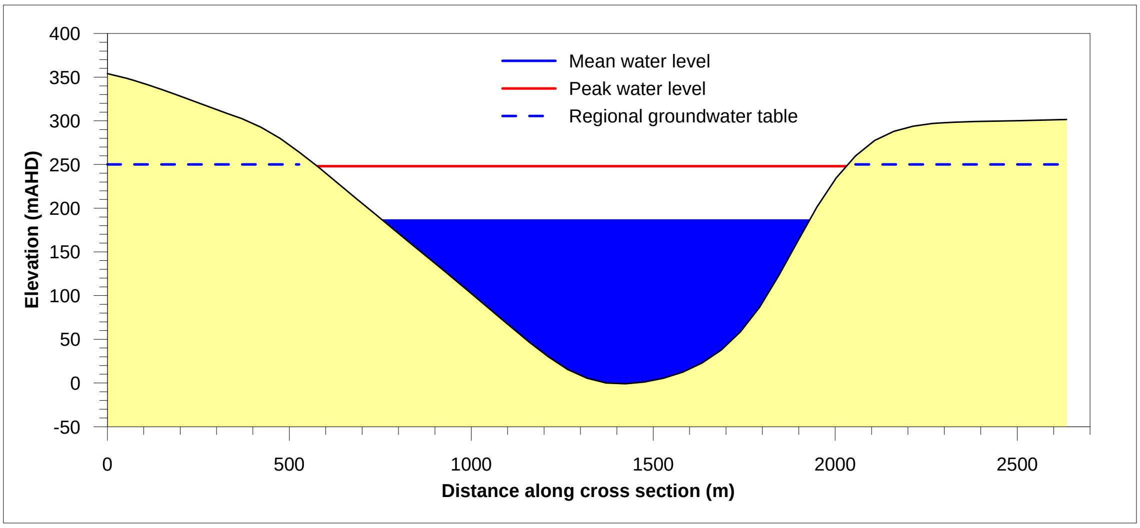


Figure 4.7
SOUTH PIT HIGH HYDRAULIC CONDUCTIVITY SCENARIO CROSS SECTION

East pit

The hydraulic conductivity applied to the east pit in the base case scenario was 2.45 x 10^{-8} m/s. The higher hydraulic conductivity case applied for sensitivity analysis was 7.81 x 10^{-7} m/s which was derived from the technical paper produced by Rob Lait and Associates (2012).

The higher hydraulic conductivity did not appear to have a large impact on the east pit lake water level. The mean steady state water level increased slightly to 251 mAHD. The model predicted the amount of time required for the pit lake to reach steady state would remain similar (110 to 120 years post mine closure). The peak predicted water level of the east pit lake was 276 mAHD, this was a slight decrease from scenario 1. The peak level was predicted at approximately 320 years post mine closure.

The model did predict that the peak water level in the pit exceeded the regional groundwater level (260 mAHD), this represents approximately a 5% chance that the water level in the pit will exceed the regional groundwater level.

Table 4.8 East pit results summary – scenario 2

Parameter	Result		Change from Scenario 1
Pit depth	120 m		
Assumed ground level	305 mAHD		
Regional groundwater level	260 mAHD	(45 mbgl)	
Mean steady state water level	250 mAHD	(55 mbgl)	+ 15 m
Peak water level (highest of 100 realisations)	275 mAHD	(30 mbgl)	- 10 m
Freeboard at peak	30 m		+ 10 m
Peak water level to groundwater	-15 m		+ 10 m

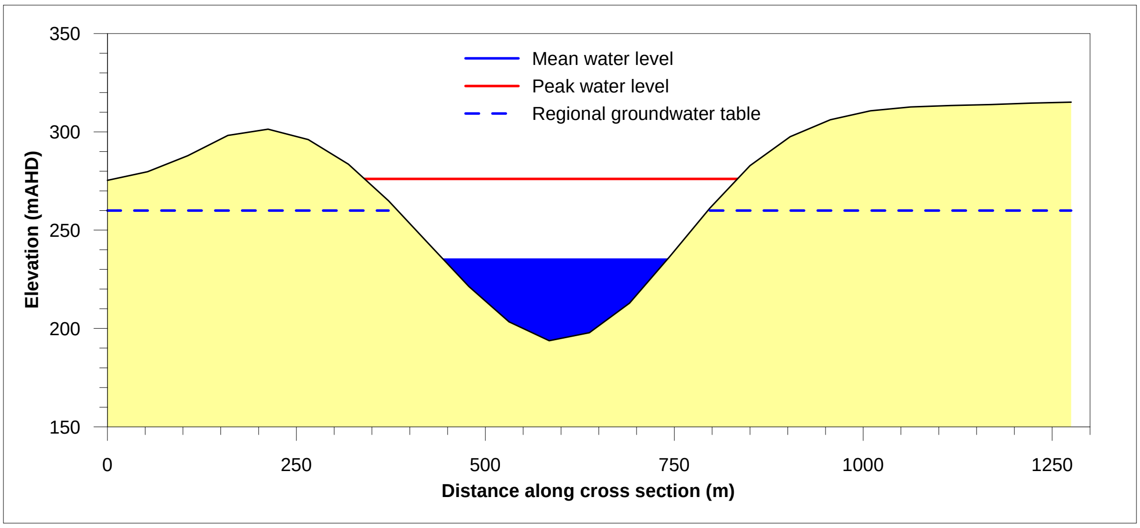


Figure 4.8
EAST PIT HIGH HYDRAULIC CONDUCTIVITY SCENARIO CROSS SECTION

Scenario 2 summary – Higher hydraulic conductivity

The higher hydraulic conductivity scenario appeared to have varied affects on the pit lake water levels. Of the three scenarios run, two of the pits (east and west) recorded only minor changes to the predicted water levels and timeframes to reach steady state. The overarching affect of the higher hydraulic conductivity was to increase the mean steady state water level. This was visible in all three of the modelled pits. Only small increases were visible in the east and west pits, the south pit however, saw an increase of 122 m in the mean water level at steady state.

The south Pit also appeared to be more sensitive to the change in hydraulic conductivity when considering the peak water level predicted increased by 108 m from the scenario 1 prediction. The east and west pits were predicted to have a decrease of 8 m and 28 m respectively from the scenario 1 predictions.

4.2.3 High emission climate change scenario

The high emission climate change scenario (IPCC (2007) scenario A1F1) derived from the climate change predictions from CSIRO (2012) are expected to provide a "worst case" climate change outcome for the final void model. The climate change factors for the year 2070 were applied to potential evapotranspiration and rainfall. The rate of change applied to the model was seasonally.

North pit

The high emission climate change scenario applied to north pit included a 10 - 40% increase in rainfall and a 12 - 20% increase in potential evapotranspiration, depending on the season. The resulting water levels in the north pit were 172 mAHD during steady state and a peak of 241 mAHD.

Compared to the scenario 1 outcomes, only minor change is detected in the north pit lake. A 2 m decrease in the steady state water level and a 6 m increase in the peak water level. The year at which the model reaches steady state is fairly similar, only 30 years apart.

Table 4.9 North pit results summary - scenario 3

Parameter	Result		Change from Scenario 1
Pit depth	210 m		
Assumed ground level	290 mAHD		
Regional groundwater level	270 mAHD	(20 mbgl)	
Mean steady state water level	170 mAHD	(120 mbgl)	- 5 m
Peak water level (highest of 100 realisations)	240 mAHD	(50 mbgl)	+ 5 m
Freeboard at peak	50 m		- 5 m
Peak water level to groundwater	30 m		- 5 m

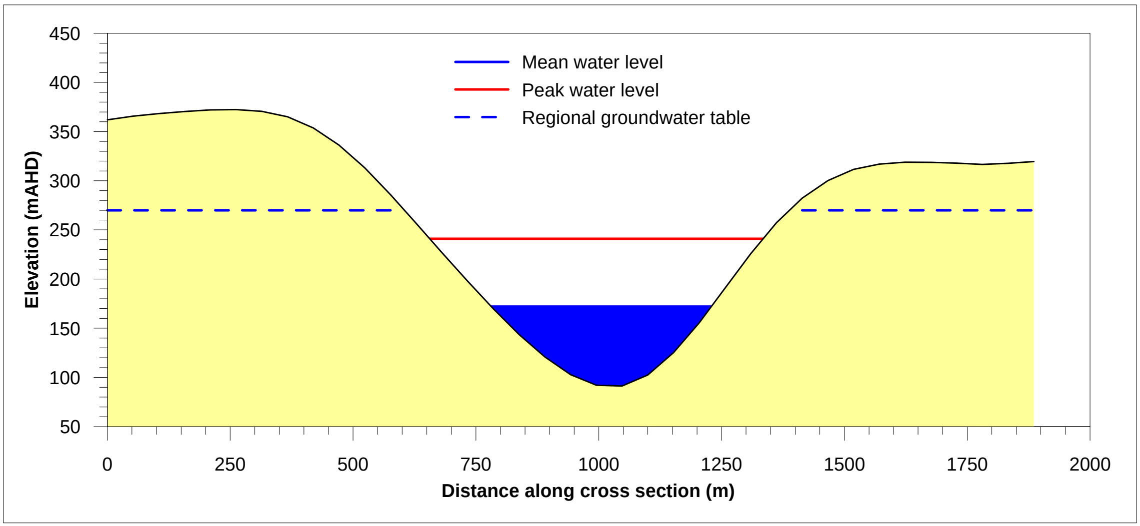


Figure 4.9
NORTH PIT HIGH EMISSION CLIMATE CHANGE SCENARIO CROSS SECTION

West pit

The high emission climate change scenario applied to west pit included a 10 – 40% increase in rainfall and a 12 - 20% increase in potential evapotranspiration, depending on the season. The resulting water levels in the west pit were 106 mAHD during steady state and a peak of 176 mAHD.

Compared to the scenario 1 outcomes, only minor change is detected in the west pit lake. A 3 m decrease in the steady state water level and a 6 m increase in the peak water level. The year at which the model reaches steady state is fairly similar, only 30 years apart. The model predicts a 15% chance that the water level in the pit will exceed the expected regional groundwater level.

Table 4.10 West pit results summary – scenario 3

Parameter	Result		Change from Scenario 1
Pit depth	295 m		
Assumed ground level	305 mAHD		
Regional groundwater level	125 mAHD	(180 mbgl)	
Mean steady state water level	105 mAHD	(200 mbgl)	- 5 m
Peak water level (highest of 100 realisations)	175 mAHD	(130 mbgl)	+ 5 m
Freeboard at peak	130 m		- 5 m
Peak water level to groundwater	-50 m		- 5 m

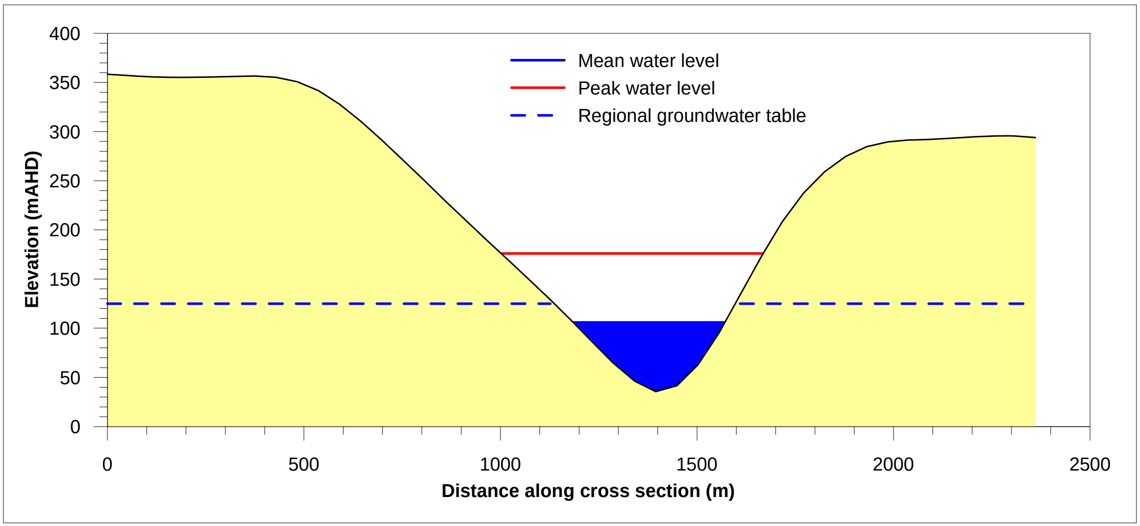


Figure 4.10
WEST PIT HIGH EMISSION CLIMATE CHANGE SCENARIO CROSS SECTION

South pit

The high emission climate change scenario applied to south pit included a 10 - 40% increase in rainfall and a 12 - 20% increase in potential evapotranspiration, depending on the season. The resulting water levels in the south pit were 60 mAHD during steady state and a peak of 154 mAHD.

Compared to the scenario 1 outcomes, only minor change is detected in the south pit lake. A 4 m decrease in the steady state water level and a 9 m increase in the peak water level. The year at which the model reaches steady state is the same in both scenarios, reaching what appears to be a steady state at around 390 years post mine closure. The model predicts no scenario where the water level in the pit will exceed the regional groundwater level.

Table 4.11 South pit results summary - scenario 3

Parameter	Result	Units	Change from Scenario 1
Pit depth	430 m		
Assumed ground level	300 mAHD		
Regional groundwater level	250 mAHD	(50 mbgl)	
Mean steady state water level	60 mAHD	(240 mbgl)	- 5 m
Peak water level (highest of 100 realisations)	155 mAHD	(145 mbgl)	+ 10 m
Freeboard at peak	145 m		- 10 m
Peak water level to groundwater	95 m		- 10 m

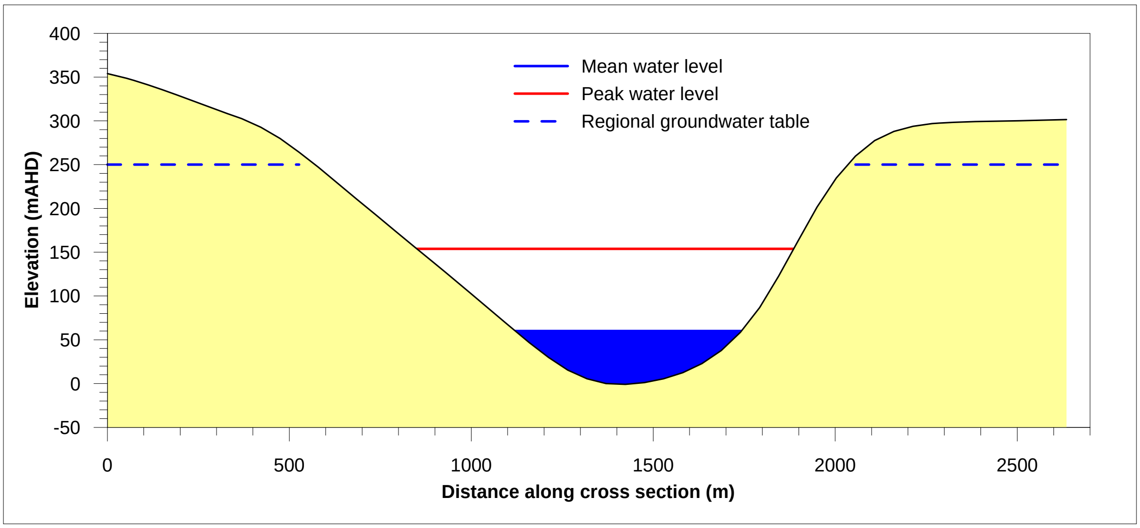


Figure 4.11
SOUTH PIT HIGH EMISSION CLIMATE CHANGE SCENARIO CROSS SECTION

East pit

The high emission climate change scenario applied to east pit included a 10 - 40% increase in rainfall and a 12 - 20% increase in potential evapotranspiration, depending on the season. The resulting water levels in the east pit were 235 mAHD during steady state and a peak of 285 mAHD.

Compared to the scenario 1 outcomes, no significant changes were noted between the steady state water levels or the peak water levels (0 m and 5 m difference respectively). The only change noticeable in the model was the increase in uncertainty of the model predictions given the climate change scenario data. The model remains close to the predictions of scenario 1 in reaching steady state 140 years post mine closure, compared to 120 in scenario 1. The model predicts a 15 % chance the water level in the pit will exceed the regional groundwater level.

Table 4.12 East pit results summary – scenario 3

Parameter	Result	Units	Change from Scenario 1
Pit depth	120 m		
Assumed ground level	305 mAHD		
Regional groundwater level	260 mAHD	(45 mbgl)	
Mean steady state water level	235 mAHD	(70 mbgl)	0 m
Peak water level (highest of 100 realisations)	290 mAHD	(25 mbgl)	+ 5 m
Freeboard at peak	15 m		- 5 m
Peak water level to groundwater	-30 m		- 5 m

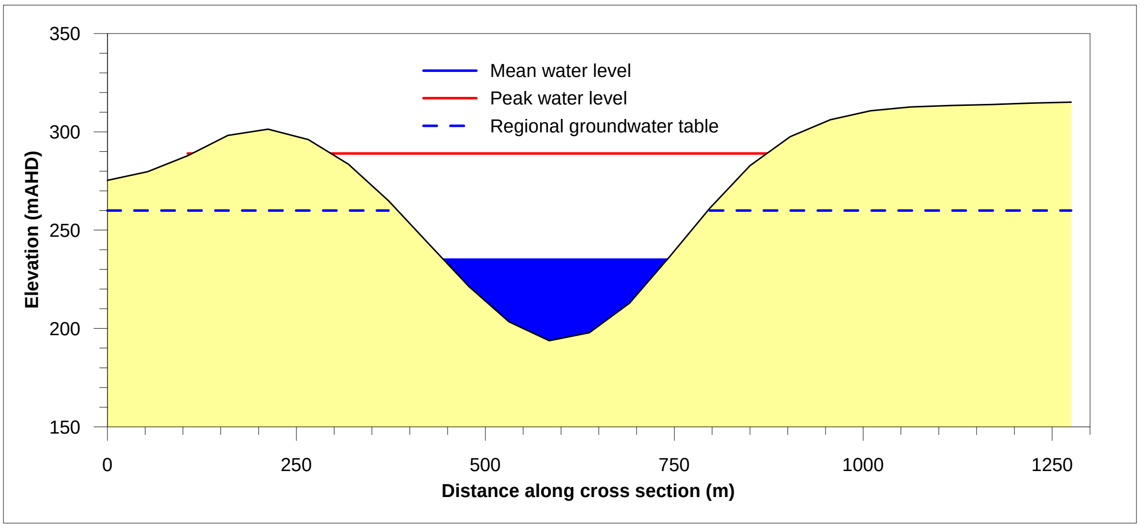


Figure 4.12
EAST PIT HIGH EMISSION CLIMATE CHANGE SCENARIO CROSS SECTION

Scenario 3 summary – Climate change scenario 1

The high emission climate change scenario (IPCC (2007) scenario A1F1) appeared to have minimal impacts on the modelled water levels in each of the pit lakes. The greatest change detailed by the modelling was a 9 m increase in the peak predicted water level of south pit lake. The overall affect of the climate change scenario was an increase in uncertainty in each of the models.

4.2.4 Low emission climate change scenario

As there were minimal affects noted from the high emission climate change scenario, it was determined that producing and reporting on models for all pits for the low emission scenario would be repetitive. As such only one pit was selected to be analysed under the low emission climate change scenario (IPCC (2007) scenario B1). The west pit was selected as it displayed some receptiveness to the high emission climate change scenario and would be fairly representative of the changes witnessed across all pits.

The low emission climate change scenario applied to west pit included a 10 - 40% decrease in rainfall and a 2 - 4% increase in potential evapotranspiration, depending on the season. The resulting water levels in the west pit were 94 mAHD during steady state and a peak of 149 mAHD.

Compared to the scenario 1 results, only minor change is detected in the west pit lake. A 15 m decrease in the steady state water level and a 21 m decrease in the peak water level. The year at which the model reaches steady state is the big change noticeable in the low emission climate change scenario, with the model reaching a steady state some 90 years earlier in the low emission climate change scenario. The model predicts a 5% chance that the water level in the pit will exceed the expected regional groundwater level.

Table 4.13 West pit results summary - scenario 4

Parameter	Result		Change from Scenario 1
Pit depth	295 m		
Assumed ground level	305 mAHD		
Regional groundwater level	125 mAHD	(180 mbgl)	
Mean steady state water level	95 mAHD	(210 mbgl)	- 15 m
Peak water level (highest of 100 realisations)	150 mAHD	(155 mbgl)	- 20 m
Freeboard at peak	155 m		+ 20 m
Peak water level to groundwater	- 25 m		+ 20 m

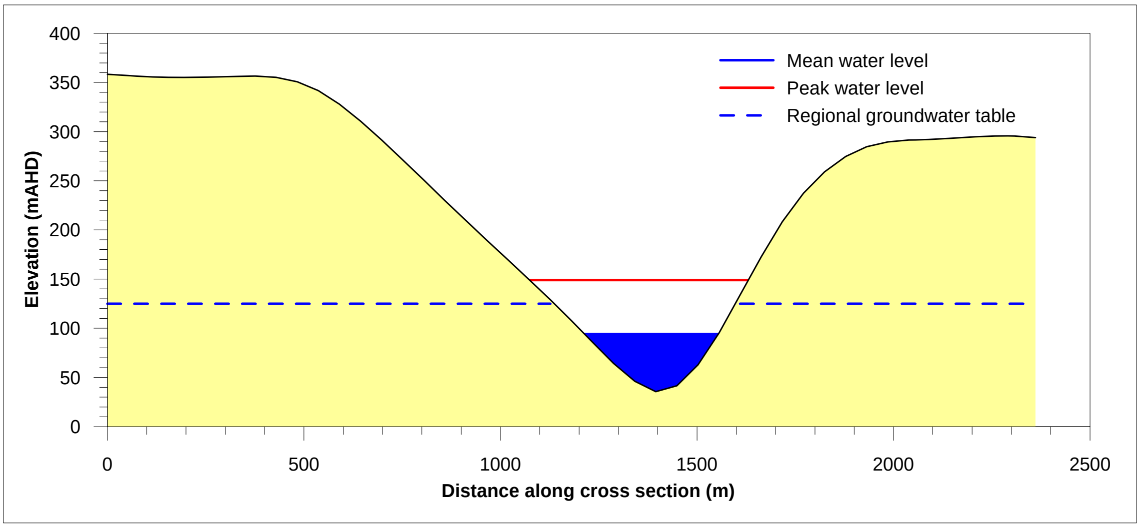


Figure 4.13
WEST PIT LOW EMISSION CLIMATE CHANGE SCENARIO CROSS SECTION

Scenario 4 summary – Climate change scenario 2

The low emission climate change scenario (IPCC (2007) scenario B1) appeared to have only small impacts on the predicted water levels in the west pit lake. As expected the water level changes were more or less in line with the observations from climate change scenario 1, but with smaller peaks and crests the water level output suggest the predictions from the low emission climate change scenario are slightly more certain. The outcomes from the west pit lake model give no reason to suggest further modelling is required to validate the results of this scenario given the results from the high emission climate change scenario.

4.2.5 Extreme rainfall

The effect of high and extreme rainfall events on the water balance was assessed by introducing the event during the quasi-steady state stage for each void (50^{th} percentile). The effect of 25, 50, 100, 200 and 1,000 year ARI design storm events was assessed, as well as Probable Maximum Precipitation (PMP). The rainfall depths associated with these storm events is summarised in Table 4.14. A 72 hour duration storm event was adopted for the assessment, being the design storm event resulting in the largest total rainfall.

Table 4.14 Intensity–Duration–Frequency relationship

ARI (yr) (72 hour storm duration)	Intensity (mm/hr)	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 amount of runoff generated by these storm events is an area of considerable uncertainty. A runoff coefficient of 1.0 is appropriate for the PMP, but a lesser value would apply to lower ARI events. For this assessment a conservative runoff coefficient of 1.0 was applied to all storm events.

The results of the assessment for each pit are discussed below.

North pit

Table 4.15 presents the runoff volume generated for storm events ranging from 25 year ARI to PMP. The water level change resulting from runoff was calculated by comparing the runoff volume to the stage-storage relationship in the final void. Given that the runoff volume is very small compared to the capacity of the void, the resulting water level changes are also small. The PMP event would result in a water level rise of approximately 5 m, which is within the range of fluctuation likely to be experienced due to climatic variability.

Table 4.15 Effect of extreme rainfall on pit lake water levels in north pit

	ARI (yr) (72 hour storm duration)					
	25	50	100	200	1000	PMP
Runoff volume (ML)	404	449	528	595	764	2,515
Steady state water level (mAHD)	165.0	165.0	165.0	165.0	165.0	165.0
Water level after event (mAHD)	165.8	165.9	166.0	166.2	166.5	169.9
Water level change^ (m)	0.8	0.9	1.0	1.2	1.5	4.9

^ compared to Base Case 50th percentile water level

West pit

Table 4.16 presents the runoff volume and associated water level changes caused by storm events in West Pit. The PMP event would result in a water level rise of approximately 8 m, which is within the range of fluctuation likely to be experienced due to climatic variability.

Table 4.16 Effect of extreme rainfall on pit lake water levels in west pit

	ARI (yr) (72 hour storm duration)					
	25	50	100	200	1000	PMP
Runoff volume (ML)	1,285	1,428	1,678	1,892	2,428	7,998
Steady state water level (mAHD)	90.0	90.0	90.0	90.0	90.0	90.0
Water level after event (mAHD)	91.3	91.5	91.7	91.9	92.5	97.8
Water level change^ (m)	1.3	1.5	1.7	1.9	2.5	7.8

^ compared to Base Case 50th percentile water level

South pit

Table 4.17 presents the runoff volume and associated water level changes caused by storm events in South Pit. The PMP event would result in a water level rise of approximately 11 m, which is within the range of fluctuation likely to be experienced due to climatic variability.

Table 4.17 Effect of extreme rainfall on pit lake water levels in south pit

	ARI (yr) (72 hour storm duration)					
	25	50	100	200	1000	PMP
Runoff volume (ML)	1,909	2,121	2,492	2,810	3,606	11,877
Steady state water level (mAHD)	19.0	19.0	19.0	19.0	19.0	19.0
Water level after event (mAHD)	20.8	21.0	21.3	21.6	22.4	30.0
Water level change^ (m)	1.8	2.0	2.3	2.6	3.4	11.0

^ compared to Base Case 50th percentile water level

East pit

Table 4.18 presents the runoff volume and associated water level changes caused by storm events in East Pit. The PMP event would result in a water level rise of approximately 9 m, which is within the range of fluctuation likely to be experienced due to climatic variability.

Table 4.18 Effect of extreme rainfall on pit lake water levels in east pit

	ARI (yr) (72 hour storm duration)					
	25	50	100	200	1000	PMP
Runoff volume (ML)	214	237	279	314	403	1,329
Steady state water level (mAHD)	229.0	229.0	229.0	229.0	229.0	229.0
Water level after event (mAHD)	230.6	230.7	231.0	231.3	231.9	238.0
Water level change^ (m)	1.6	1.7	2.0	2.3	2.9	9.0

^ compared to Base Case 50th percentile water level

4.2.6 Flooding

Figure 4.1 shows mainstream flooding in the Suttor River during a Probable Maximum Flood (PMF) event. These floodwaters would not interact with any of the final voids. The PMF inundation extent is shown in Figure 4.1.

Floodwaters from local tributaries near final voids have the potential to interact with final voids. In the event that floodwater entered a final void, this 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 levees will serve two purposes: access control for safety and protection of floodwaters during extreme events (i.e. isolation of the pit lakes from surface runoff). The levees will be designed to a 100 year ARI design standard.

The proposed levees around the pits are to be regulated structures. They are to be designed to cope with a 1:1000 year storm event with appropriate geotechnical safety factors. The structures will be permanent 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.

5 Pit lake water quality

The water quality within the Byerwen voids is an important consideration that requires an understanding of the key processes that can affect pit lake water quality. These include hydrogeological, limnological, biological and biochemical processes.

As the hydrological and chemical factors concerning a final void differ from those of natural systems, the evolution of the pit lake in a water quality sense is difficult to predict. Notwithstanding this, the Byerwen voids have been assessed in terms of the physical processes (in particular inputs and outputs) which can influence the dynamics of the pit lakes. Key factors in this assessment include an assessment of pit lake water quality in terms of salinity, stratification potential, biological succession and trace metals and geochemical behaviour.

5.1 PHYSICAL FACTORS AFFECTING PIT LAKES

Some of the key physical factors affecting pit lakes include meteorological drivers, inflows in the form of rainfall, surface runoff and groundwater and losses in the form of evaporation. These are discussed in later sections.

The Byerwen voids are expected to operate like groundwater sinks. The regional water table surrounding the voids is expected to be elevated above the pit lake water level, thus drawing groundwater towards the void. A diagrammatic cross section of this is presented in Figure 5.1. A local increase in salinity due to evapo-concentration effects as depicted by the orange zone in Figure 5.1 could occur within the Byerwen pit lakes.

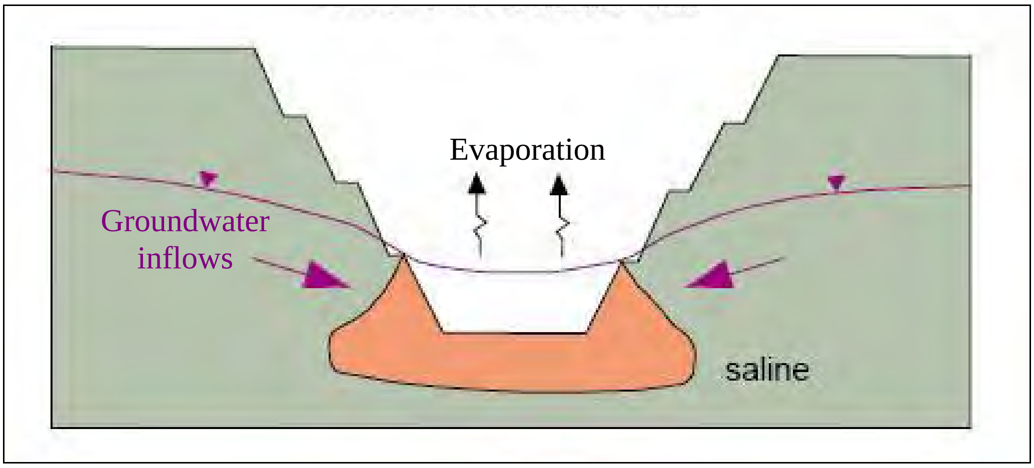


Figure 5.1
PREDICTED HYDROGEOLOGICAL MAKE-UP OF THE BYERWEN VOIDS
Source: Johnson and Wright (2003)

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 lake is at steady state. A high percentage of the inflow on a volume basis is expected to come from pit wall runoff, with less coming from direct rainfall and groundwater inflows.

A water balance analysis of the South Pit final void was conducted in order to determine the relative source of inflows under steady state water level conditions. The South Pit final void was selected as it was considered a typically representative example of the other Byerwen voids in terms of system dynamics and relationship with key influences. Results from the dataset analysed are presented in Table 5.1.

Table 5.1 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 (highwall and lowwall)	658	61
Waste rock dump seepage	36	3

In addition to understanding the dynamics of the pit lakes from a water quantity perspective, the quality of these inflow sources is significant as this can have a major bearing on pit lake dynamics. The effect of the quality of the inflow sources on the water quality within the voids is discussed in the following sections.

5.2 ASSESSMENT OF SOURCE WATER QUALITY

5.2.1 Groundwater

Groundwater inflows are a contributor to the water within the Byerwen voids. In addition to groundwater flows from the greater area surrounding the void, groundwater inflows include rainfall that has fallen on the waste rock stockpile and percolated through to the saturated zone. As discussed in Section 3, it is assumed that a groundwater mound would form underneath the rock stockpile allowing for water to flow down-gradient and into the pit lake. In order to understand the potential effects of these inflow sources on the water quality within the pit lake, data from groundwater monitoring bores and from waste rock spoil samples have been assessed.

Groundwater quality

Groundwater monitoring for a range of physico-chemical parameters has recently been undertaken at a number of monitoring bores within the Project area. These groundwater monitoring bores are screened within a number of different geological units. These geological units (along with the number of groundwater monitoring bores within each included in brackets) include:

- Basalt (2).
- Exmoor formation (1).
- Tertiary sand below basalt (1).
- Fort Cooper coal measures (3).
- Moranbah coal measures (1).

- Rangal coal measures (3).

Groundwater quality data is available from monitoring undertaken during wet and dry seasons over 2011 and 2012 over four separate monitoring events. Summary water quality data (expressed as median values) for a suite of key water quality parameters is presented in Table 5.2 for each geological unit. It is noted that the groundwater data from the Fort Cooper, Moranbah and Rangal coal measure aquifers have been grouped for the purposes of this assessment. The number of observations is presented alongside the median value for each parameter. It should be noted that when interpreting the data in Table 5.2, that as with any numerical data set, the median values presented from a smaller data set not be as representative as values from a larger data set.

Table 5.2 Median groundwater quality data for various geological units

		Coal measures	n	Basalt	n	Exmoor formation	n	Tertiary sand below basalt	n
pH#	pH units	7.7	20	8.7	6	11.4	2	7.6	3
SAR	ratio	12.4	19	23.8	6	31.9	2	20.4	3
TDS (Total Dissolved Solids)	mg/L	1,900	19	7955	6	13,100	2	1310	3
EC	µS/cm	2,930	20	12215	6	20,200	2	2010	3
Total anions	meq/L	28.2	19	109.4	6	175	2	20.6	3
Total cations	meq/L	26.9	19	103.7	6	167	2	19.3	3
Total alkalinity	mg/L	259	26	435.5	8	865	3	265	4
Ammonia as N*	mg/L	0.96	20	1.0	6	2.5	2	0.36	3
Nitrite as N*	mg/L	0.01	19	0.01	6	0.01	2	0.01	3
Nitrate as N*	mg/L	0.02	19	0.015	6	0.02	2	0.02	3
Total P*	mg/L	0.065	20	0.045	6	0.185	2	0.09	3

Limit Of Reporting (LOR) has been adopted for values <LOR when determining statistics
* by discreet analyser
# field observation

It is expected that groundwater flow into the pit lakes will predominantly be associated with the coal measure aquifers. The water quality within the coal measures is neutral to slightly alkaline, within the brackish range, and generally contains low concentrations of oxidised nitrogen and total phosphorus. Ammonia concentrations have been observed higher than the oxidised form of nitrogen.

The general water chemistry of the Basalt and Exmoor Formation aquifers are markedly different to that of the coal measures. These two different types of geological formations exhibit a higher pH (slight to moderate alkalinity), higher salinity (up to four times), and generally higher concentrations of nutrients. Total alkalinity values and the Sodium Adsorption Ratio (SAR) ratio are higher in these formations than the coal measures.

The water chemistry of the “tertiary sand below basalt” is generally consistent with that of the coal measures. However, it is noted that the small number of data points used to derive the summary data is not likely enough to provide a representative snapshot of the range in groundwater quality within this aquifer.

The water quality characteristics of the coal measures (the aquifer most expected to contribute to pit lake inflows) is of moderate quality. The slightly alkaline, brackish groundwater with generally low concentrations of nutrients is expected to have some bearing on the water quality within the pit lake during initial inflows. Inflows from the waste rock dump 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.

5.2.2 Waste rock geochemistry

A geochemical assessment of spoil and potential coal reject materials has been prepared for the Project by RGS and is included in RGS (2012). The assessment comprised an analysis of 238 waste rock samples and 41 potential coal reject samples for the following parameters:

- pH and EC (1:5 w:v)
- Total sulphur
- Acid neutralising capacity (ANC)
- Net Acid Producing Potential
- Chromium reducible sulphur*
- Sulphate*
- Carbon (total, organic and inorganic)*
- Net Acid Generation (including sequential)*
- Total elements in solids*
- Exchangeable cations*
- Soluble elements and major ions in 1:5 water extract*
- Soluble elements, major ions, nitrite and nitrate by TCLP*
- Emerson Class*.

Parameters followed by an asterisk (*) were not analysed on the full range of samples.

Of the 238 waste rock samples, 35% were taken from the Quaternary and Tertiary materials, 6% from the Fort Cooper coal measures, 56% from the Moranbah coal measures and the remaining 3% from the Exmoor Formation. As this assessment is focussed on the geochemistry of the waste rock, geochemistry results of the potential coal reject samples are not discussed further.

The waste rock samples analysed were generally alkaline with a median pH of 9.2, whilst exhibiting a moderate salinity with an estimated median Total Dissolved Solids (TDS) of approximately 360 mg/L, based on a median EC of 539 µS/cm with an applied conversion factor of 0.67 times EC. The majority of the waste rock samples did not show any signs of acid generation (very low concentrations of sulphur and sulfide) with 97% classified as non-acid forming. Although many of the waste rock samples analysed were strongly sodic, concentrations of total metals and metalloids were generally below the applied health-based guideline for waste rock (RGS, 2012).

Interpretation of the waste rock analysis results can provide an indication on the quality of water that is expected to enter the voids both via groundwater flow from rainfall on the rehabilitated waste rock dump 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 pit lake walls are expected to be generally consistent with the waste rock data discussed previously.

Seepage into groundwater from rainfall percolating through the rehabilitated waste rock dump would be within the alkaline range. Although the salinity of rainfall would be very low (typically <20 mg/L) contact between the percolating water and the waste rock is expected to increase the salinity of the water before entering the saturated zone. It is assumed that some of the rainfall will be transported to the saturated zone. Surface runoff from rainfall on the exposed faces of the void is expected to be of similar quality to the water from the waste rock dump.

As the waste rock generally exhibits low concentrations of total metals and metalloids, the water entering the pit lake from both the rehabilitated waste rock dump and from surface runoff from exposed sections of the pit lake walls is not expected to significantly affect the water quality within the pit lake. Although there would remain the added benefit of mixing and dilution associated with transport of water from the rehabilitated waste rock dump within the saturated zone, this process has not been captured in the predictive analysis presented in this report. It is noted that the waste rock dump will be rehabilitated to a standard that is generally consistent with natural areas in the region. Therefore surface runoff quality from this rehabilitated area into the downstream surface water catchment is expected to be characteristic of a typical natural area.

5.2.3 Direct rainfall

Direct rainfall onto the surface area of the pit lake will likely remain in the upper section of the water column due to density effects of the low salinity rainwater. As noted previously, the salinity of rainwater will be much lower than the salinity within the pit lake. The amount of rainfall added to the pit lake on an annual average basis is expected to be in the order of 24% of total inflows. 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.

5.2.4 Summary of source water quality

Acting as a groundwater sink, the Byerwen voids will receive flows from a number of different sources including the regional groundwater, the waste rock dump (percolation of surface water into groundwater), pit wall surface runoff and direct rainfall. The primary source of inflow by volume is from pit wall surface runoff, from exposed walls of the pit lakes. The quality of the surrounding groundwater (coal measures aquifer) is generally alkaline and brackish with low concentrations of nutrients and metals. Inflows from the waste rock dump and from pit wall surface runoff is expected to be in the alkaline range. These sources of inflow are expected to have a lower salinity than the groundwater inflows. Direct rainfall onto the pit lake will be of a higher quality than the other sources of inflow. The behaviour of the voids in terms of salinity predictions, stratification and mixing potential, biological succession and trace metals is included in the following sections. These considerations have been based on the source water quality of the void water inflows.

5.3 SALINITY PREDICTION METHODOLOGY

5.3.1 Overview

Salt will be present in water inflows to the final voids. The major water outflow from each pit is evaporation, and salt is a species in water which does not evaporate – it will remain in solution and increase within the system. As the water evaporates and salinity within the pit increases, a partial reduction in evaporation potential will be observed.

The contaminant transport module was adopted as part of the Goldsim 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.

5.3.2 Model inputs

Three separate salinity profiles were generated for the model. The profiles are assigned to the catchment types entering the final void. Each profile was derived based on available data sets (for each catchment) by arranging the data into histograms. Monitoring data was selected based on suitable reference sites (in the case of overland flow from external catchments), or observed conditions within the defined catchment system.

The range of water quality data used for these salinity profiles were collected from:

- Surface water monitoring.
- Geochemical investigations of the rock types likely to be present in the waste rock dumps and exposed in the pit wall (RGS, 2012).
- Groundwater monitoring.

There is a large scatter in the results, both temporary and spatially, which needs to be reflected in the final void model. The distribution of TDS values for each water type which are reflected in the water balance model is provided below.

Natural External Catchments

A suitable reference site for the Suttor River catchment (KBR, 2012a) has been adopted in this assessment to represent any external catchment inputs from areas not distributed by mining. The distribution of TDS values in this data is shown in Figure 5.2.

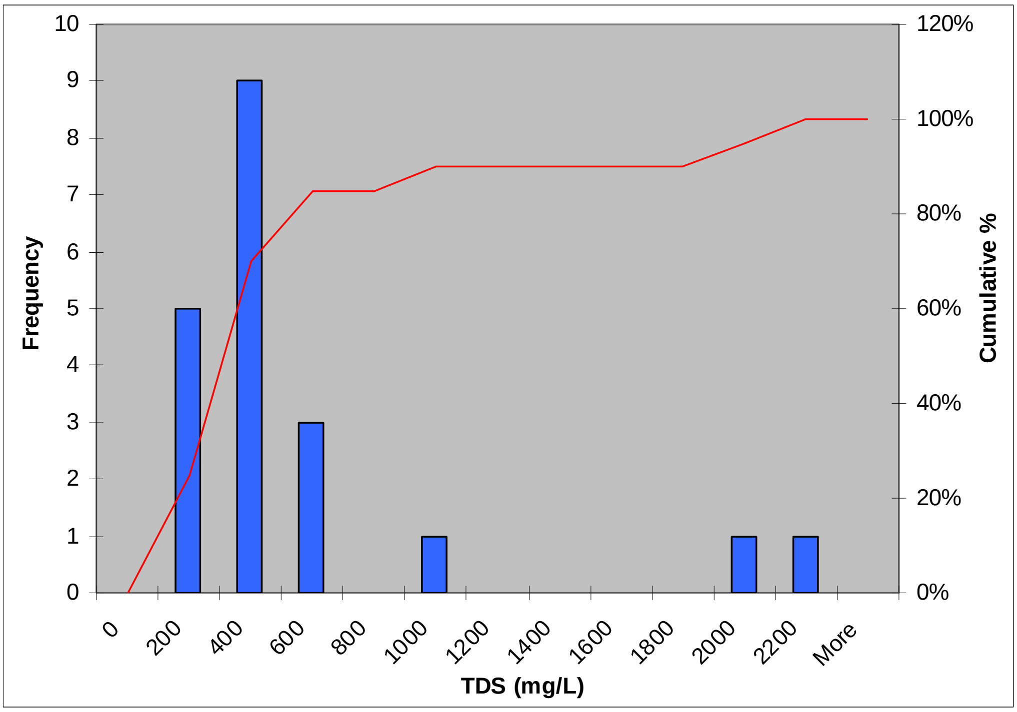


Figure 5.2
SUTTOR RIVER CATCHMENT TDS VARIATION (BASED ON FSS07)

Waste rock geochemistry

Waste rock reporting to the spoil dumps would be a mixture of various overburden lithologies. The available TDS data for all lithologies were lumped together to provide an indication of the likely spread of results from a mixed waste rock dump. The results are presented in Figure 5.3.

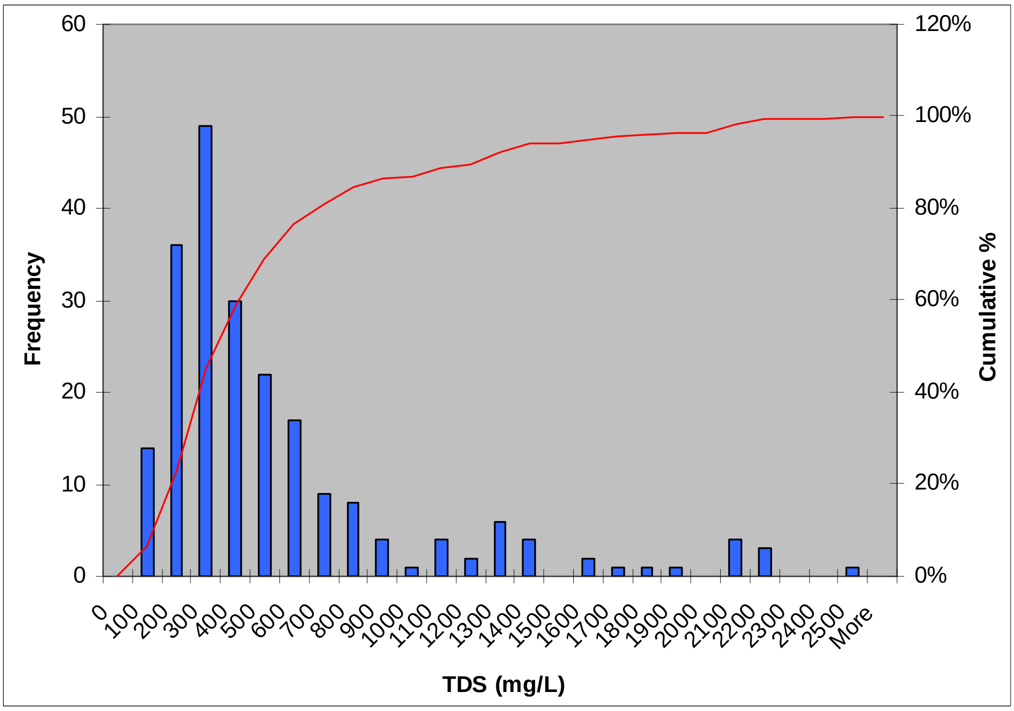


Figure 5.3
PREDICTED WASTE ROCK TDS (BASED ON ALL LITHOLOGIES)

Groundwater quality

As previously stated, groundwater quality data is available from monitoring undertaken during wet and dry seasons over 2011 and 2012 over four separate monitoring events; however, any numerical data analysis can be improved with a larger data set. The electrical conductivity information adopted was gathered between September 2011 and July 2012 and compiled for following units:

- Rangal Coal Measures (RCM) – 15 independent observations.
- Fort Cooper Coal Measures (FCCM) – 15 independent observations.
- Moranbah Coal Measures (MCM) – 4 independent observation.

On the basis that the majority of the groundwater will be attributed to the coal measures, the electrical conductivity values observed from the coal measures were extracted, transformed and analysed, as shown in Figure 5.4.

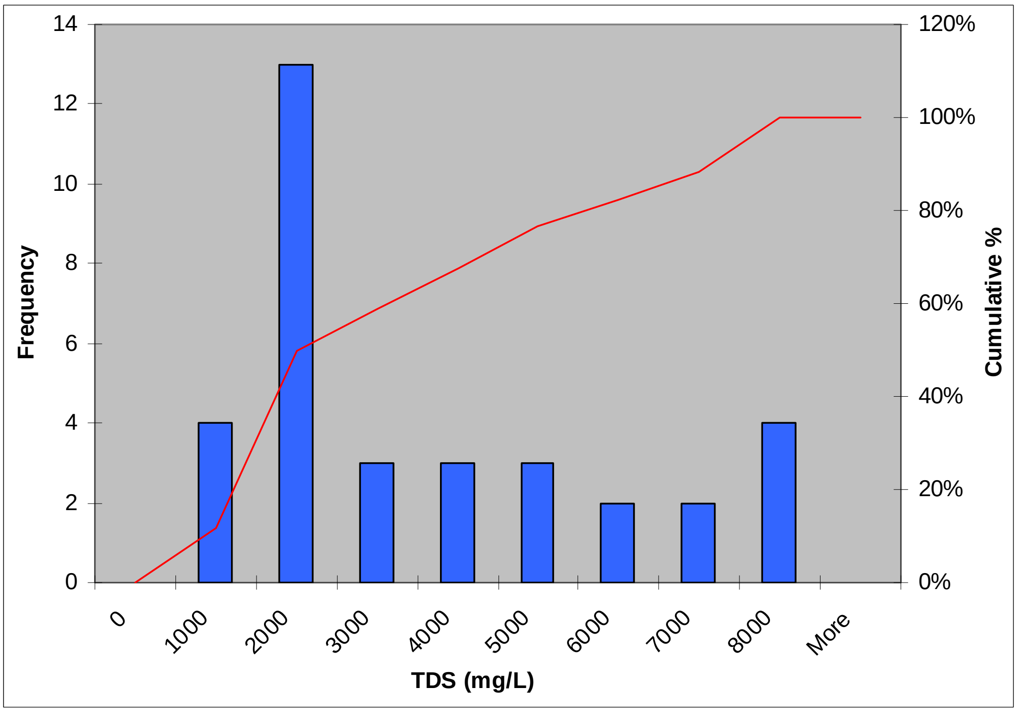
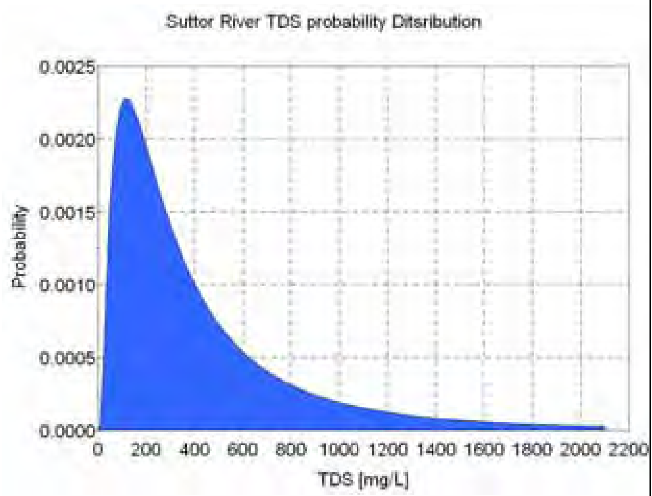
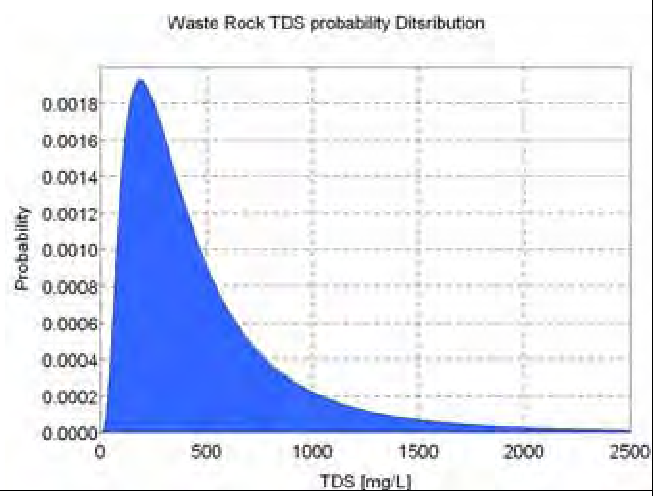
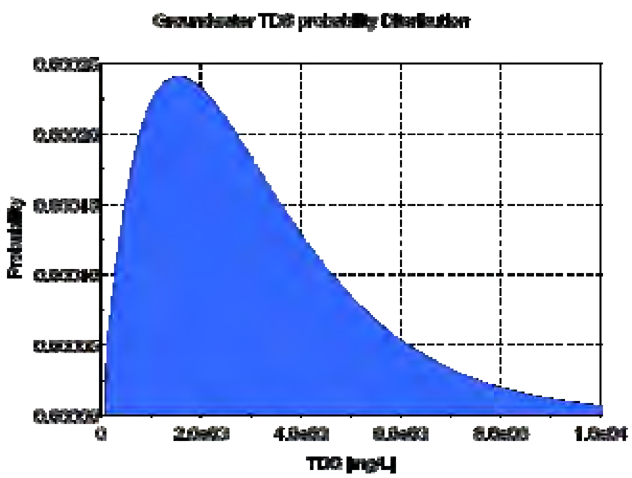


Figure 5.4
GROUNDWATER EC VARIATION IN THE COAL MEASURES

Adopted total dissolved salt ranges

Probability functions were fitted to the TDS distributions presented above. Two of the datasets followed a log normal distribution and one was best represented with a gamma distribution. The probability distribution functions are shown in Table 5.3.

Table 5.3 Adopted probability distribution functions

Water quality characteristics	Probability distribution
Undisturbed - Suttor Type: Log Normal Distribution Mean: 470mg/L SD:580mg/L	
Waste Rock Type: Log Normal Distribution Mean: 495mg/L SD: 742mg/L	
Groundwater Type: Gamma Distribution Mean: 3100mg/L SD: 2200mg/L	

The table above provides a visual representation of the probability distribution for each catchment. Table 5.4 describes the statistical variation between the raw data sets and the probability distributions by comparing the values at given percentiles. From the data below, TDS values for water draining 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.

Table 5.4 Comparison of data distribution

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
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

5.4 SALINITY PREDICTION RESULTS

The model results confirm the conceptual model that salinity will increase over time due to evapo-concentration effects. As described in Section 6, the pit lake water level model suggests that the final voids will act as sinks in most scenarios predicted. Under these conditions each pit is expected to gradually accumulate salts over time.

There is a large amount of uncertainty surrounding salinity concentration in the pit lakes, and how these conditions are likely to change over time. This is reflected in the model predictions in the form of very high peak salinity values with minimal impact on the mean salinity value. The overall trend of increasing salinity with time in each pit is consistent however, with time and increasing salt in the pit lake uncertainty also increases. Most of the pit lakes have a mean salinity concentration which falls within the slightly brackish range by the 400 year post mine closure timeframe.

5.4.1 Scenario 1 – Base case

The mean predictions of salinity for the base case is summarised in Table 5.5 with three time steps to show the gradual increase. The range of results taking into account model uncertainties is discussed in the following sections.

Table 5.5 Mean salinity predictions

Final Void	Salinity (mg/L)		
	Year 100	Year 200	Year 400
North	3,500	5,500	10,000
East	1,750	3,000	6,500
South	1,250	1,500	2,000
West	1,100	1,500	3,000

North pit

Salinity in the model is predicted to steadily increase. At 100 years post mine closure, the range of salinity in the north pit lake is likely to fall between 2,000 and 5,000 mg/L ($25^{th}/75^{th}$ percentile). By 200 years post mine closure the expected salinity range has increased to between 2,500 and 8,000 mg/L. Towards the end of the modelled time series the modelled results show some peaks in the outlying concentrations, these have a limited effect on the most likely scenarios, however the range of values predicted at 400 years post mine closure is between 3,500 and 15,000 mg/L. The peak values of salinity predicted was in excess of 27,000 mg/L.

West pit

At 100 years post mine closure the range of salinity is predicted to fall between 500 and 1,700 mg/L ($25^{th}/75^{th}$ percentile). There is a considerable amount of uncertainty and a number of peaks in the early stages of the west pit model which are attributed to the size of the pit surface area, during the early stages the pit is modelled to have large losses due to evaporation which skews the concentration of salinity, this is not likely to have a significant impact on the overall trend of salinity in the west pit lake. By 200 years post mine closure, the salinity ranges expected has increased to between 600 and 2,500 mg/L. Towards the end of the modelled time series the modelled results show some high peaks associated with evaporation of the pit lake. The range ($25^{th}/75^{th}$ percentile) of values predicted at 400 years post mine closure is between 750 and 7,000 mg/L. The peak predicted salinity concentration for the west pit lake was 42,000 mg/L at 360 years post mine closure.

South pit

At 100 years post mine closure the range of salinity is predicted to fall between 600 and 1,700 mg/L ($25^{th}/75^{th}$ percentile). By 200 years post mine the expected salinity range has increased to between 700 and 2,000 mg/L. Towards the end of the modelled time series the modelled results show some peaks in the outlying concentrations, these have a limited effect on the most likely scenarios, however the range of values predicted at 400 years post mine closure is between 800 and 4,500 mg/L. Peak values of salinity predicted were close to 6,750 mg/L.

East pit

At 100 years post mine closure the range of salinity is predicted to fall between 750 and 2,500 mg/L ($25^{th}/75^{th}$ percentile). By 200 years the expected salinity range has increased to between 1,000 and 4,500 mg/L. Towards the end of the modelled time series the modelled results show some extreme peaks of the outlying concentrations which in turn create smaller spikes in the most likely scenarios. The range of values predicted at 400 years post mine closure is between 1,500 and 11,500 mg/L. Peak values of salinity are well in excess of 66,000 mg/L.

Scenario 1 summary

The overall trend of increasing salinity concentration with time was upheld in all of the pit lakes. 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 lake), 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 (25^{th} to 75^{th} percentile) was considerably increased by spike predictions.

5.4.2 Scenario 2 – High hydraulic conductivity scenario

The mean predictions of salinity for the high hydraulic conductivity scenario is summarised in Table 5.6 with three time steps to show the gradual increase. The range of results taking into account model uncertainties is discussed in the following sections

Table 5.6 Mean salinity predictions

Final Void	Salinity (mg/L)		
	Year 100	Year 200	Year 400
North	3,500	5,500	10,000
East	5,500	9,000	16,000
South	3,000	3,500	4,500
West	2,250	3,250	6,000

North Pit

A higher hydraulic conductivity value was not used to test the sensitivity of the North pit. The hydraulic conductivity remained constant at 1.28×10^{-7} m/s. This assumption was based on the technical paper produced by Rob Lait (2012).

West Pit

The change in hydraulic conductivity resulted in a significant increase in the salinity of the West pit, and also a notable reduction in the magnitude of the peak outlying values predicted by the model. The range of salinity concentration predicted (25^{th} to 75^{th} percentile) at 100 years post mine closure is 1,250 mg/L to 4,000 mg/L. At 200 years post mine closure, the range predicted has increased to 1,250 mg/L to 6,000 mg/L. The range of values predicted at 400 years post mine closure is between 1,500 and 10,000 mg/L. Peak values of salinity are well in excess of 24,000 mg/L.

South Pit

At 100 years post mine closure the range of salinity is predicted to fall between 2,250 and 3,750 mg/L (25^{th}/75^{th} percentile). By 200 years post mine the expected salinity range has increased to between 2,500 and 4,500 mg/L. The range of values predicted at 400 years post mine closure is between 2,500 and 8,000 mg/L. Peak values of salinity predicted were close to 10,000 mg/L at 395 years post mine closure.

East Pit

At 100 years post mine closure the range of salinity is predicted to fall between 2,250 and 9,000 mg/L (25^{th}/75^{th} percentile). By 200 years post mine the expected salinity range has increased to between 3,000 and 15,000 mg/L. The range of values predicted at 400 years post mine closure is between 4,000 and 25,000 mg/L. Peak values of salinity predicted were close to 42,000 mg/L at 395 years post mine closure.

Scenario 2 summary

The higher hydraulic conductivity scenario resulted in a large increase in the mean prediction of the salinity of the pit lakes, but a reduction in the peak values predicted by the model. This outcome would suggest less uncertainty in the model overall. The trend of an increase in salinity concentration with time was still prevalent in all of the pit lake models. As in the previous scenario, uncertainty in the model also increased with time.

5.4.3 Scenario 3 – High emission climate change scenario

The mean predictions of salinity for the high emission climate change scenario is summarised in Table 5.7 with three time steps to show the gradual increase. The range of results taking into account model uncertainties is discussed in the following sections

Table 5.7 Mean salinity predictions

Final Void	Salinity (mg/L)		
	Year 100	Year 200	Year 400
North	4,000	6,000	11,000
East	2,000	3,000	6,500
South	1,250	1,500	2,250
West	1,250	1,750	4,000

North Pit

The high emission climate change scenario had little effect on the North pit lake salinity concentration. The peak value predicted was 29,900 mg/L (similar to the base case scenario) after 360 years. The expected range for 100 years post mine closure (25^{th} to 75^{th} percentile) was between 2,000 mg/L and 5,500 mg/L. The expected range for 200 years post mine closure (25^{th} to 75^{th} percentile) was between 2,500 mg/L and 10,000 mg/L. The expected range for 400 years post mine closure (25^{th} to 75^{th} percentile) was between 3,000 mg/L and 16,500 mg/L.

West Pit

The range of salinity concentration predicted (25^{th} to 75^{th} percentile) at 100 years post mine closure is 600 mg/L to 2,000 mg/L. At 200 years post mine closure, the range predicted has increased to 750 mg/L to 3,000 mg/L. The range of values predicted at 400 years post mine closure is between 1,000 and 9,000 mg/L. Peak values of salinity are well in excess of 134,000 mg/L predicted during a spike after 130 years. It is unclear why such a large spike is predicted after 130 years, given that the salinity in the lake is predicted to quickly recover to much lower concentrations. Aside from the large spike values, the overall trends of the west pit salinity concentration follow closely with the scenario 1 prediction.

South Pit

At 100 years post mine closure the range of salinity is predicted to fall between 600 and 2,000 mg/L (25^{th}/75^{th} percentile). By 200 years post mine the expected salinity range has increased to between 750 and 2,500 mg/L. The range of values predicted at 400 years post mine closure is between 1,000 and 5,000 mg/L. Peak values of salinity predicted were close to 9,250 mg/L at 375 years post mine closure.

East Pit

The range of salinity concentration predicted (25th to 75th percentile) at 100 years post mine closure in the east pit lake is 750 mg/L to 3,500 mg/L. At 200 years post mine closure, the range predicted has increased to 1,000 mg/L to 5,000 mg/L. The range of values predicted at 400 years post mine closure is between 1,500 and 16,000 mg/L. Peak values of salinity are well in excess of 105,000 mg/L predicted after 360 years post mine closure.

Scenario 3 summary

The high emission climate change scenario did not result in any unusual changes in the mean salinity predictions for any of the pit lakes, however there were large increases to the peak values predicted by the model. This outcome would suggest there is a significant increase in uncertainty in the model. As in the previous scenario, uncertainty in the model also increased with time, but spikes in the early years were much more prevalent in the scenario 3 predictions.

5.4.4 Low emission climate change scenario

The low emission climate change scenario had little affect on the salinity concentration trends realised by the model, however the concentration of salinity predicted was generally higher than the Base Case predictions. The mean predicted salinity level at 100 years post mine closure is 1,250 mg/L with a range (25th to 75th percentile) of between 750 mg/L and 2,250 mg/L. The mean predicted salinity level at 200 years post mine closure is 2,500 mg/L with a range (25th to 75th percentile) of between 750 mg/L and 4,500 mg/L. At 400 years the expected range of concentrations is between 2,000 and 11,000 mg/L, and the mean salinity concentration is 6,500 mg/L.

The peak salinity concentration recorded in scenario 4 was 220,000 mg/L occurring 120 years post mine closure. Similar to scenario 3 (high emission climate change scenario) there area 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.

5.5 STRATIFICATION AND MIXING

Stratification refers to the separation of a water body into multiple layers. This separation is brought about by the different properties of the water body which can occur at different depths. Mixing throughout the profile is another important factor which can impact on pit lake water quality. Mixing and stratification are related factors as the potential for and degree of mixing and stratification is primarily driven by meteorological conditions.

Stratification can occur in relatively shallow water bodies such as lakes and reservoirs (typically <10 m in depth) and is more likely to occur in deeper water bodies such as the Byerwen pit lakes. Additionally, the relatively steep gradient of the void walls (below the void water level) would increase the potential for stratification to occur. In addition to the physical characteristics of the void, other factors such as meteorological conditions can influence the likelihood of the voids developing either a thermocline (temperature separation between layers) or a chemocline (salinity, oxygen or other chemical separation between layers).

5.5.1 Meteorological drivers

Wind, temperature and rainfall are the dominant meteorological drivers which can have the greatest affect on the stratification potential of the pit lakes. These factors are considered seasonally variable and have varying degrees of influence throughout each of the four seasons.

Variations in meteorological conditions over the seasons are expected to greatly influence the stratification and mixing potential of the Byerwen voids. Figure 5.5 shows the temperature range between the average monthly minimum and maximum temperatures along with average 9 am and 3 pm wind speeds. This data has been sourced from over 50 years of observations. Presented in Table 5.8 is the variation in temperature, wind speed, rainfall and evaporation between seasons. Rainfall and evaporation data is from DataDrill (refer Section 3.1).

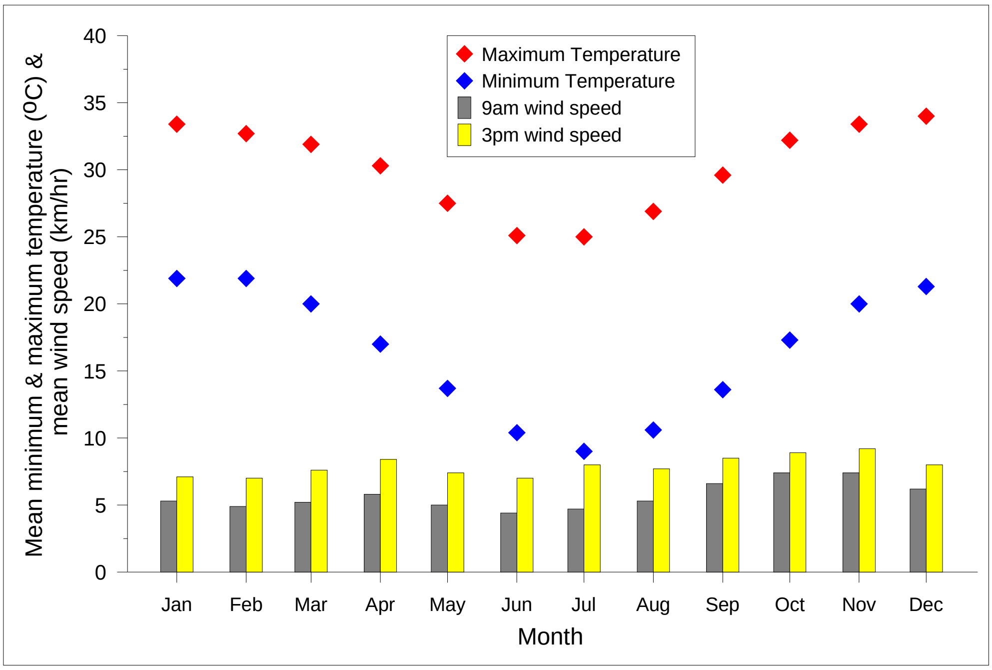


Figure 5.5
TEMPERATURE AND WIND SPEED (COLLINSVILLE P.O. BOM STATION)

Table 5.8 Variation in temperature and rainfall between seasons

	Average minimum temperature (°C)	Average temperature (°C)	Average maximum temperature (°C)	Average 9am wind speed (km/hr)	Average 3pm wind speed (km/hr)	Average rainfall (mm)	Average evaporation (mm)
Summer	21.7	27.5	33.4	5.5	7.4	307	622
Autumn	16.9	23.4	29.9	5.3	7.8	114	439
Winter	10.0	17.8	25.7	4.8	7.6	58	325
Spring	17.0	24.4	31.7	7.1	8.9	90	614

Wind

Wind through shearing forces on the waters surface can increase the mixing potential of the water within the Byerwen pit lakes. The effect of this would likely be limited to the upper layer of the water column. The average 9 am and 3 pm wind speeds (refer to Table 5.8) are generally consistent throughout the seasons, however, slightly higher wind speeds are observed during Spring than during the other seasons.

Due to the geometry of the voids whereby the water is confined within an excavation with generally steep side slopes and at a considerable distance from the surface, the potential for the wind to have an impact on the surface of the pit lake would likely be very limited.

Temperature

During the warmer seasons (summer, autumn and spring) the upper layers of the pit lake water column are expected to be warmer than the water in the lower section of the void water column as a result of direct radiation from the sun. This would produce a thermocline at a point in the water column. During the cooler months (winter plus the months either side), the variation in temperature between the upper and lower sections of the pit lake is expected to be much smaller. A typical thermocline may not be developed during this period. It is noted that from the affect of shading from the void walls and other features surrounding the voids, heating of the surface waters from direct radiation is expected to occur at a lower rate than what would normally be observed in natural lakes with minimal shading.

Rainfall

Rainfall is an important input which can have a bearing on the stratification dynamics of the pit lakes. Direct rainfall onto the lakes surface would bring about an injection of freshwater (likely at cooler temperatures than the pit water lake) into the upper section of the water column. Higher rainfall is more common during the warmer seasons (refer Table 5.8) at a time when the temperature differences are expected to produce a thermocline. This influx of freshwater is expected to occupy the top layer of the water column due to the lower densities in comparison to the more dense deeper waters. Evaporation rates (which are greater than double that of rainfall for each season) will have an effect on increasing the concentration of constituents within the pit lake through evapo-concentration.

5.5.2 Likely cycle of the Byerwen voids

Further to the above preliminary discussions on the likely dynamics of the Byerwen pit lakes on the basis of simplistic relationships between meteorological, inflow, outflow and void geometry data, a more complex assessment on the likely behaviour of the pit lakes was carried out. The one-dimensional Dynamic Reservoir Simulation Model (DYRESM version 2) was used to further assess the stratification and mixing potential of the lake predicted to form in the South Pit. The South Pit, as one of the deeper voids, was selected for investigation as the potential for stratification was considered more likely than the voids with a shallower water depth. DYRESM can be used to predict the vertical distribution of the key stratification indicators temperature, salinity and density. This assessment of the South Pit can be used to draw conclusions for the other pit lakes.

Four scenarios involving South Pit 1 were simulated to determine the variation in pit lake behaviour under different conditions. Key inputs for the four scenarios are presented in Table 5.9.

Table 5.9 South Pit 1 DYRESM scenarios and key inputs

	Scenario 1	Scenario2	Scenario 3	Scenario 4
Conditions	50th percentile (median)	50th percentile (median)	95th percentile	95th percentile
Simulation period	30–50 years	480–500 years	30–50 years	480–500 years
Initial pit lake salinity (TDS)	1,270 mg/L	4,490 mg/L	4,690 mg/L	22,240 mg/L
Salinity of groundwater inflow (TDS)	2,570 mg/L	2,570 mg/L	6,980 mg/L	6,980 mg/L
Salinity of pit wall runoff (TDS)	360 mg/L	360 mg/L	1,270 mg/L	1,270 mg/L
Salinity of waste rock dump inflows (TDS)	360 mg/L	360 mg/L	1,270 mg/L	1,270 mg/L

Typical physical and chemical features representative of a generic mine pit lake are presented in Figure 5.6. Each of these processes is expected to occur within the Byerwen pit lakes with the exception of the groundwater outflow feature. The Byerwen voids under most conditions are expected to form groundwater sinks below the elevation of the regional groundwater table. The aim of this detailed analysis is to predict the dynamics of the pit lake during the early stages of the lake filling period (Scenarios 1 and 3) and at a quasi steady state level (Scenarios 2 and 4).

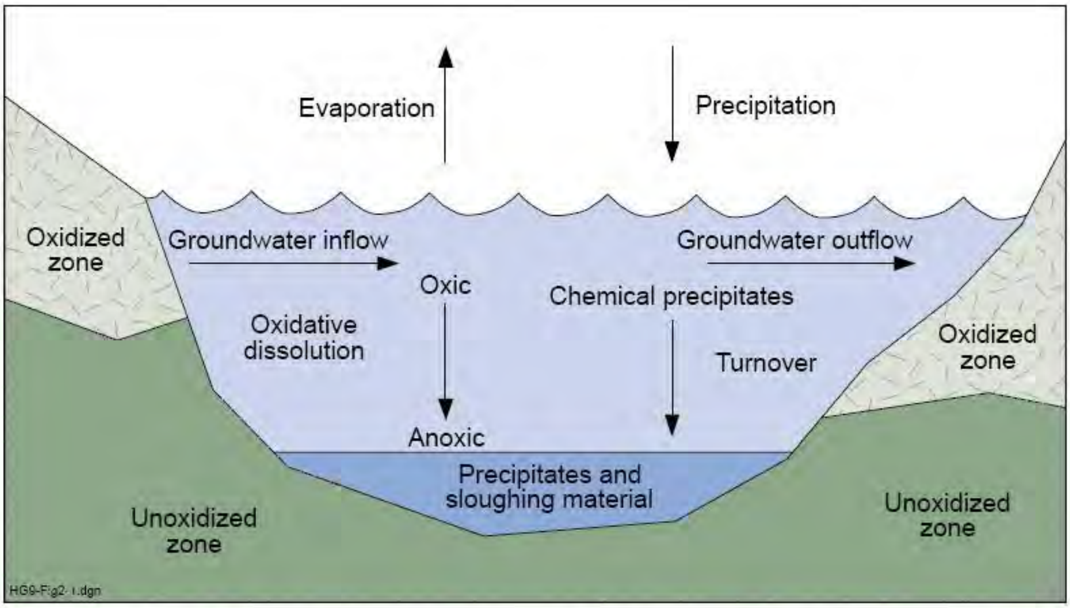


Figure 5.6
GENERIC CHEMICAL AND PHYSICAL PROCESSES WITHIN MINING VOIDS
Source: Johnson and Wright (2003) after Miller et al (1996)

The results of Scenarios 1 and 2 are presented in Figure 5.7, and the results of Scenarios 3 and 4 are presented in Figure 5.8. These results present the vertical distribution of the pit lake over the simulation period for temperature, salinity and density.

Early on in the filling of the void (years 30 to 50), South Pit 1 is predicted to be somewhat responsive to seasonal changes in temperature (refer Figure 5.7). This is highlighted by the annual mixing (warming and cooling) of the upper 15 m of the pit lake. A distinct hypolimnium (the dense bottom layer of the water column) comprising a salinity of around 1,300 mg/L and a density of around 998 kg/m^3 is predicted to develop from about 40 m above the floor of the pit (~45 m below the lake surface). Salinity behaviour in the epilimnion (the less dense upper layer of the water column) is sporadic and does not exhibit any trends. This could be a function of the higher salinity groundwater (2,570 mg/L) which was modelled as surface runoff or seepage from the pit walls. In addition, the predicted increase in water level as the void progressively fills is captured throughout this simulation period.

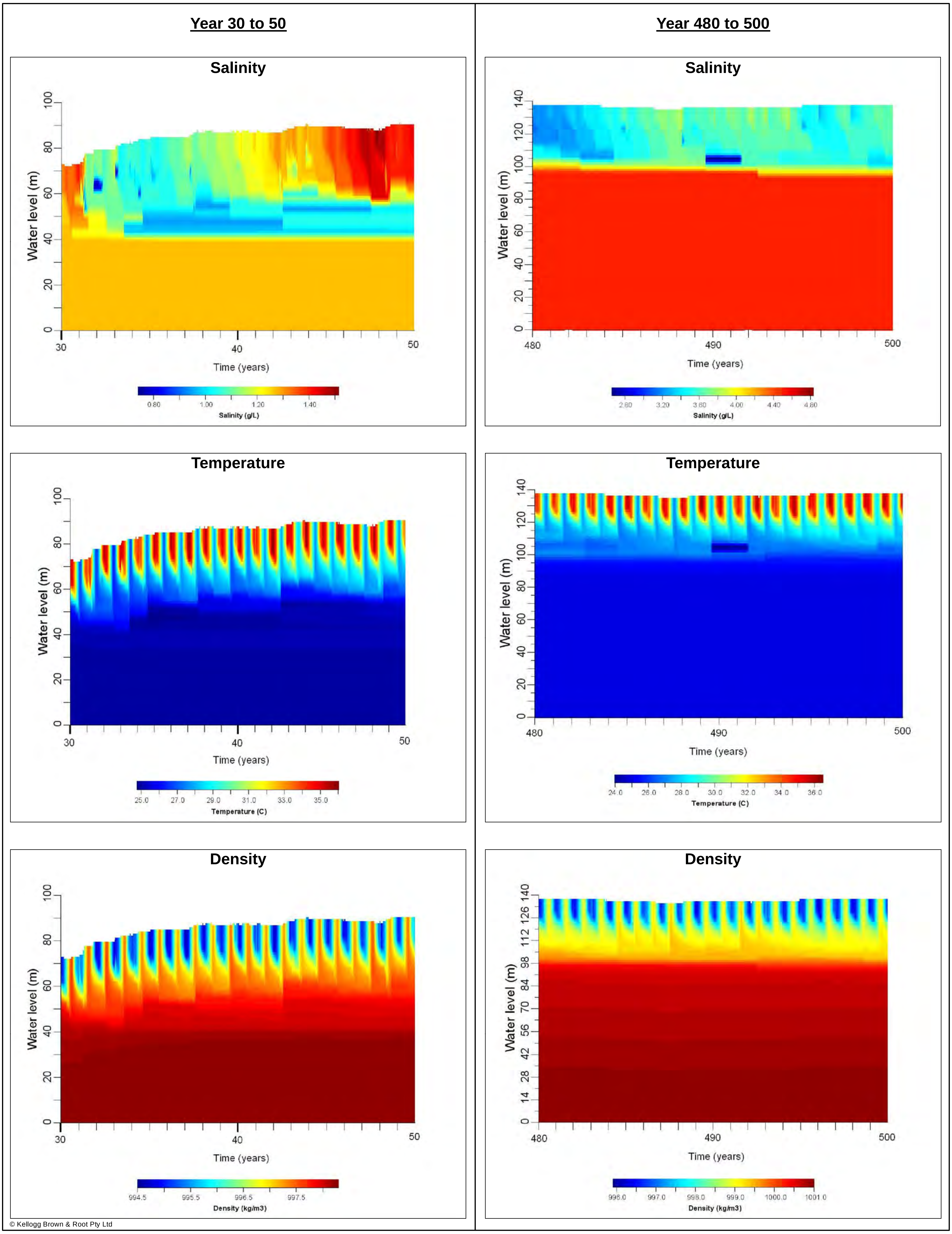
Under the same conditions but at a quasi state water level (years 480 to 500), there is further distinction between the saline hypolimnion and the fresher and less dense eplimnion (refer Figure 5.7). Salinity concentrations in the hypolimnion have increased to around 4,600 mg/L from the initial salinity observed during the previous simulation. Additionally, density has increased to around 1,001 kg/m^3 in this deeper layer. The effects of the cooling and warming of the surface layer throughout the change in seasons is predicted to extend to about 25 m below the surface. The water below this thermocline is stable and is expected to remain at around 25 ºC. It is noted that the water level is more stable during this ‘steady state’ simulation period.

The results of the simulations under the 95th percentile conditions (Scenarios 3 and 4 in Figure 5.8) are comparable to what was observed in terms of general stratification and mixing processes within the lake. Salinity concentrations within the stratified hypolimnion are predicted to be in the order of 5,000 mg/L and 22,000 mg/L after 50 and 500 years respectively. At steady state, salinity concentrations increase from about 6,000 mg/L in the epilimnion to around 22,000 mg/L within approximately 5 m of water depth.

After 30 years, the epilimnion experiences the same warming and cooling effect during changes in seasons, however, the depth to which this occurs appears slightly greater than the 50th percentile condition scenario. For the steady state scenario, temperature changes in the upper layer of the lake have been predicted. In addition, a distinct thermocline is expected to develop approximately 35 m below the surface.

As a function of the higher salinity within the hypolimnium, the densities are greater than what was simulated for the 50th percentile scenarios (998 kg/m^3 vs 1,001 kg/m^3 after 50 years and 1,001 kg/m^3 vs 1,014 kg/m^3 after 500 years).

In the early filling of the void (years 30 to 50) and at a quasi steady state water level (years 480 to 500) the South Pit lake is predicted to behave similarly under the two different conditions. The stratification potential and mixing processes within the pit lake involve the formation of a stable saline layer in the hypolimnium. The surface layer of the water column (upper 15 m at year 30 or upper 30 m at year 500) undergoes seasonal mixing from the warming and cooling of the surface layers.



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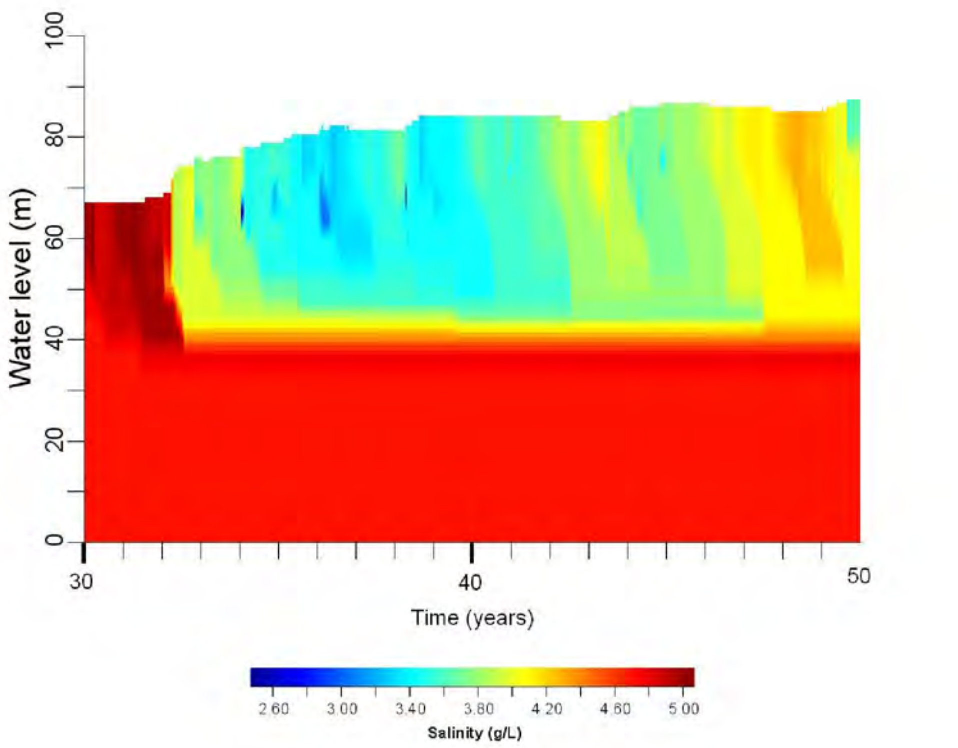
50th Percentile Conditions

FIGURE 5.7

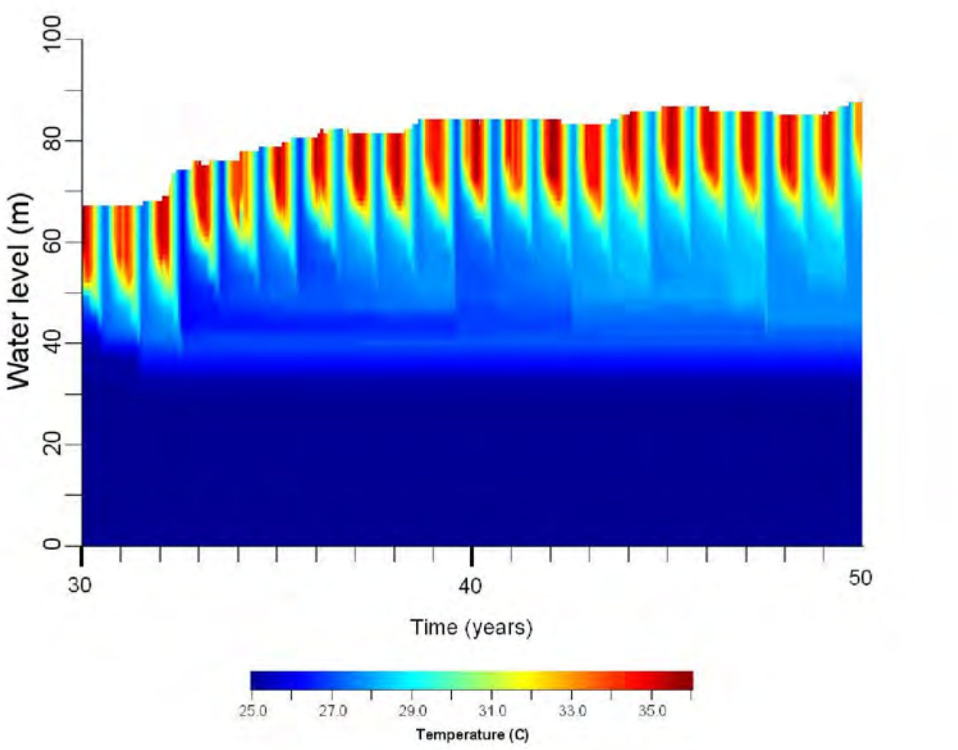
Rev A

Year 30 to 50

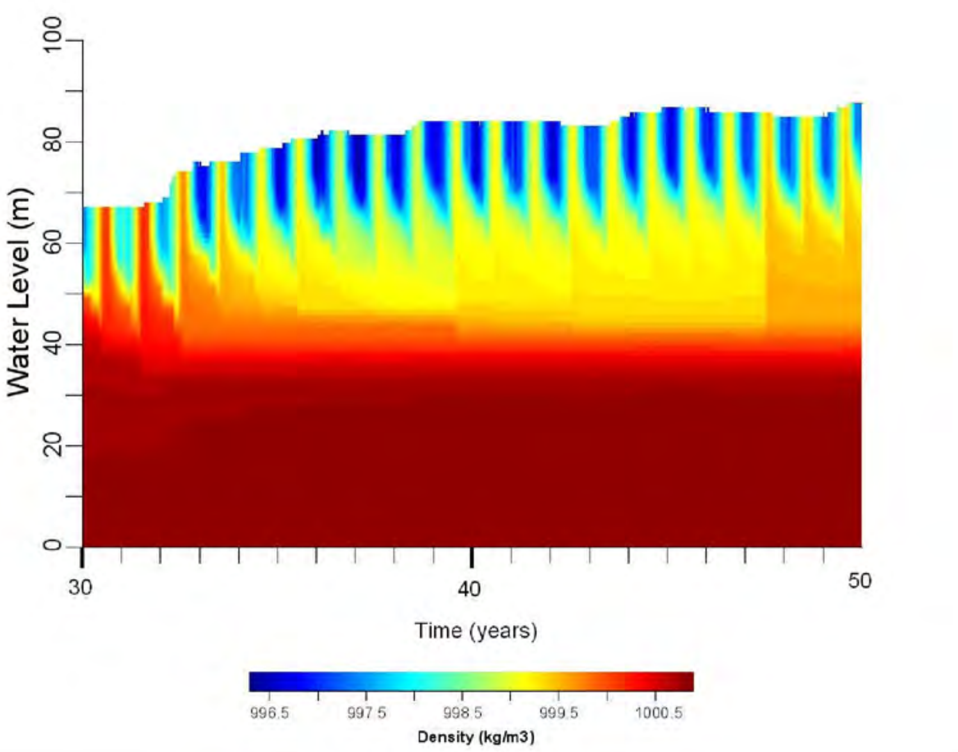
Salinity



Temperature

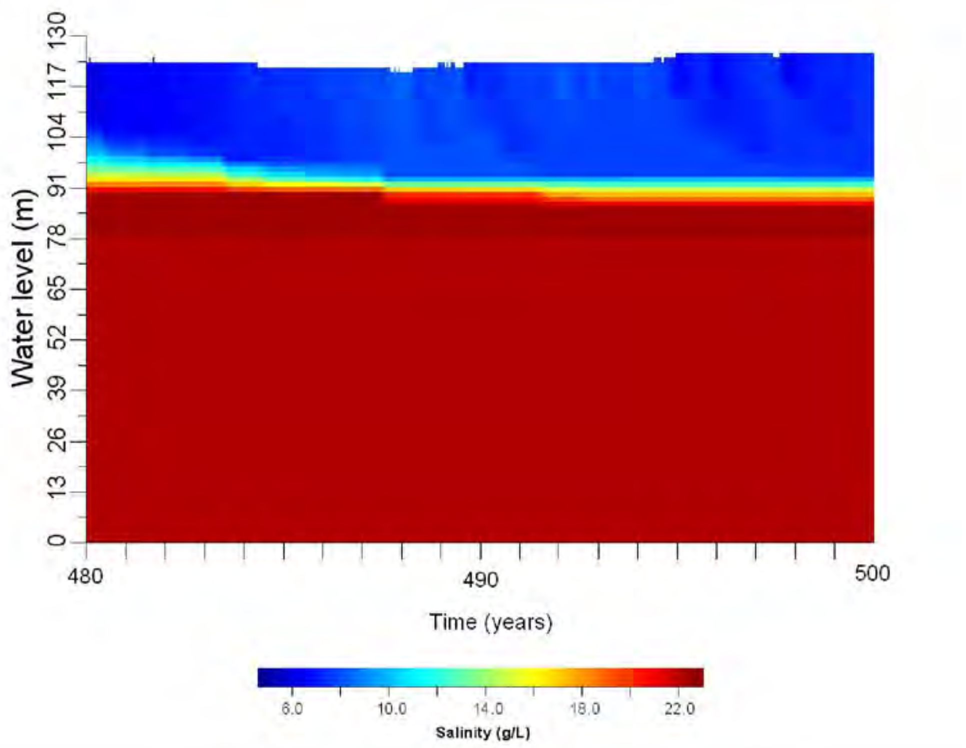


Density

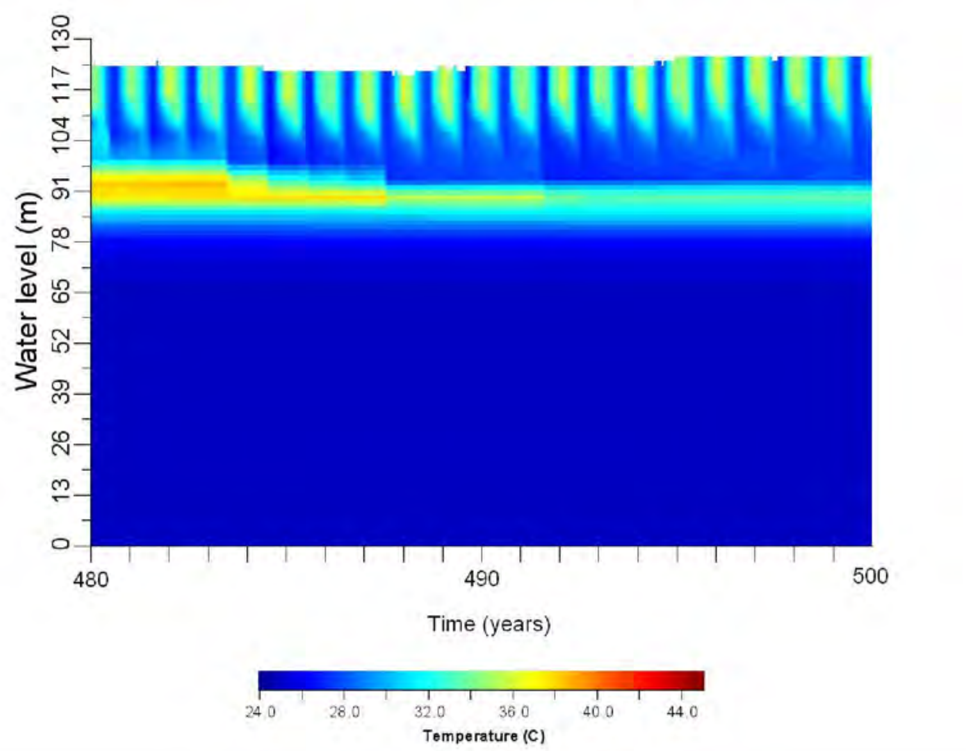


Year 480 to 500

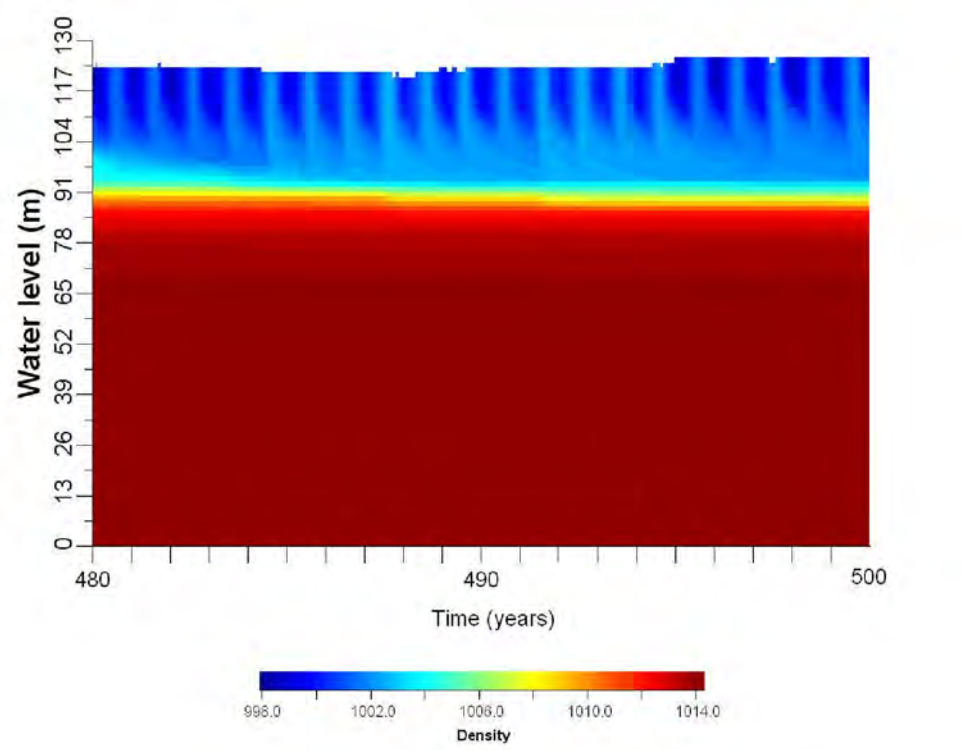
Salinity



Temperature



Density



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95th Percentile Conditions

FIGURE 5.8

Rev A

5.6 BIOLOGICAL SUCCESSION

5.6.1 Primary production

Primary production is considered as the photosynthetic process whereby organic compounds are produced in the presence of carbon dioxide (CO_2)and nutrients. Algal growth in open water bodies such as the Byerwen voids is determined by the availability of bioavailable forms of nutrients, with total phosphorus the primary limiting nutrient. The concentration of nutrients within a water body (being the level of primary production or degree of eutrophication) can be broadly classified into three main groups.

Oligotrophic refers to a system that has limited biological production and has <10 µg/L total phosphorus on an annual average basis. Mesotrophic systems are intermediate systems with between 10 µg/L and 20 µg/L total phosphorus by definition. Eutrophic systems have an over supply of nutrients (>20 µg/L total phosphorus on an annual average basis) and can often generate algal blooms under the correct conditions (Schnoor, 1996). Among other undesirable effects on water quality, anoxic conditions (a loss of dissolved oxygen) can be generated in highly productive eutrophic systems.

Median nutrient data for the groundwater inflows (coal measure aquifers) indicate TP concentrations of 65 µg/L and TN concentrations of 0.99 µg/L. Considering only this inflow, the pit lake is expected to reach eutrophic status. However, as the groundwater inflow is only a small percentage of the total volume of inflows, the other inflow sources (in particular direct rainfall) are expected to contain a lower concentration of nutrients which will in-turn produce a dilution effect on the lake.

In addition to using TN and TP concentration data for the inflows into the pit lake, the ratio between these two nutrients can provide both an indication on the trophic status of the lake as well as the limiting factor for eutrophication potential. The 'Redfield ratio' is expressed as TN divided by TP (N:P). A ratio of greater than 16:1 usually indicates a low potential for eutrophication, whereas a ratio of less than 16:1 can be indicative of waters with eutrophication potential. By adopting the median values of the water quality data, the N:P ratio of the groundwater inflows is around 15:1. The ratio of the other sources of pit lake inflow cannot be estimated due to the lack of available data. On the basis of the available information, it is considered possible that the nutrient concentrations within the pit lake could at times be sufficient enough to cause eutrophication and support algal growth. However, additional data for the inflow sources (including soluble phosphorus) is required before a reliable prediction can be made.

The final voids will have steep sides and will be fenced/bunded around the perimeter so as to minimise the potential for stock access to the waters edge. The pit lake will incorporate deep zones and areas of shallow water. It is acknowledged that mosquito populations will colonise within the pit lakes however, due to the characteristics of the lake, these populations are not anticipated to develop into plague like proportions.

5.7 TRACE METALS AND GEOCHEMICAL BEHAVIOUR

There are three main inflow sources to the final voids: direct rainfall, groundwater inflow and void runoff. 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 as discussed previously.

The main source of solutes into the pit lakes will be from groundwater and void runoff. Several groundwater systems would be intersected by the pits and would mix within the void. A summary of the water chemistry observations for these groundwater systems is provided in Table 5.10.

Water that enters waste rock dumps may eventually report to the pit lake, and carry solutes derived from the waste rock. Estimates of the likely water quality from waste rock have been the subject of a study by RGS (2012). 1:5 extracts were analysed from a range of lithogies that represent the waste rock that will be produced by the Project. These extracts are typically conservative (i.e. overestimate the solute production) that would occur in the field, unless the rock types are particularly reactive, which is not the case for the Project. Waste rock data from all lithologies tested were combined in order to assess the likely runoff chemistry from the mix of rock types. Waste rock runoff chemistry is also provided in Table 5.10.

Table 5.10 Median values of key water quality parameters in groundwater and waste rock

Parameter	Unit	Coal Measures	n	Basalt	n	Exmoor Formation	n	Tertiary sand below basalt	n	Waste rock	n
pH	pH units	7.7	20	8.7	6	11.425	2	7.63	3	8.6	10
EC	µS/cm	2930	19	12215	6	20200	2	2010	3	537	10
TDS	mg/L	1963	C	8184	C	13534	C	1347	C	360	C
Total Alkalinity	mg $CaCO_3$/L	259	26	436	8	865	3	265	4	107	10
Bicarbonate alkalinity	mg $CaCO_3$/L	163	26	182	8	1	3	216.5	4	84	10
Carbonate alkalinity	mg $CaCO_3$/L	1	26	11	8	75	3	29.5	4	4.7	10
Major Ions (dissolved)											
Calcium	mg/L	57.6	26	99.3	8	661	3	13	4	2	10
Magnesium	mg/L	6.93	26	27	8	1	3	11	4	2	10
Sodium	mg/L	444	26	870	8	2880	3	419	4	104	10
Potassium	mg/L	9.5	26	11	8	61	3	4	4	4	10
Chloride	mg/L	689	26	1055	8	5087	3	235	4	55	10
Sulphate	mg/L	49	26	190	8	88	3	13	4	61	10
Nutrients											
Ammonia as N	mg/L	0.96	20	1.0	6	2.5	2	0.36	3	n/a	n/a
Nitrite as N	mg/L	0.01	19	0.01	6	0.01	2	0.01	3	n/a	n/a
Nitrate as N	mg/L	0.02	19	0.015	6	0.02	2	0.02	3	n/a	n/a
Total P	mg/L	0.065	20	0.045	6	0.185	2	0.09	3	n/a	n/a

Parameter	Unit	Coal Measures	n	Basalt	n	Exmoor Formation	n	Tertiary sand below basalt	n	Waste rock	n
Dissolved Metals											
Aluminium	mg/L	0.07	27	0.045	8	0.13	3	0.024	4	0.2	10
Antimony	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.02	10
Arsenic	mg/L	0.004	27	0.002	8	0.006	3	0.0115	4	0.02	10
Boron	mg/L	N/A	-	N/A	-	N/A	-		-	0.2	10
Cadmium	mg/L	0.0001	27	0.0001	8	0.0001	3	0.0001	4	0.02	10
Chromium	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.02	10
Cobalt	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.02	10
Copper	mg/L	0.002	27	0.0035	8	0.033	3	0.001	4	0.02	10
Iron	mg/L	0.07	27	0.1465	8	0.08	3	0.1445	4	0.2	10
Lead	mg/L	0.001	27	0.001	8	0.004	3	0.001	4	0.02	10
Manganese	mg/L	0.058	27	0.0445	8	0.002	3	0.008	4	0.02	10
Mercury	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.0001	10
Molybdenum	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.02	10
Nickel	mg/L	N/A	-	N/A	-	N/A	--	N/A	-	0.02	10
Selenium	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.02	10
Vanadium	mg/L	N/A	-	N/A	-	N/A	-	N/A	-	0.02	10
Zinc	mg/L	0.005	27	0.005	8	0.005	3	0.005	4	0.02	10

n number of observations
N/A data not available
C calculated

The water quality results presented in Table 5.10 were analysed using the geochemical modelling package, PHREEQC, produced by the United States Geological Survey (USGS). The acronym PHREEQC stands for the most important parts of the model which includes pH (PH), redox (RE), equilibrium (EQ) and the C programming language (C) (Parkhurst and Appelo, 1999).

Minerals are chemical precipitates generated when constituent ions jointly exceed the "solubility product" for that mineral. Waters where this occurs are described as "saturated" with respect to that mineral.

Characterisation of waters by the minerals with which each is saturated (in relation to a solid phase) provides a system for classifying waters in terms of potential mineral formation. This classification can be quantified by calculation of a 'saturation index' (SI). Minerals that have SI values that equal or exceed zero are saturated and if environmental conditions are suitable and kinetics favourable, the supersaturated mineral phases may begin to precipitate.

Table 5.11 presents a summary of the saturation state of major mineral phases for input waters to the pit lake. The table indicates whether a mineral phase is either supersaturated (✓) or under-saturated (×). The saturation state of minerals is often sensitive to the redox conditions. Redox conditions have been assumed for each water type based on the likely exposure of water to oxygen prior to entering the pit lake.

Table 5.11 Saturation state of mineral phases for input waters

Mineral phase	Groundwater				Waste rock
	Coal measures	Basalt	Exmoor formation	Tertiary sand below basalt	
Apatite phases	✓	✓	✓	✓	ID
Ferrihydrite	×	✓	✓	✓	✓
Aluminium oxyhydroxides	✓	✓	✓	✓	✓
Calcite	✓	✓	✓	✓	✓
Gypsum	×	✓	✓	×	×
Magnesite	✓	✓	✓	✓	✓
Malachite	×	×	×	×	×
Manganese oxides	×	×	×	×	×
Manganese carbonates	✓	✓	×	✓	✓
Halite	×	×	×	×	×

✓ *supersaturated* × *under-saturated* *ID - insufficient data*

Table 5.11 indicates that input waters are supersaturated with respect to various mineral phases, meaning they could precipitate and alter the quality of the water entering the pit lake. Ferrihydrite and aluminium oxy hydroxides are likely to play a key role in the geochemistry of the pit lake. These minerals adsorb a range of anions and cations onto their surface and cause a reduction in their concentration in the water column.

Other phases that are likely to have an important role in pit lake chemistry include calcite and gypsum, which are likely to compete for the available calcium.

Redox sensitive minerals such as copper and iron are likely to undergo cyclical precipitation in the upper oxygenated zone of the pit lakes, and dissolution at depth under anoxic conditions. In the event that destratification occurs during winter, copper and iron concentrations are likely to remain low throughout the water column.

The precipitation of mineral phases identified in Table 5.12 can also influence a range of other metals and ions in the water column through adsorption and co-precipitation. A summary of the likely changes caused by these minerals is summarised in Table 5.12.

Table 5.12 Mineral precipitation and geochemical consequences

Mineral	Influences
Apatite phases	Aluminium, Fluorine, Calcium, Carbonate, Phosphorus, Lead[(a)]
Ferrihydrite	Iron, Lead[(b)], Zinc[(b)], Copper[(b)], Calcium[(b)], Nickel[(b)], Manganese[(b)], Barium[(b)], Uranium[(b)], Magnesium[(b)], Sulfate[(b)], Fluorine[(b)], Phosphorus[(b)], Arsenic[(b)]
Aluminium oxyhydroxides	Aluminium
Calcite	Calcium, Carbonate, Manganese[(a)], Zinc[(a)], Nickel[(a)], Magnesium[(a)]
Gypsum	Calcium, Sulfate, Barium[(a)]
Magnesite	Magnesium, Carbonate
Malachite	Copper, Carbonate
Manganese oxides	Manganese
Manganese carbonates	Manganese, Carbonate
Halite	Sodium, Chloride, Lead[(a)]

* *co-precipitation*

^ *adsorption*

The available data suggests 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, many of which incorporate, co-precipitate or adsorb metals during the process. This is further supported by the fact that acid forming materials have not been identified in the geochemical characterisation studies.

5.8 OTHER WATER QUALITY CONSIDERATIONS

5.8.1 Dissolved oxygen

In natural open water bodies such as in lakes, dams and reservoirs, the surface area to depth ratio is generally quite large. For mine voids, this ratio is usually a lot lower due to the abnormal shape of the mine void (deep with a small surface area). Given this, the meteorological effects on the void water are expected to be very limited when compared with a natural system. This will reduce the potential for dissolved oxygen to mix throughout the void water profile.

For the Project pit lakes, the oxic zone is expected to be limited to the upper layers of the void water column, whereas the anoxic zone will comprise the deeper more stable saline section of the water column. A typical chemocline that reflects a distinct change in dissolved oxygen concentration between the epilimnion and the hypolimnion is expected to develop.

5.8.2 Turbidity

Turbidity is a measure of the finer particles within a water body and is measured in Nephelometric Turbidity Units (NTU). A low turbidity relates to a water body with a low fraction of suspended particulates and in-turn high clarity, whereas a high turbidity relates to a water body with a high fraction of suspended particles. Turbidity 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.

Turbidity as a relative measure of water quality (not concentration based) is often correlated with Total Suspended Solids (TSS) measurements. This facilitates the concentration based assessment of sediment loads within a water body. Generally, TSS and turbidity measurements correlate around a mg/L:NTU ratio of 1:1 up to a ratio of around 1:1.5. This ratio is dependant on the specific characteristics of the sediment investigated.

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 quasi steady state water level conditions. As the majority of the Byerwen voids are not influenced by external surface water runoff, the sources of turbidity are likely limited to runoff from the pit wall. The characteristics of the particulates within the pit lake will have a bearing on the settling rates of these particles and as such the turbidity profile throughout the water column.

5.9 LIMNOLOGY CHANGES DURING PIT LAKE EVOLUTION

The final water quality of the voids is dependant on a number of key factors. These may include 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 enacting within the void may continue to evolve with time. This evolution may have a bearing on the routine physical changes which occur during the different seasons.

6 Management strategy

The strategy for the Byerwen 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 (Johnson and Wright, 2003).

Data will be collected over the life of the mining operation to help inform these strategies. This should include data on groundwater inflow rates, surface water hydrology, surface water quality and groundwater quality, which will reduce the uncertainties associated with the understanding of pit lake behaviour.

It is currently anticipated that the pit lakes will not require ongoing maintenance. Additional effort may be required in the early stages of filling to establish conditions that promote biological activity and ecosystem development. This may include addition of nutrients, fish etc. This is an area of science subject to a number of current research projects, which over time should help inform decision making and result in better environmental outcomes.

7 Conclusions

The Byerwen Coal Project will create four voids that remain as permanent depressions in the landscape and will act as groundwater sinks following the cessation of mining. Water inflows from groundwater, surface water runoff and direct rainfall will result in the formation of pit lakes within these voids. These 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.

It is most likely that the steady state water level of all four pits will lie below the regional groundwater level, meaning that they will cause a permanent groundwater sink. As the voids will form a regional sink, environmental discharge to surrounding groundwater is not expected.

There is a remote chance 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 modelling suggests there is a very low probability of this occurring.

Despite the uncertainty around some of the water balance inputs to the final voids, the uncertainty analysis completed indicates that under no conditions will water from within the void rise to final void rim. Therefore discharges to the surface water system should not occur.

The water quality of all water inflows to the voids has been assessed. Pit wall runoff is expected to be the primary source of void water inflow (refer Table 5.1). Waste rock geochemistry testing suggests that there is a very low risk of acid generation, and the water quality entering the voids from the void walls would not adversely affect void water quality.

Although meteorological drivers can have an effect on the stratification and mixing potential of open water bodies, the geometry of the voids significantly reduces its influence. As a consequence of 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. Chemoclines in the form of dissolved oxygen and salinity are expected to develop. As the pit lakes mature, the salinity is expected to gradually increase causing strong and permanent stratification to occur.

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 pycnocline (the layer separating water of two different densities).

8 References

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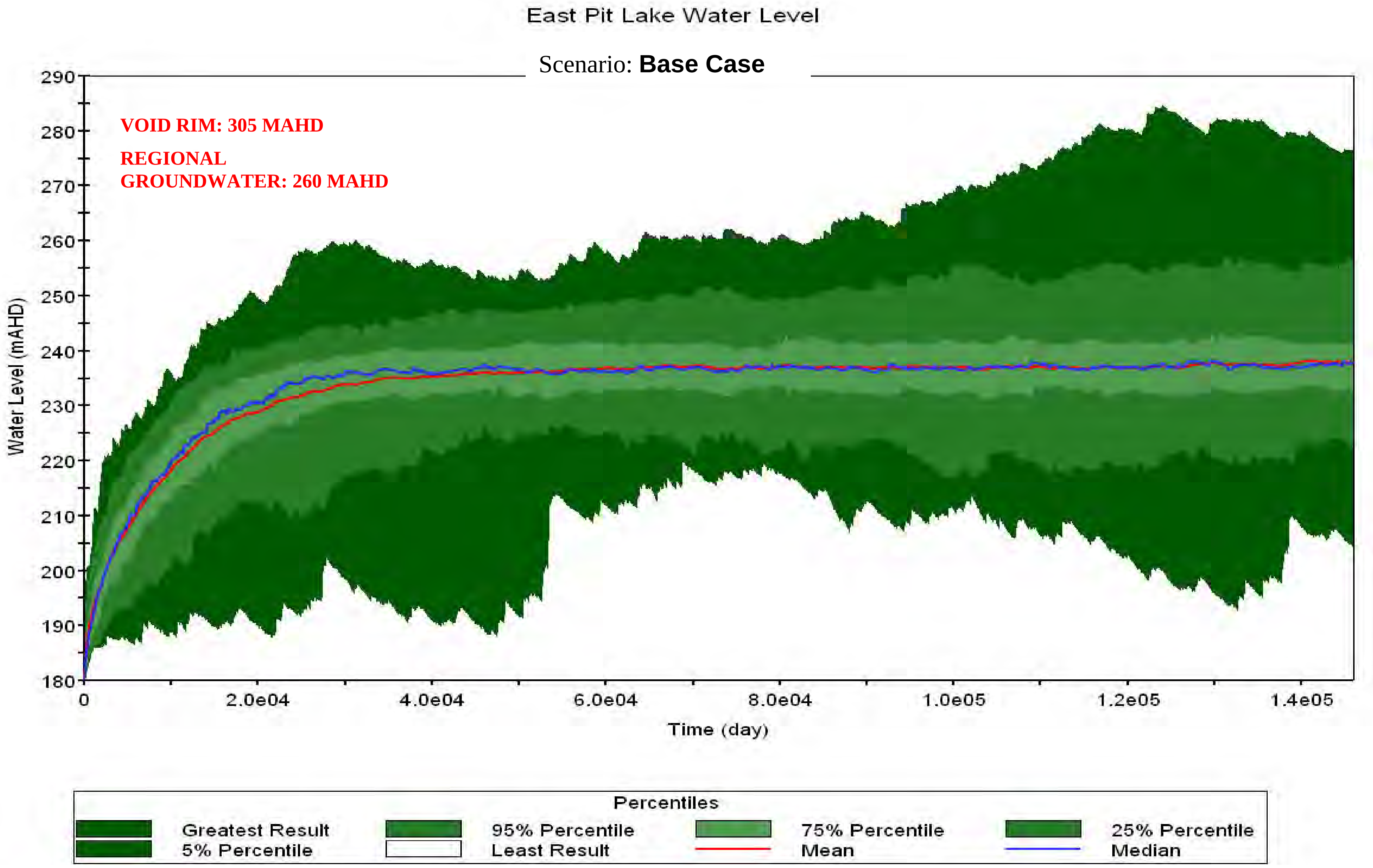
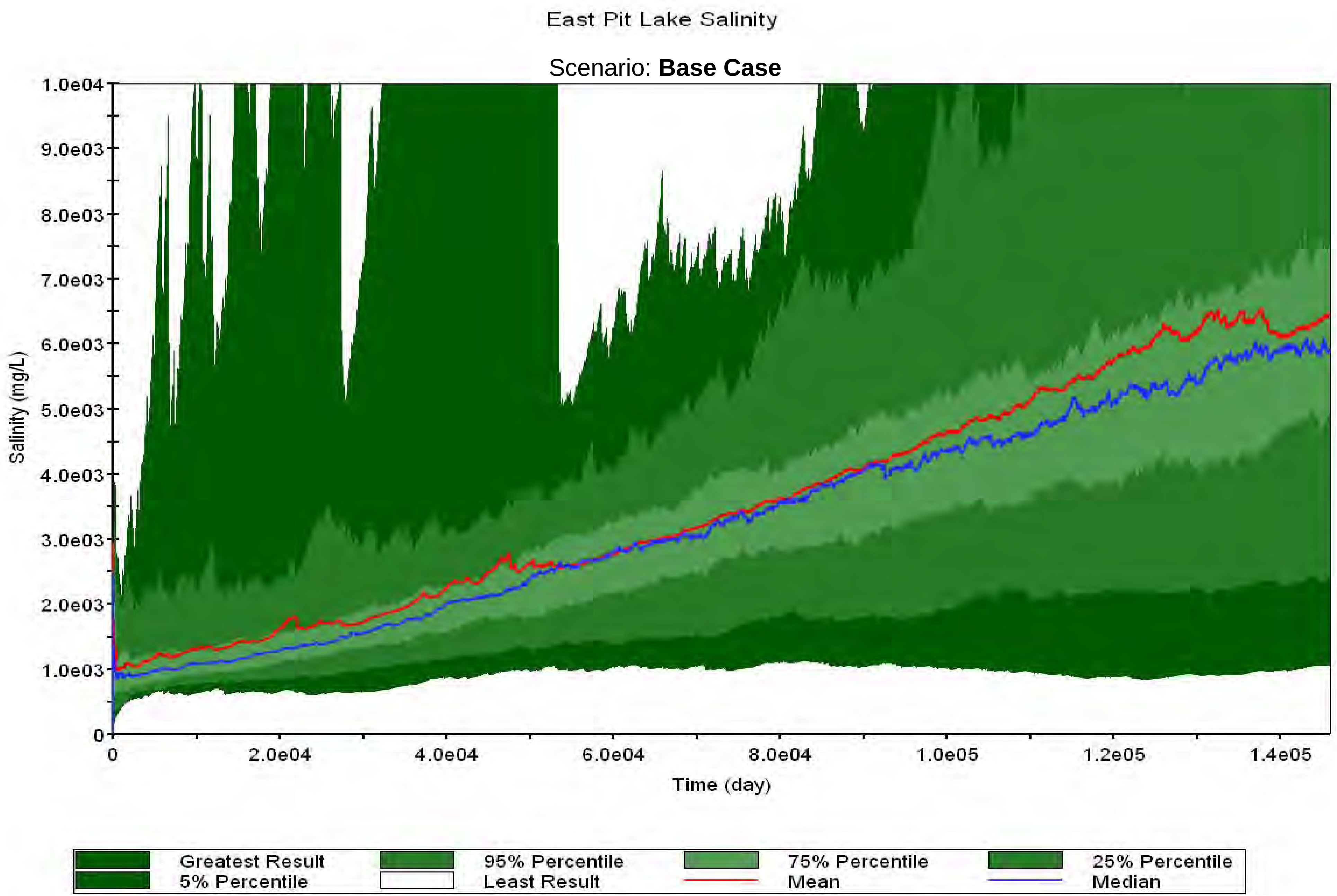
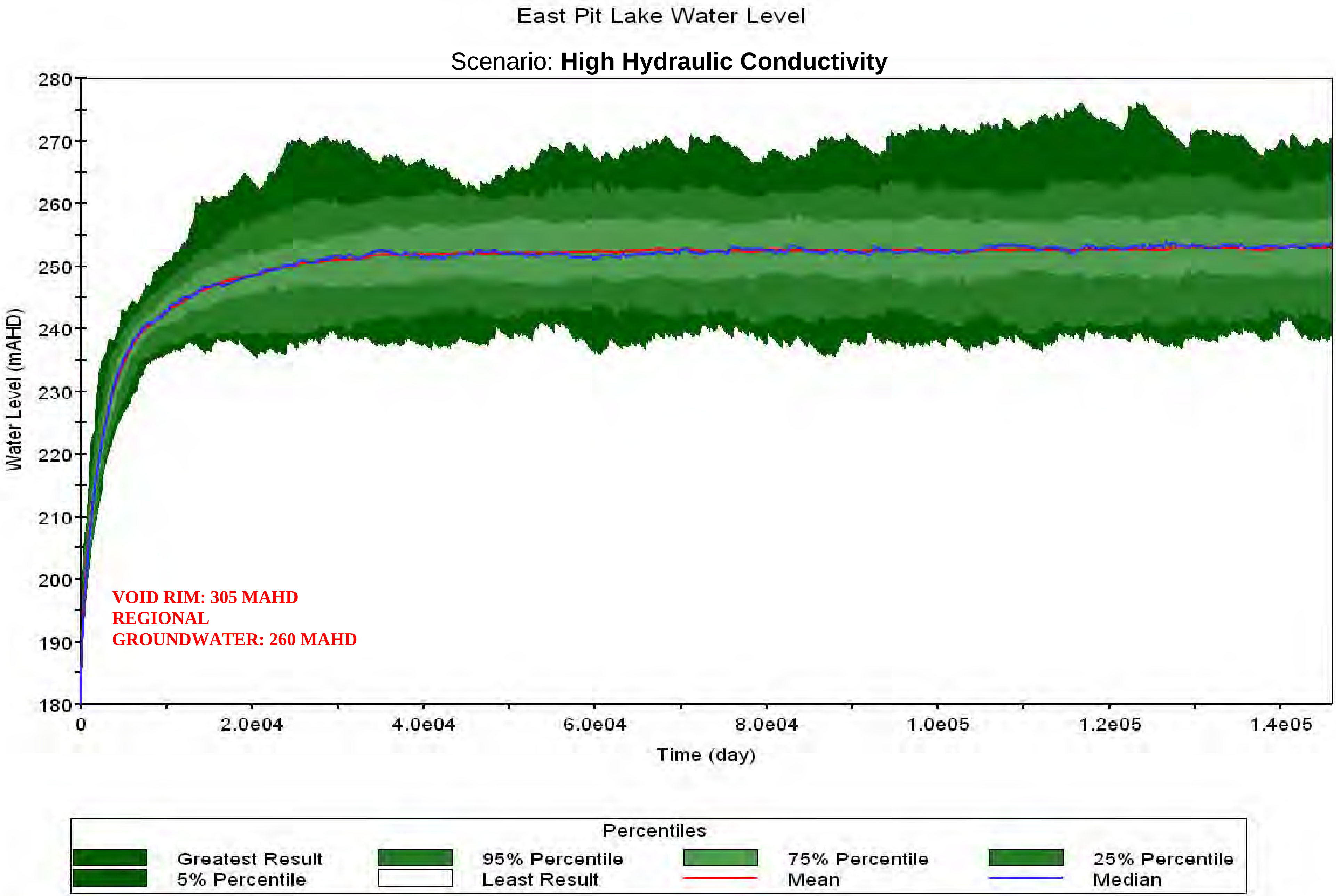
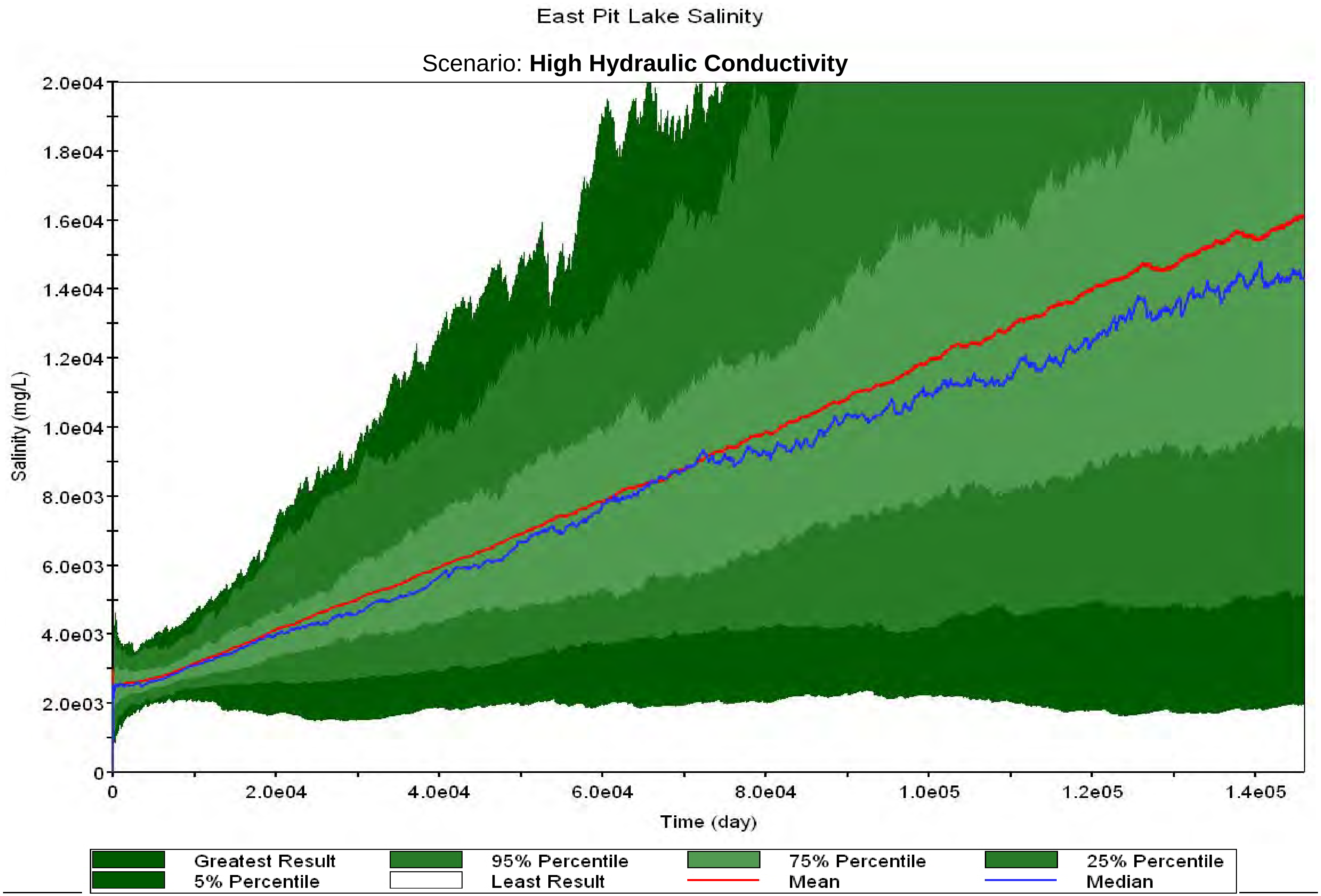
Appendix A

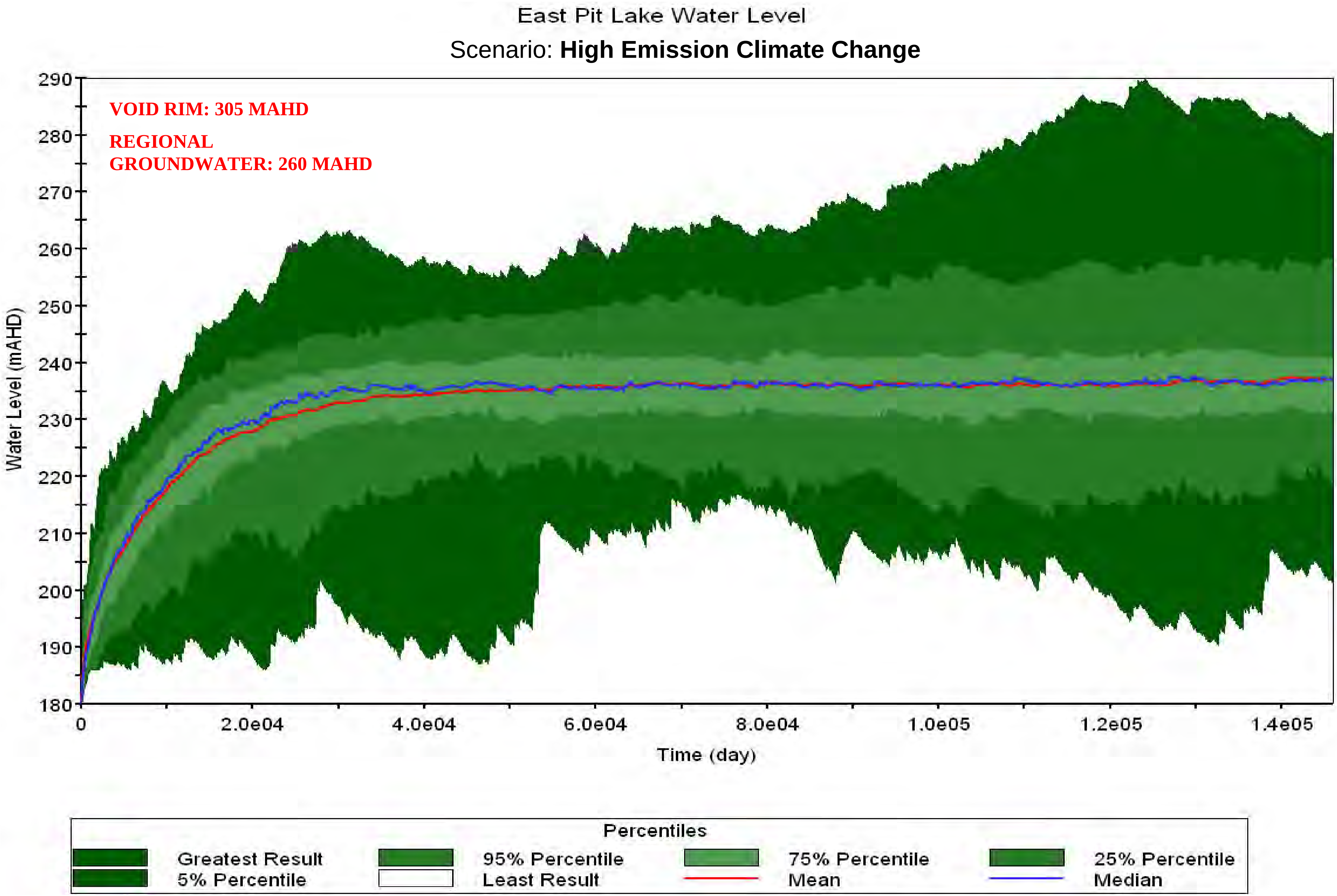
EAST PIT RESULTS

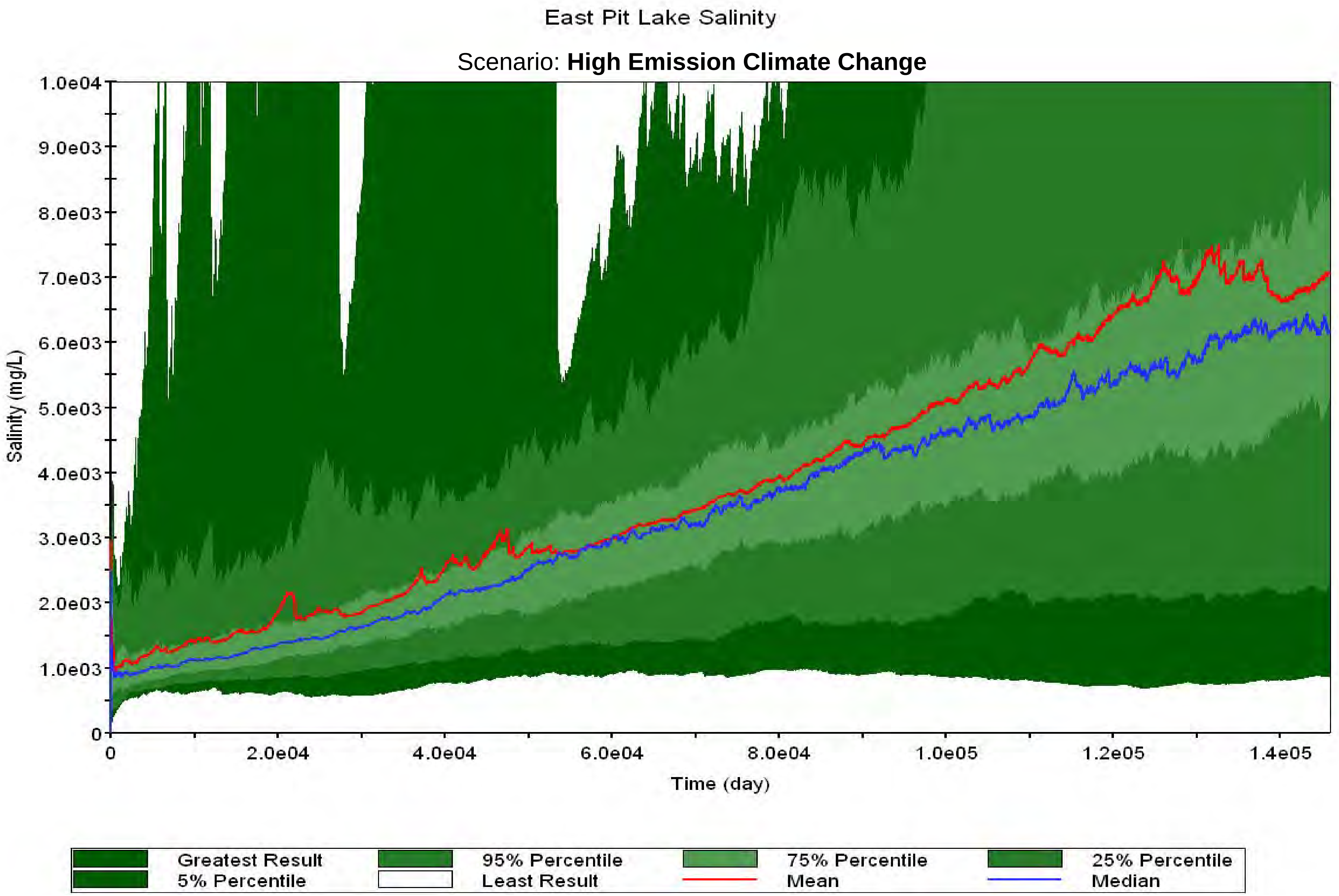

East Pit Lake Water Level
Scenario: Base Case
VOID RIM: 305 MAHD
REGIONAL
GROUNDWATER: 260 MAHD
Water Level (mAHD)
290
280
270
260
250
240
230
220
210
200
190
180
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


East Pit Lake Salinity
Scenario: **Base Case**
Salinity (mg/L)
1.0e04
9.0e03
8.0e03
7.0e03
6.0e03
5.0e03
4.0e03
3.0e03
2.0e03
1.0e03
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


East Pit Lake Water Level
Scenario: High Hydraulic Conductivity
Water Level (mAHD)
280
270
260
250
240
230
220
210
200
190
180
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
VOID RIM: 305 MAHD
REGIONAL
GROUNDWATER: 260 MAHD
Percentiles
Greatest Result
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Least Result
Mean
Median

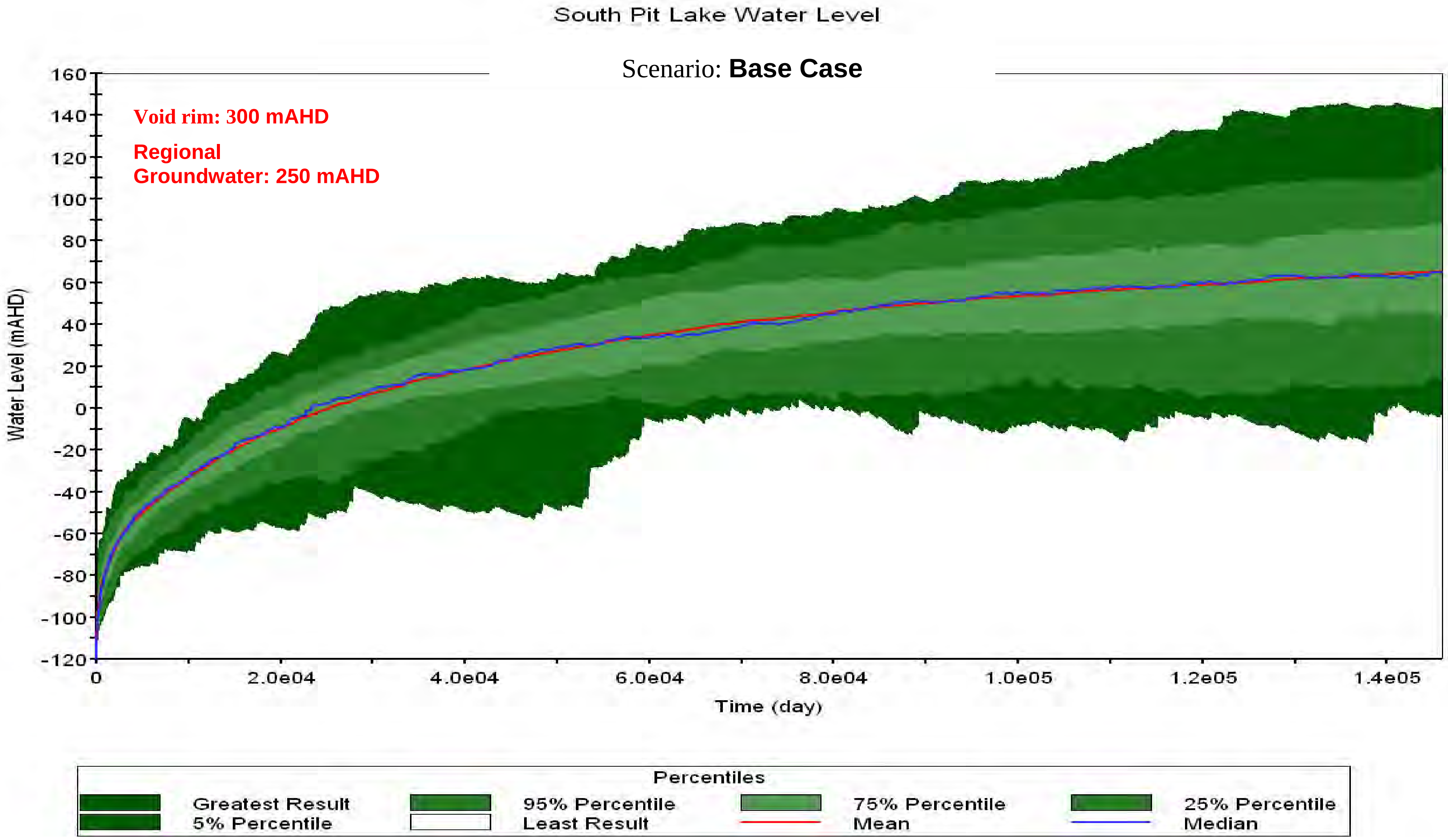

East Pit Lake Salinity
Scenario: High Hydraulic Conductivity
Salinity (mg/L)
Time (day)
0
2.0e03
4.0e03
6.0e03
8.0e03
1.0e04
1.2e04
1.4e04
1.6e04
1.8e04
2.0e04
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Greatest Result
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Least Result
Mean
Median

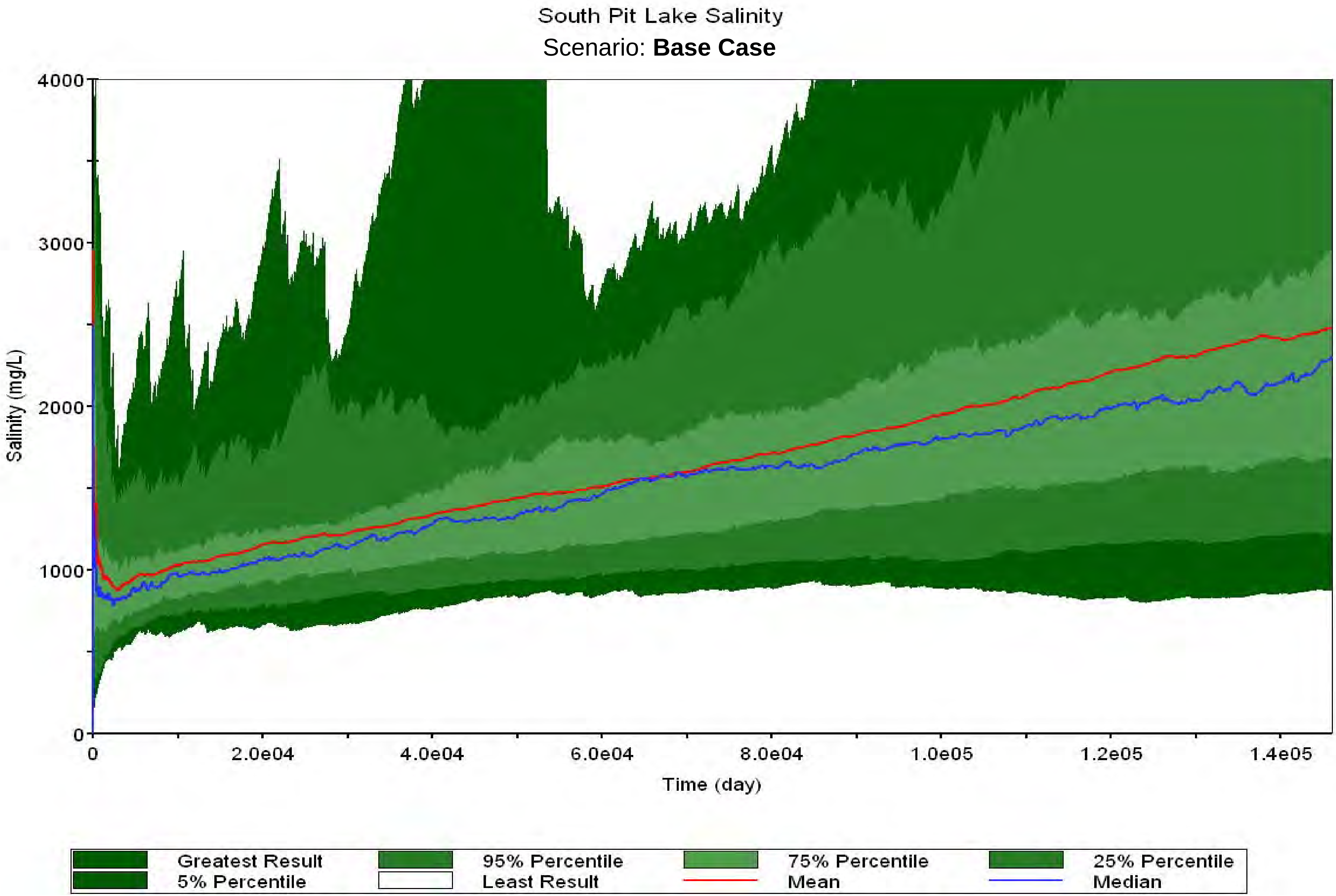

East Pit Lake Water Level
Scenario: High Emission Climate Change
VOID RIM: 305 MAHD
REGIONAL
GROUNDWATER: 260 MAHD
Water Level (mAHD)
290
280
270
260
250
240
230
220
210
200
190
180
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

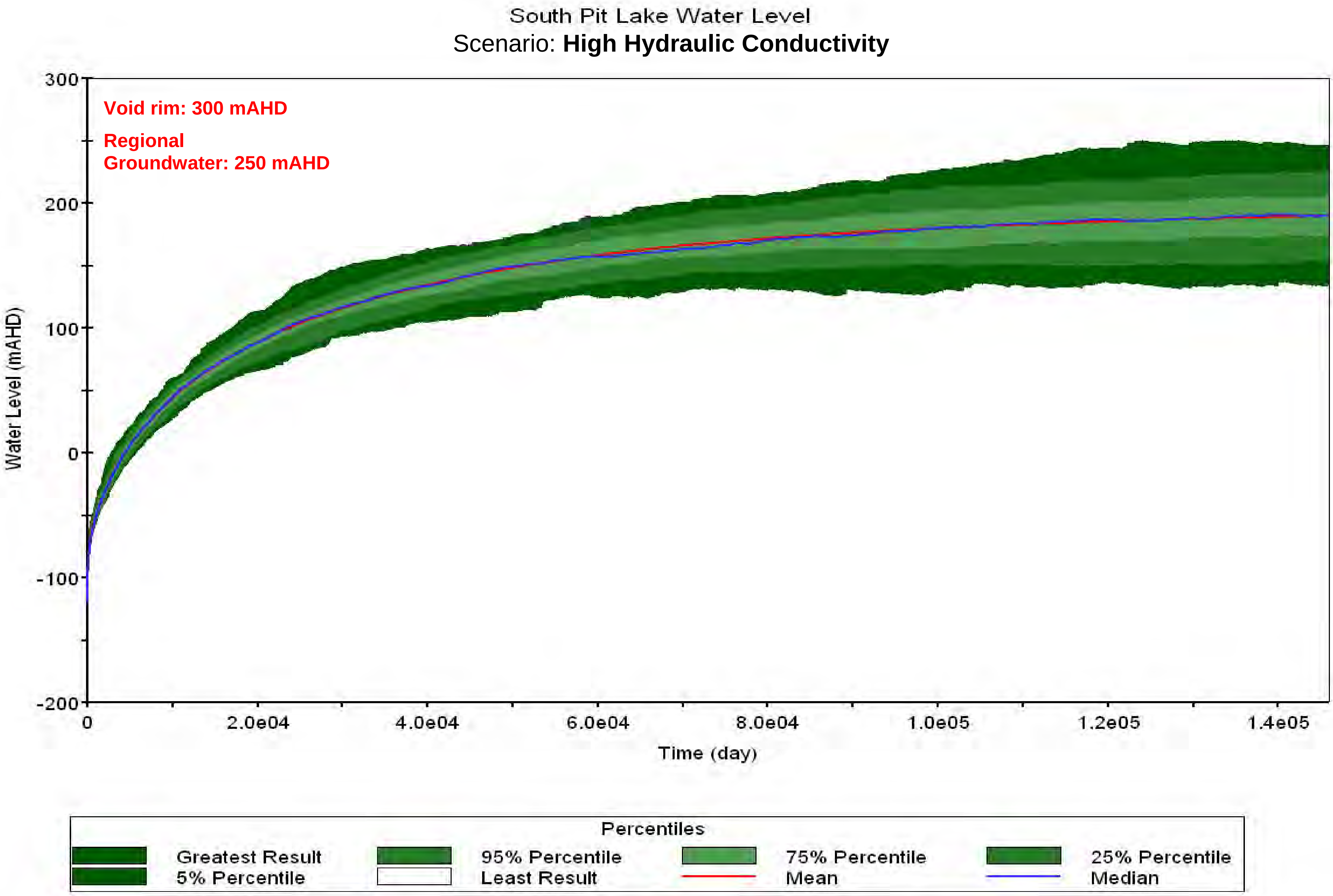

East Pit Lake Salinity
Scenario: High Emission Climate Change
Salinity (mg/L)
1.0e04
9.0e03
8.0e03
7.0e03
6.0e03
5.0e03
4.0e03
3.0e03
2.0e03
1.0e03
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

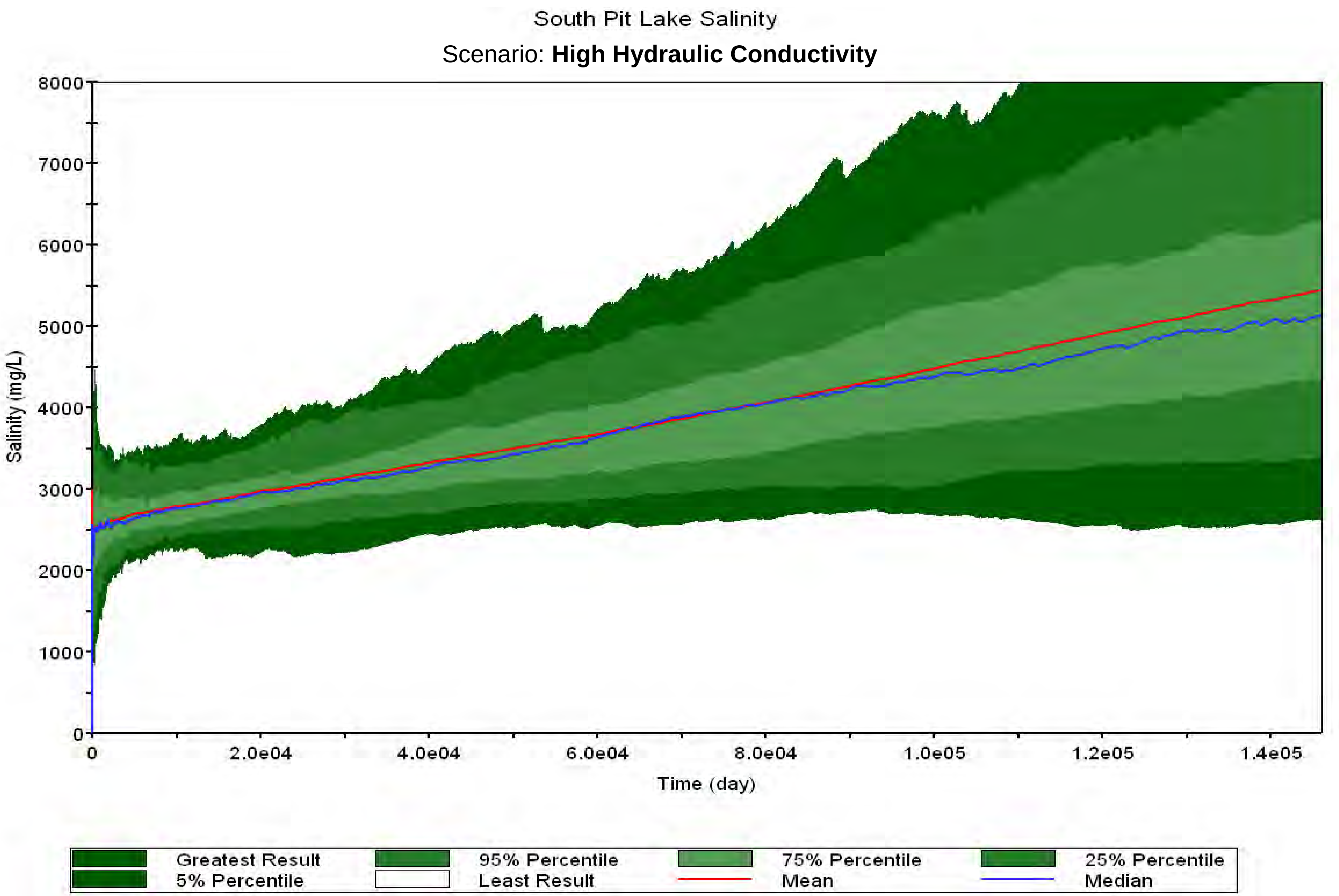
Appendix B

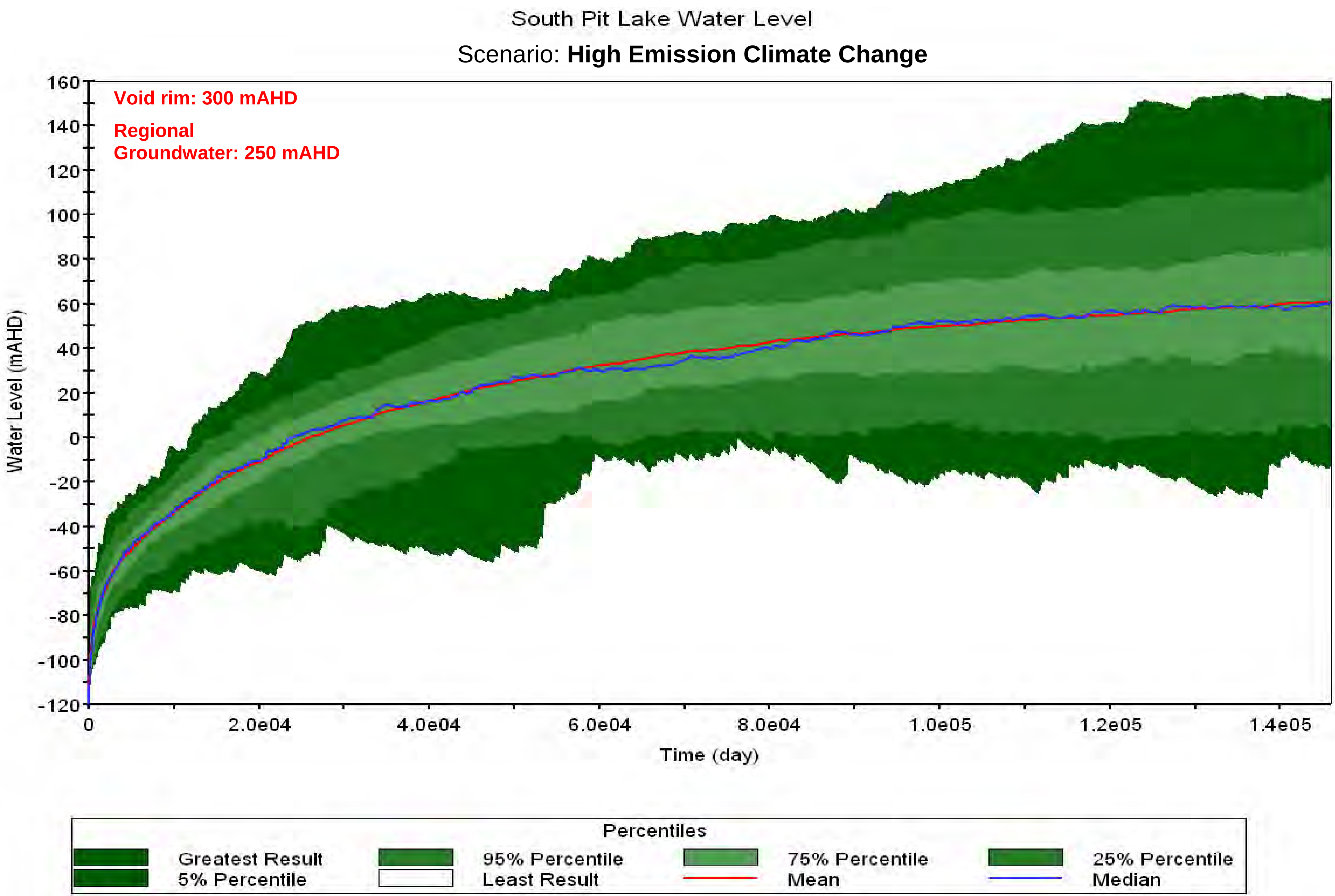
SOUTH PIT RESULTS

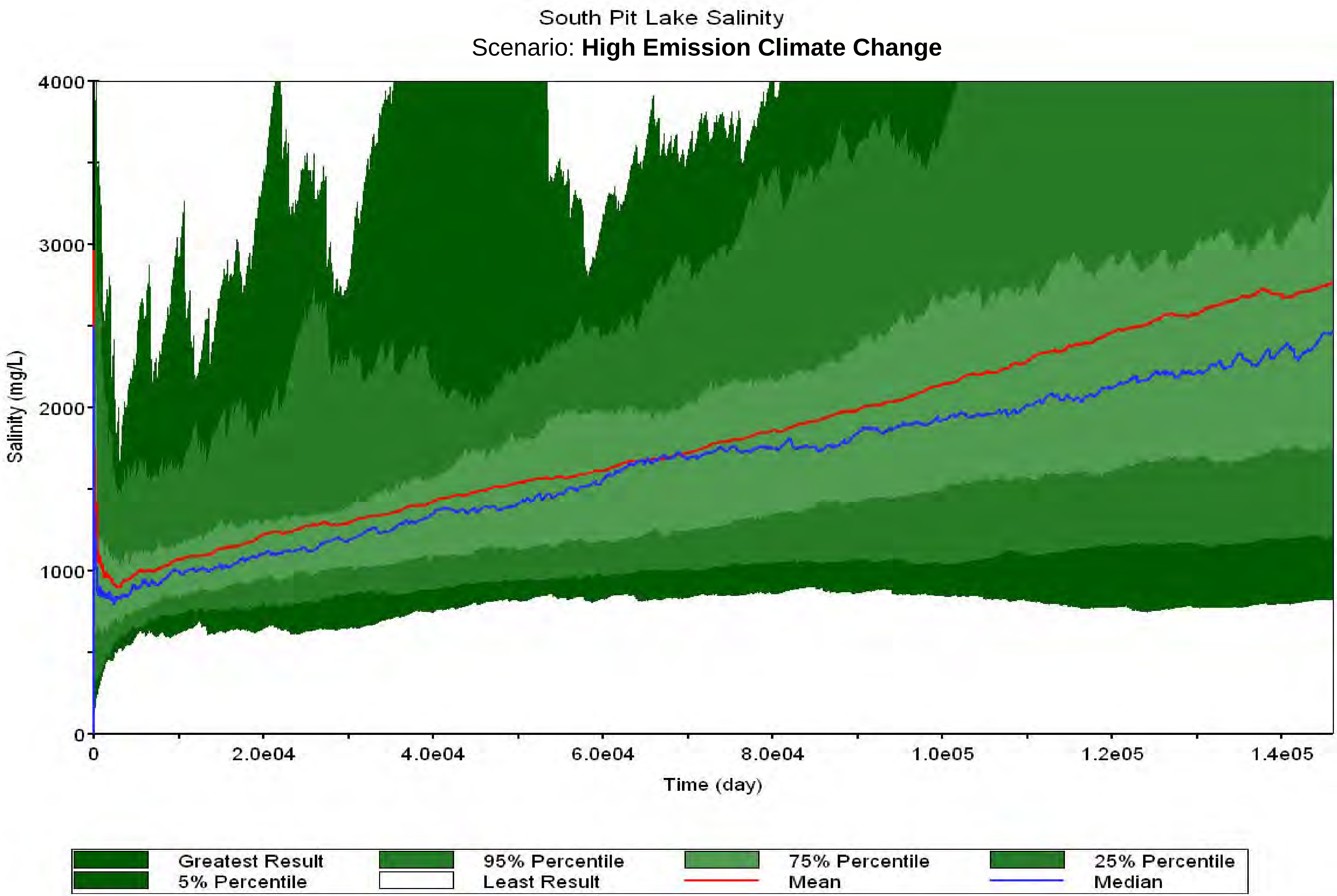

South Pit Lake Water Level
Scenario: Base Case
Void rim: 300 mAHD
Regional
Groundwater: 250 mAHD
Water Level (mAHD)
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


South Pit Lake Salinity
Scenario: **Base Case**
Salinity (mg/L)
4000
3000
2000
1000
0
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


South Pit Lake Water Level
Scenario: High Hydraulic Conductivity
Void rim: 300 mAHD
Regional
Groundwater: 250 mAHD
Water Level (mAHD)
300
200
100
0
-100
-200
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

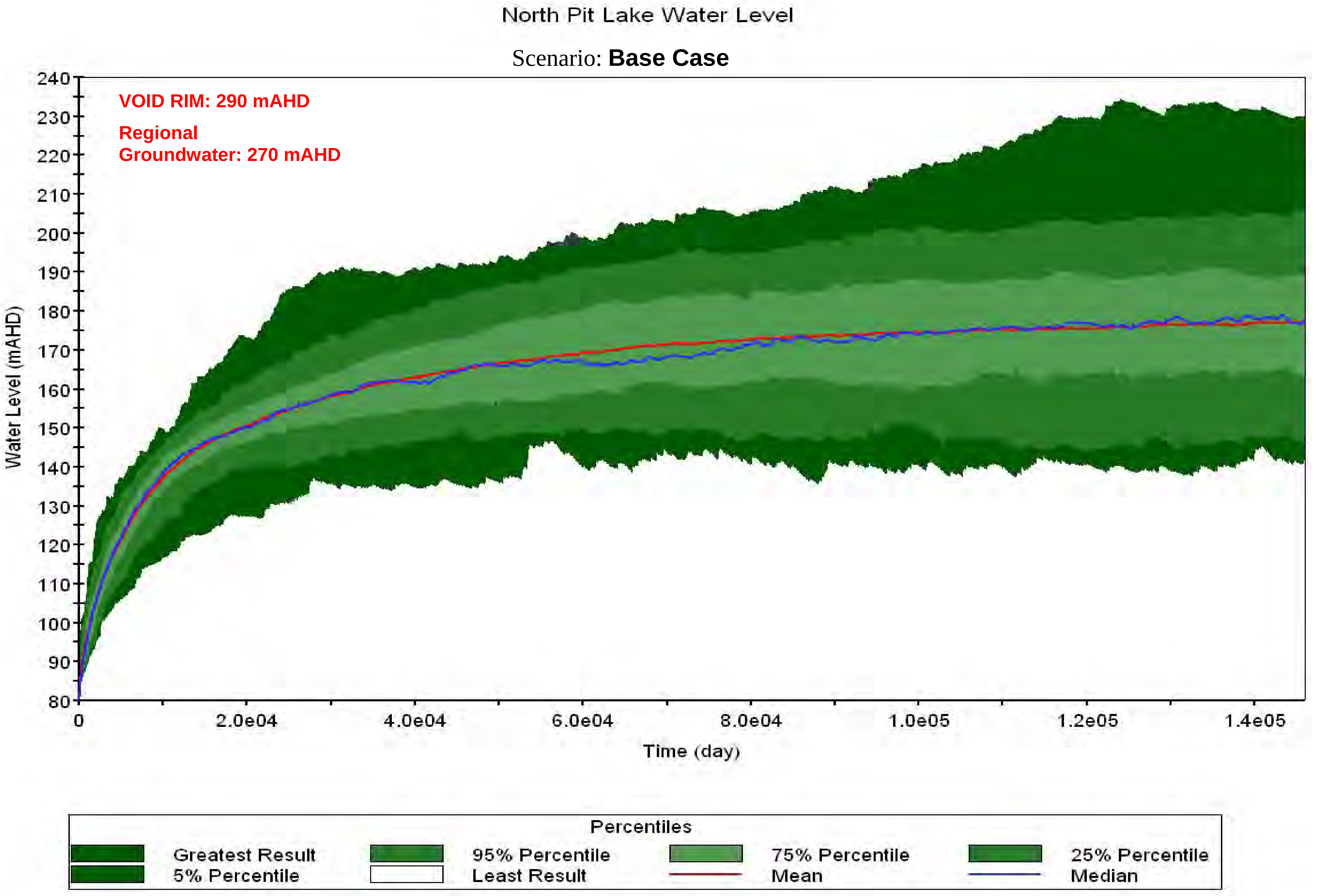

South Pit Lake Salinity
Scenario: High Hydraulic Conductivity
Salinity (mg/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

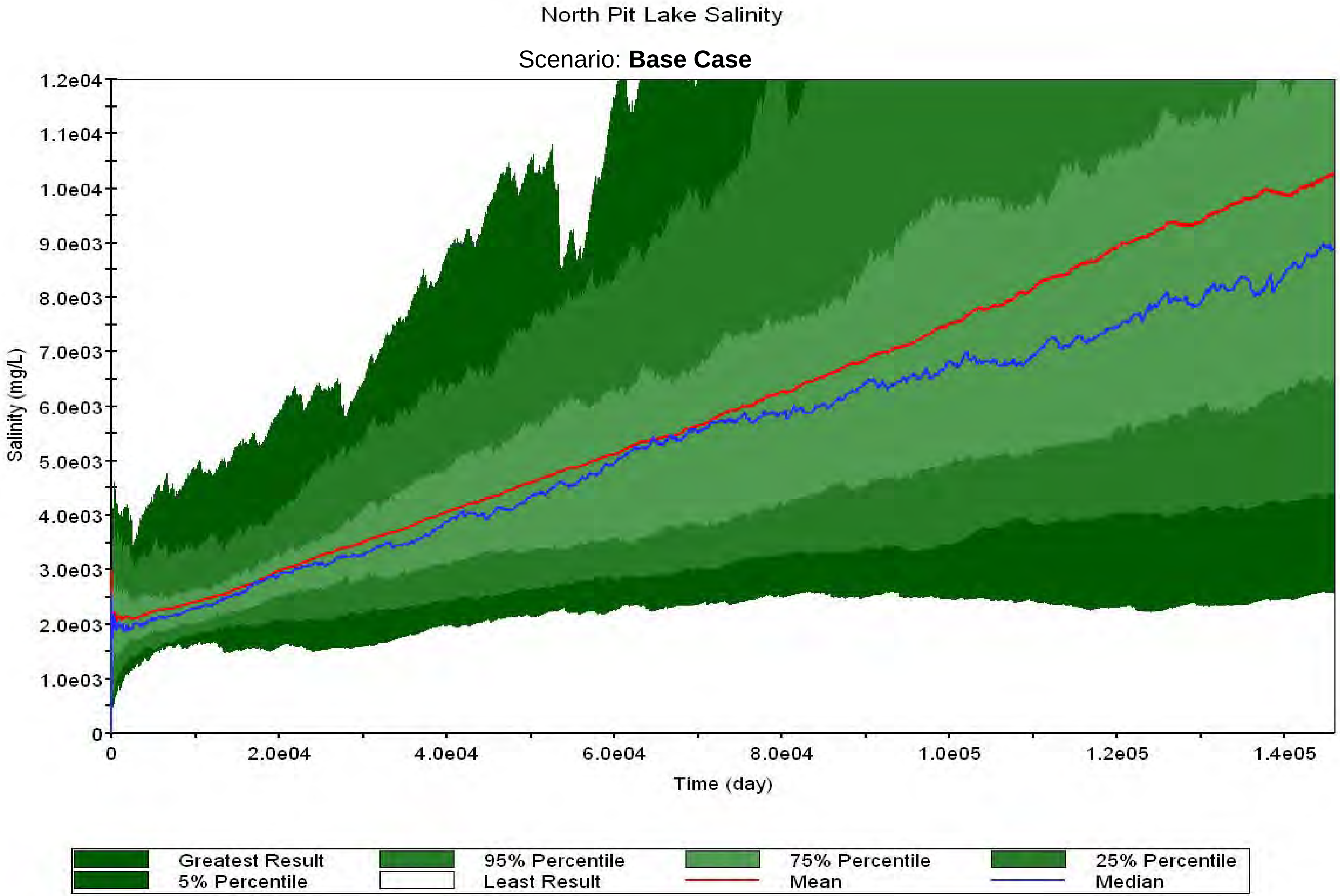

South Pit Lake Water Level
Scenario: High Emission Climate Change
Void rim: 300 mAHD
Regional
Groundwater: 250 mAHD
Water Level (mAHD)
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


South Pit Lake Salinity
Scenario: High Emission Climate Change
Salinity (mg/L)
4000
3000
2000
1000
0
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Least Result
Mean
Median

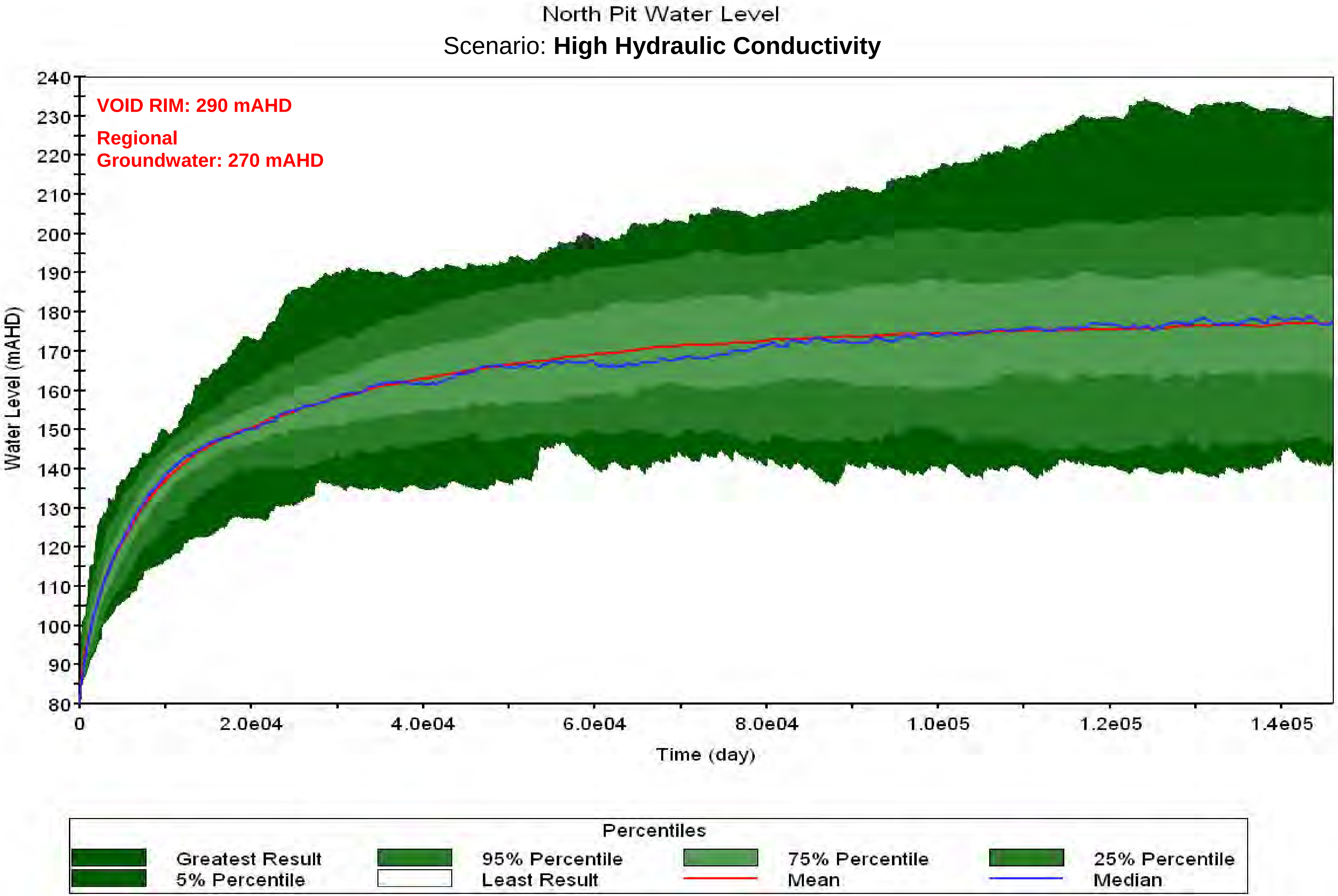
Appendix C

NORTH PIT RESULTS

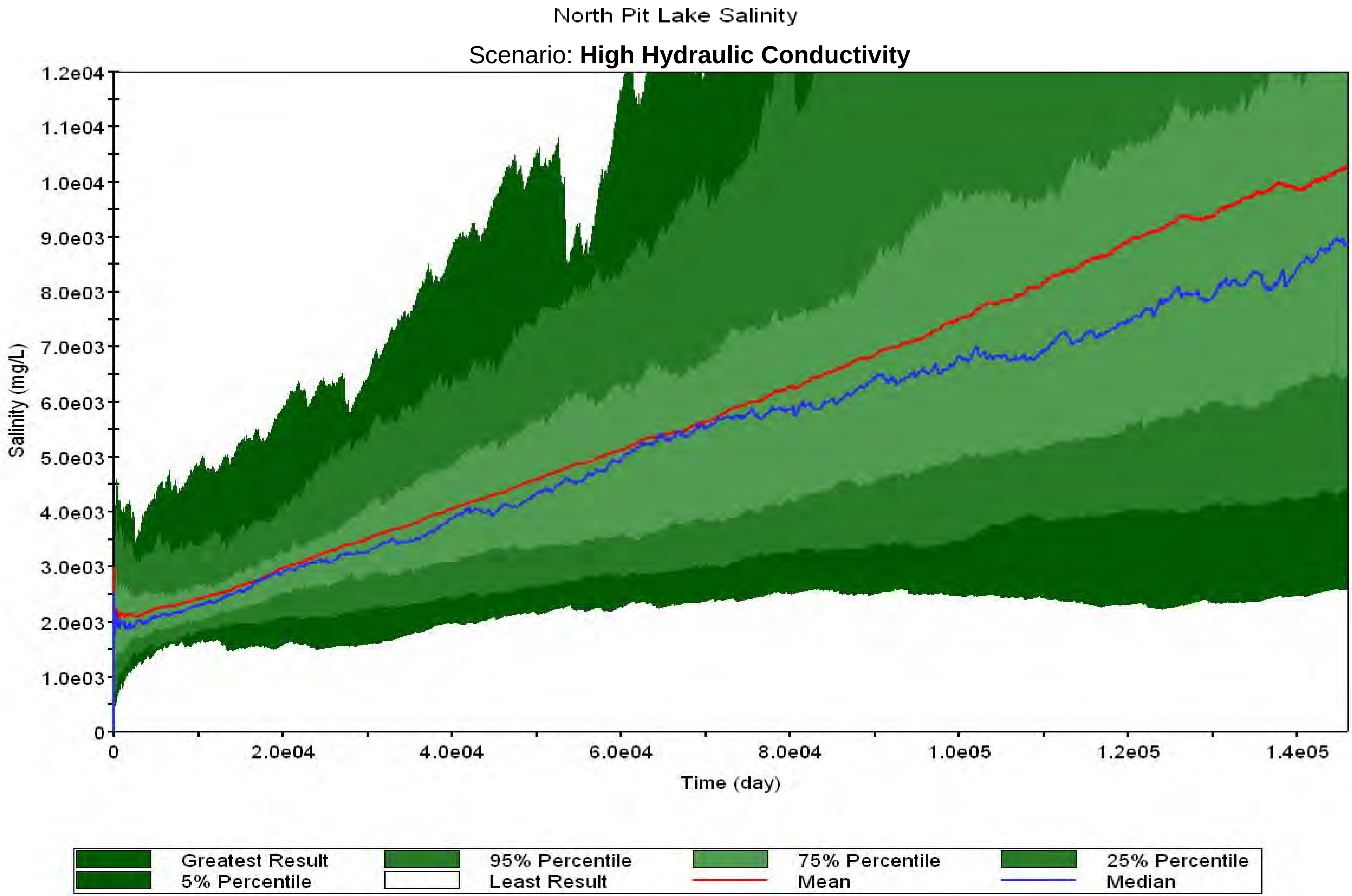

North Pit Lake Water Level
Scenario: Base Case
VOID RIM: 290 mAHD
Regional
Groundwater: 270 mAHD
Water Level (mAHD)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

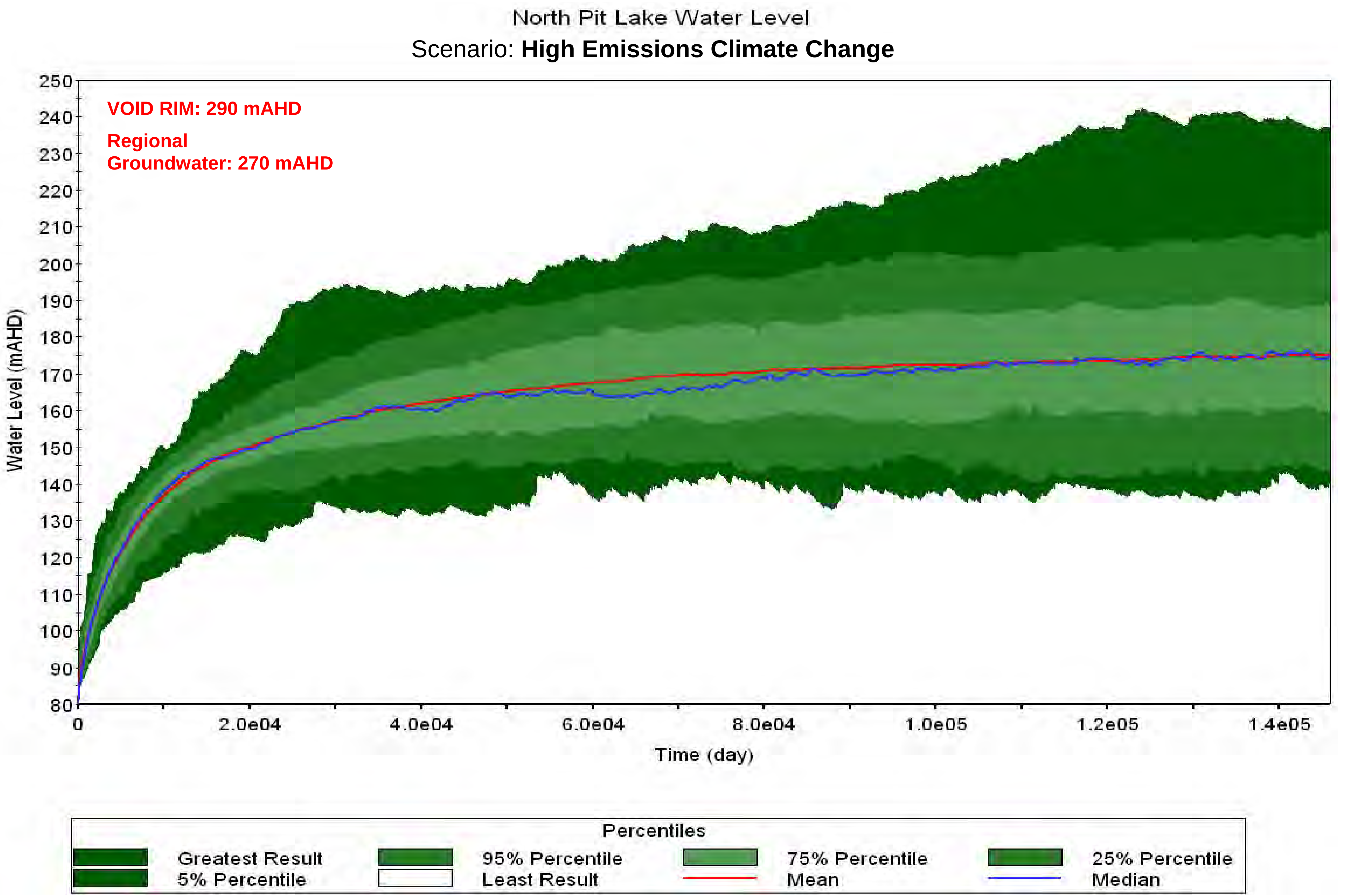


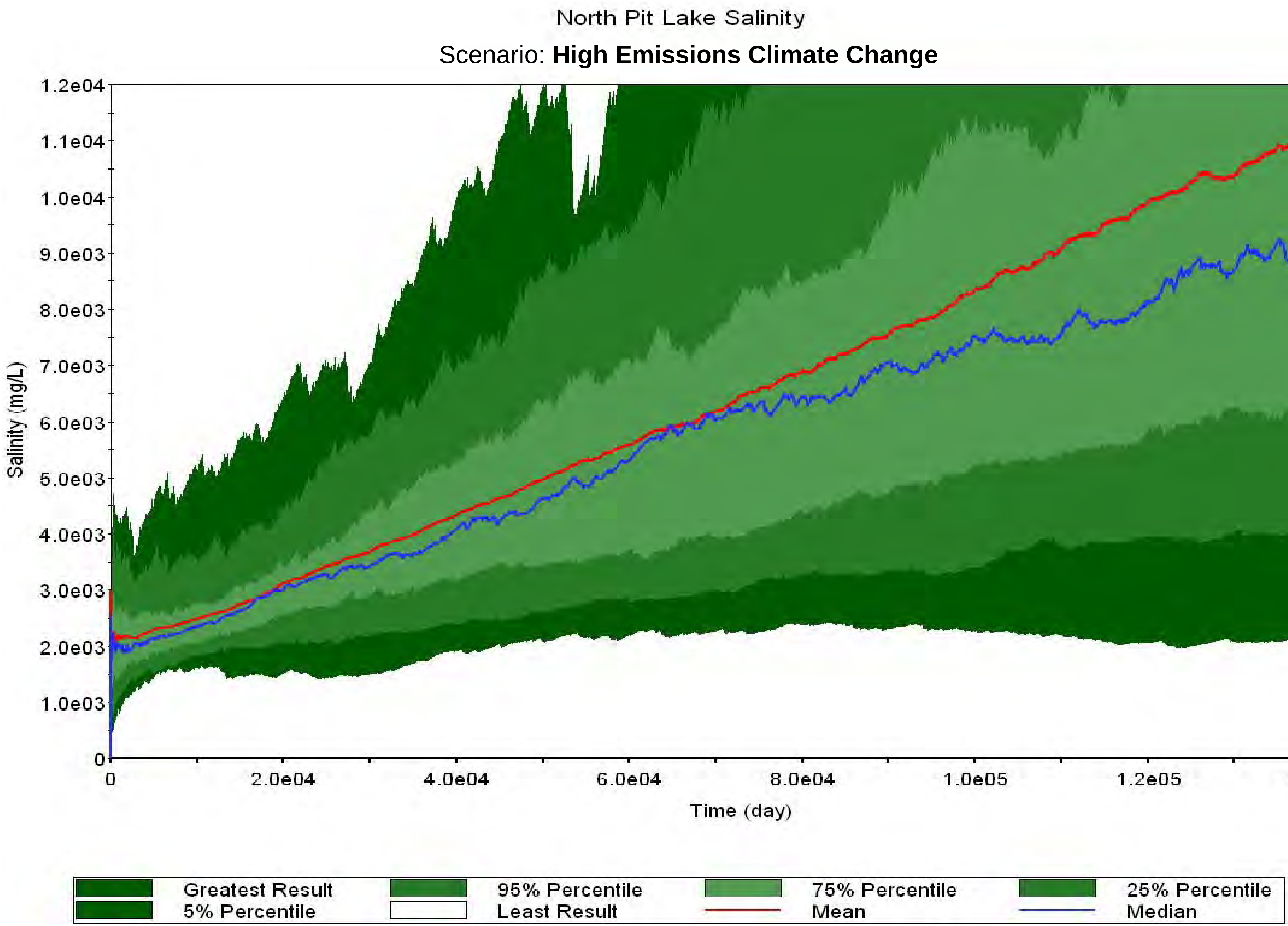
North Pit Lake Salinity
Scenario: Base Case
Salinity (mg/L)
1.2e04
1.1e04
1.0e04
9.0e03
8.0e03
7.0e03
6.0e03
5.0e03
4.0e03
3.0e03
2.0e03
1.0e03
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median



North Pit Water Level
Scenario: High Hydraulic Conductivity
VOID RIM: 290 mAHD
Regional
Groundwater: 270 mAHD
Water Level (mAHD)
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

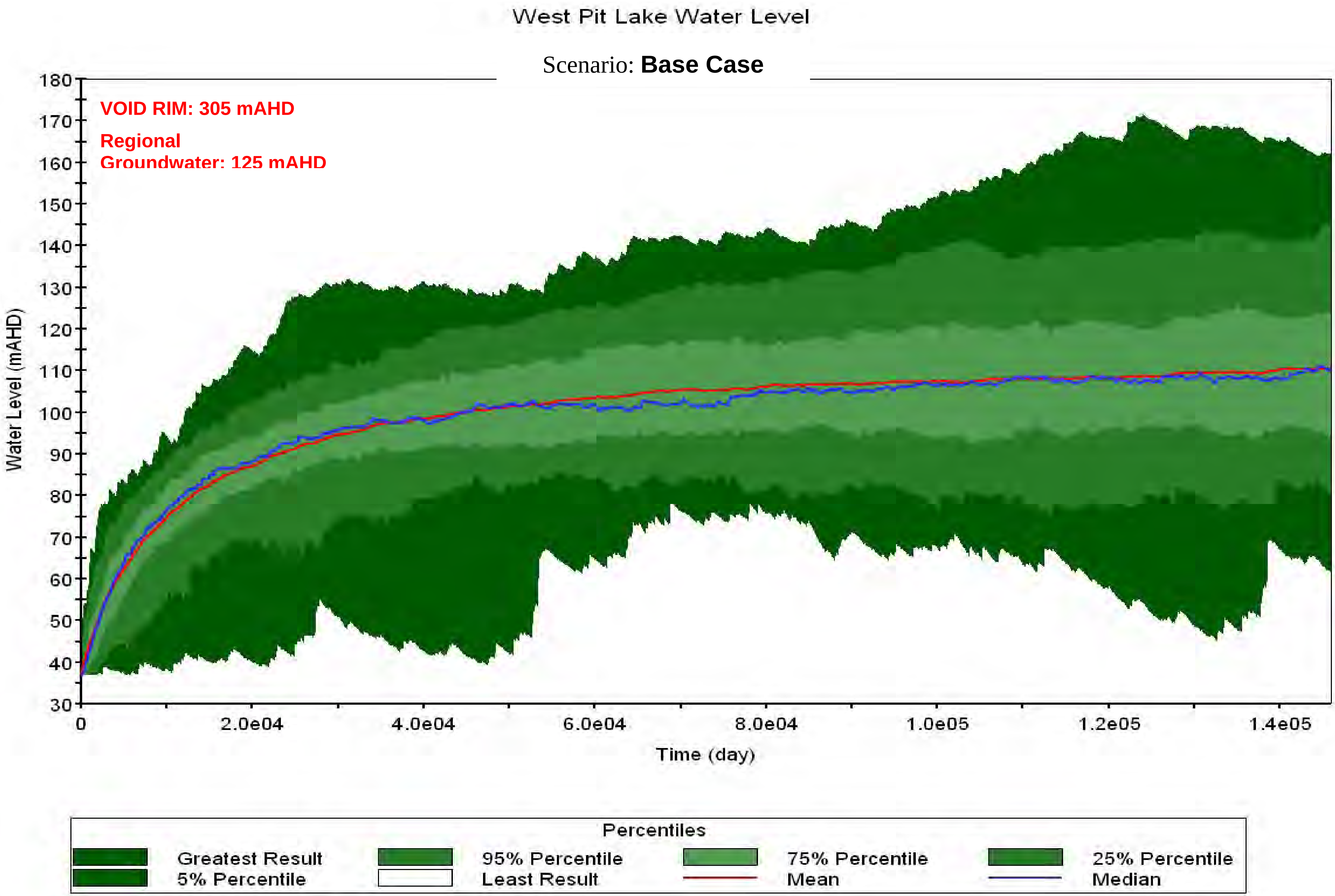

North Pit Lake Salinity
Scenario: **High Hydraulic Conductivity**
Salinity (mg/L)
1.2e04
1.1e04
1.0e04
9.0e03
8.0e03
7.0e03
6.0e03
5.0e03
4.0e03
3.0e03
2.0e03
1.0e03
0
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
95% Percentile
75% Percentile
25% Percentile
5% Percentile
Least Result
Mean
Median

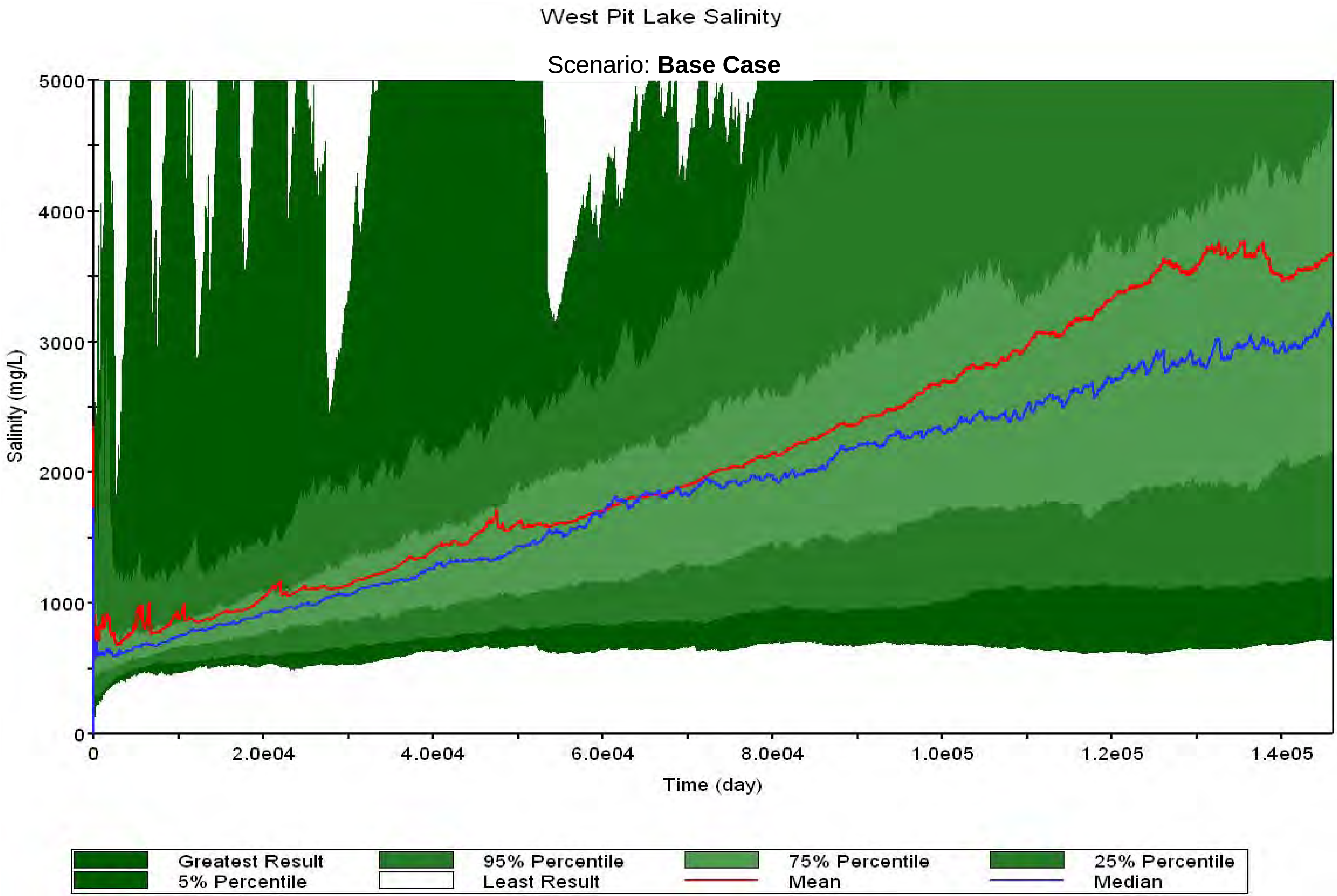

North Pit Lake Water Level
Scenario: High Emissions Climate Change
VOID RIM: 290 mAHD
Regional
Groundwater: 270 mAHD
Water Level (mAHD)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


North Pit Lake Salinity
Scenario: High Emissions Climate Change
Salinity (mg/L)
1.2e04
1.1e04
1.0e04
9.0e03
8.0e03
7.0e03
6.0e03
5.0e03
4.0e03
3.0e03
2.0e03
1.0e03
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

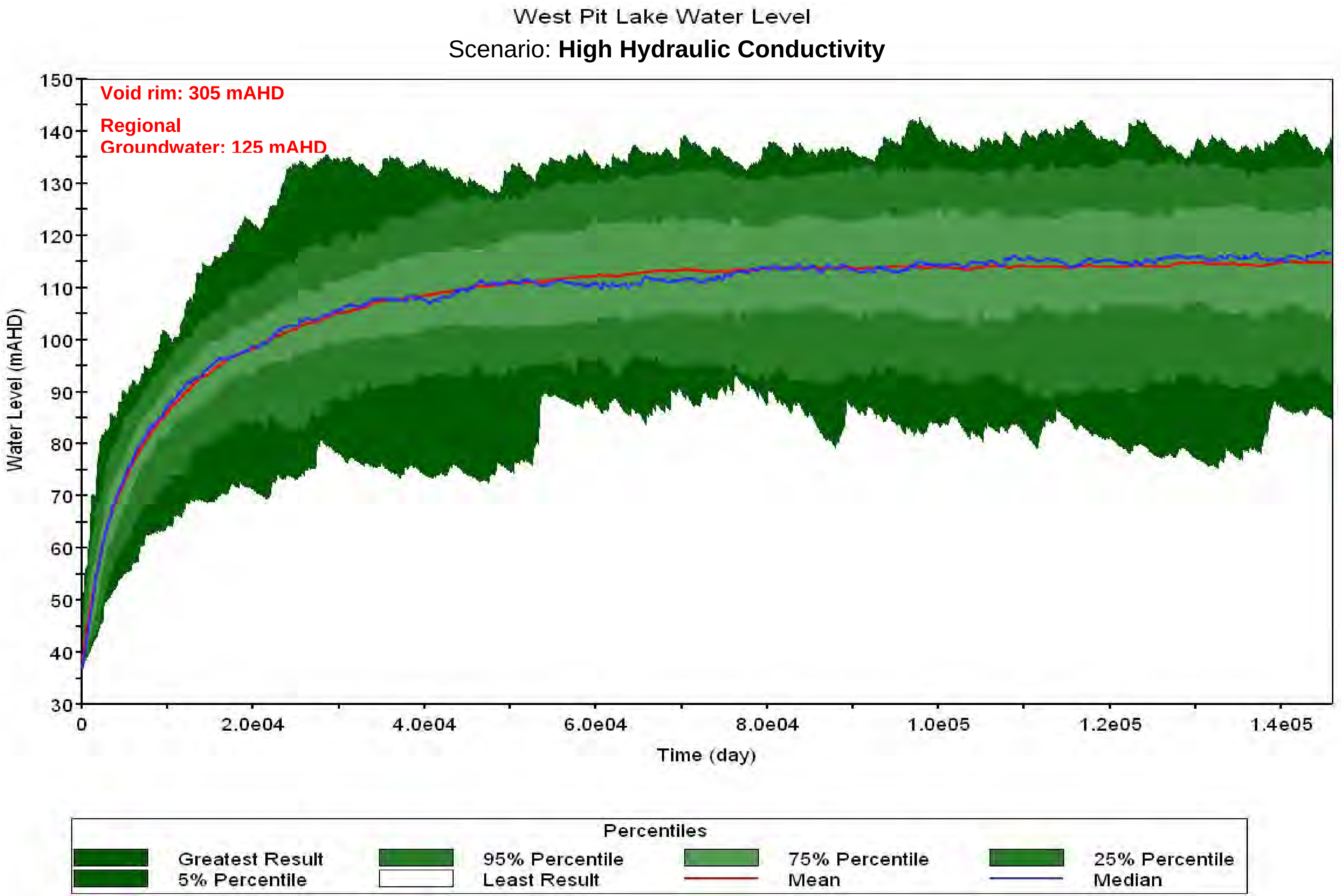
Appendix D

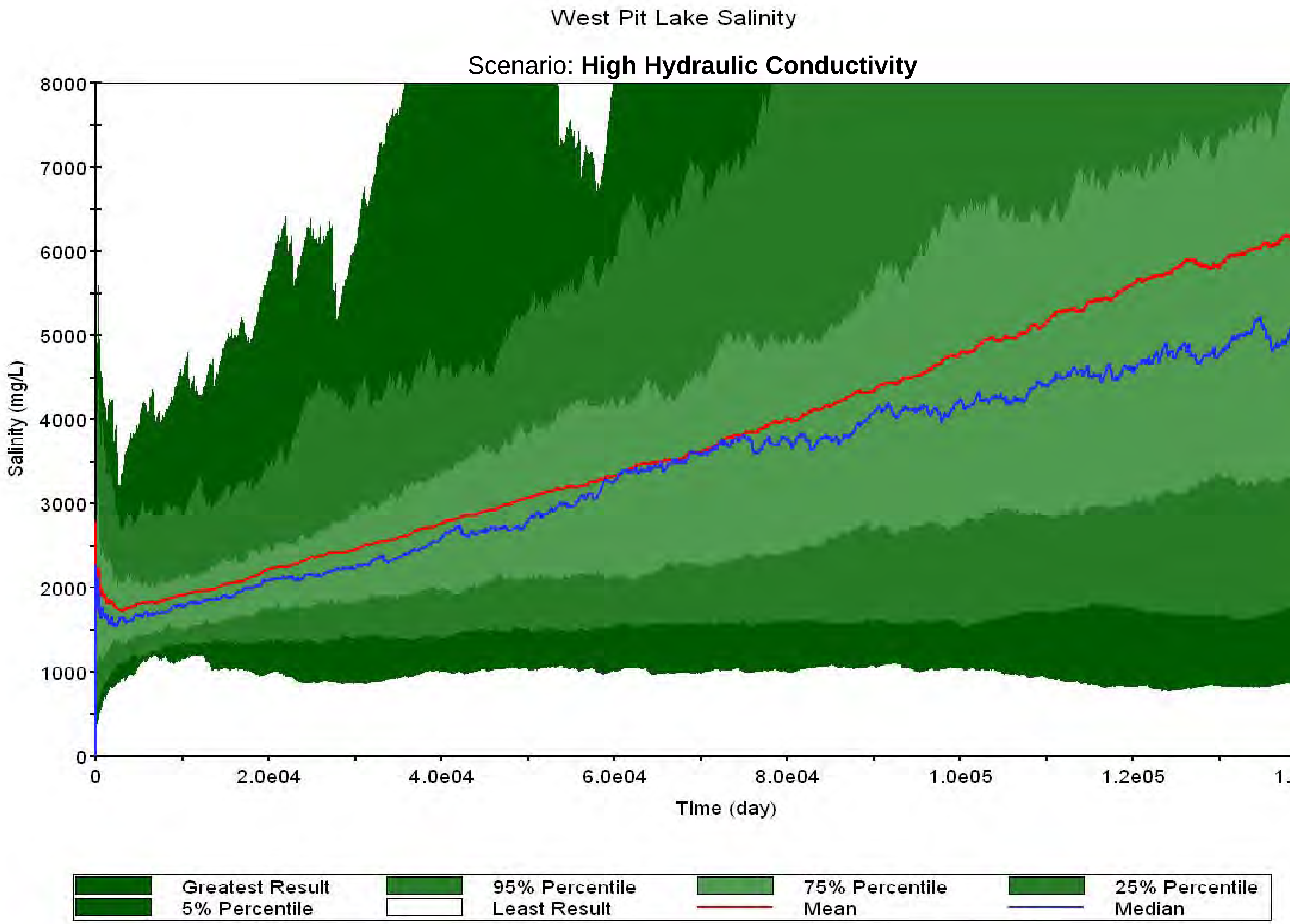
WEST PIT RESULTS

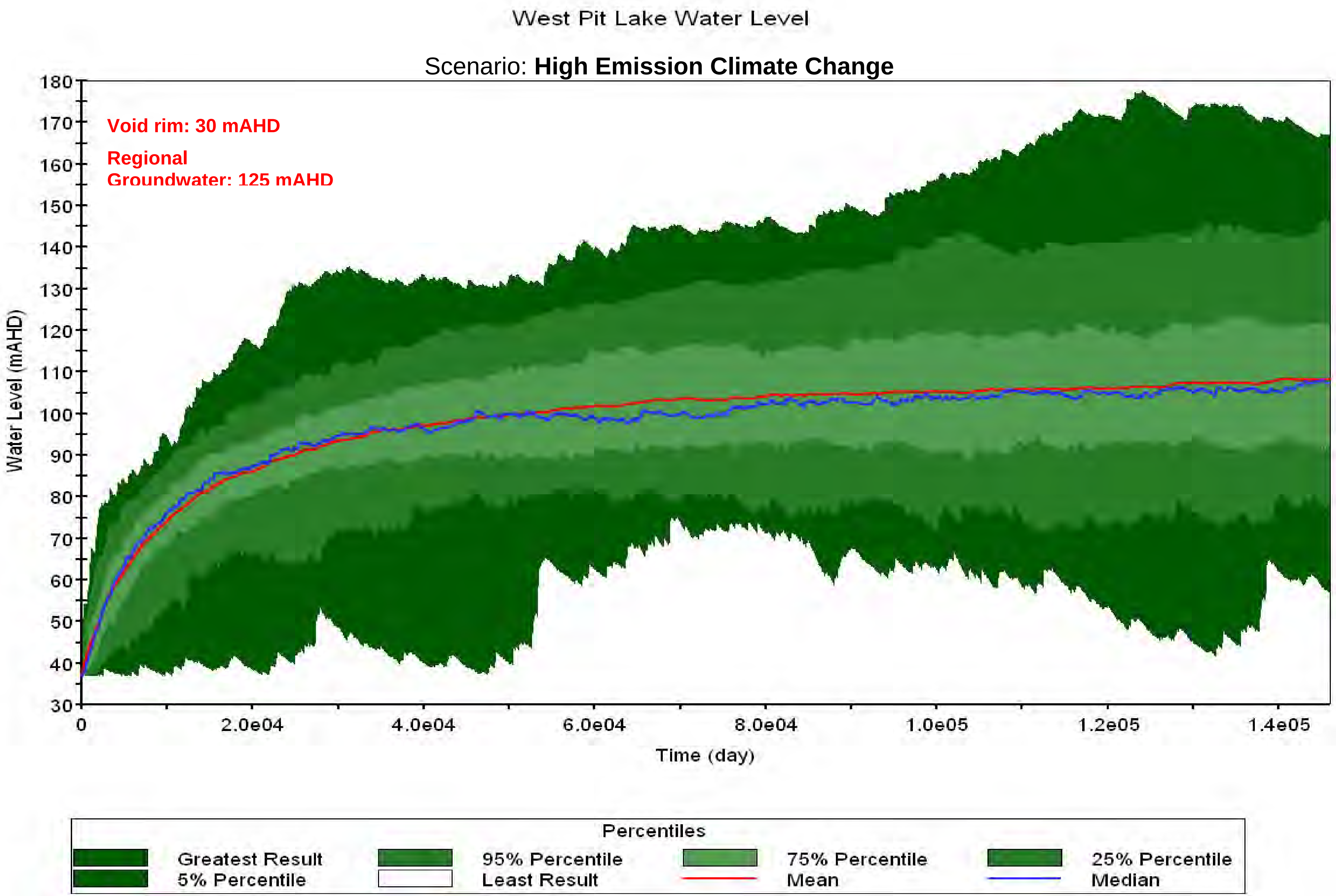

West Pit Lake Water Level
Scenario: Base Case
VOID RIM: 305 mAHD
Regional
Groundwater: 125 mAHD
Water Level (mAHD)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median



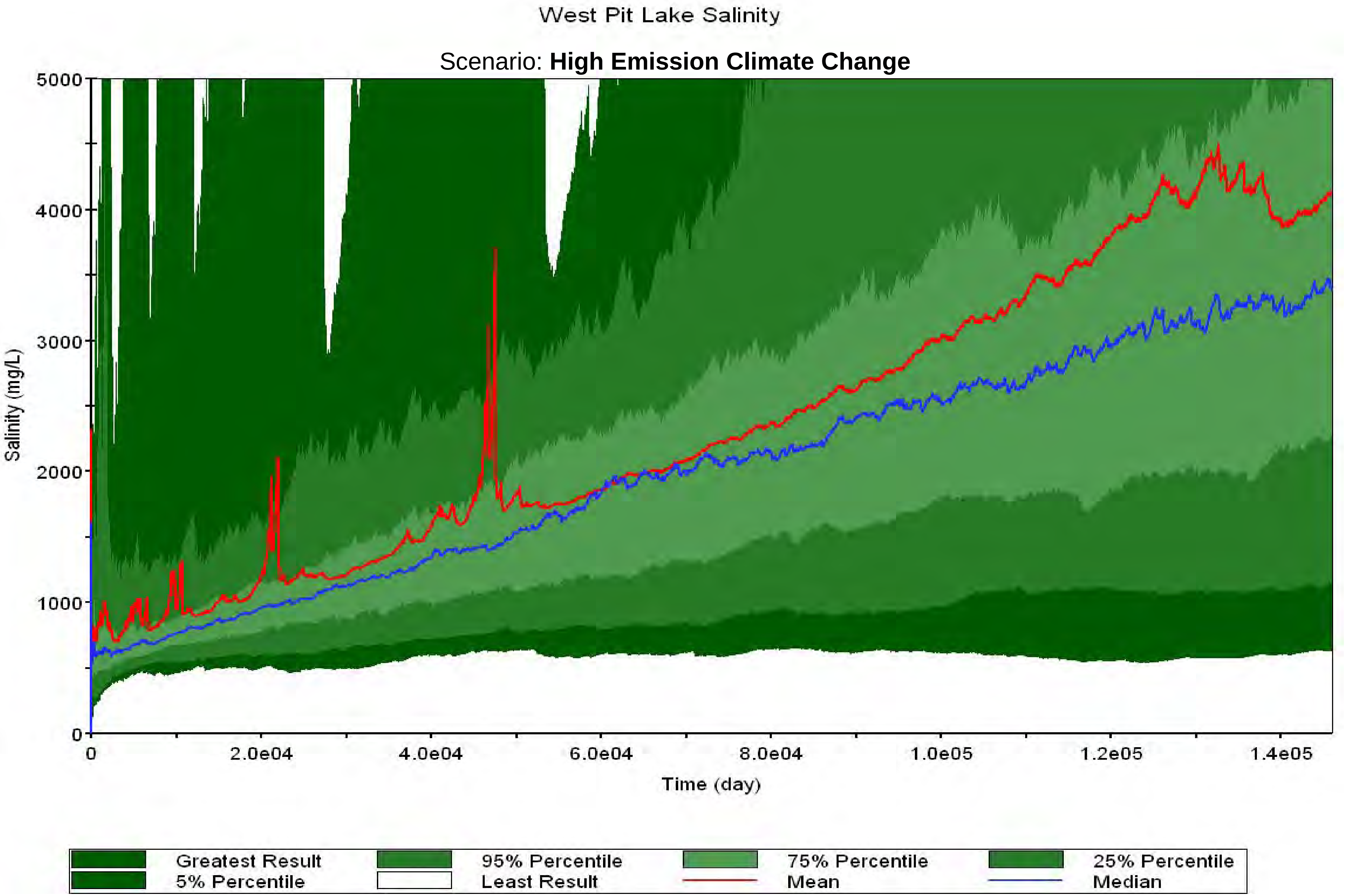
West Pit Lake Salinity
Scenario: **Base Case**
5000
4000
3000
2000
1000
0
Salinity (mg/L)
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

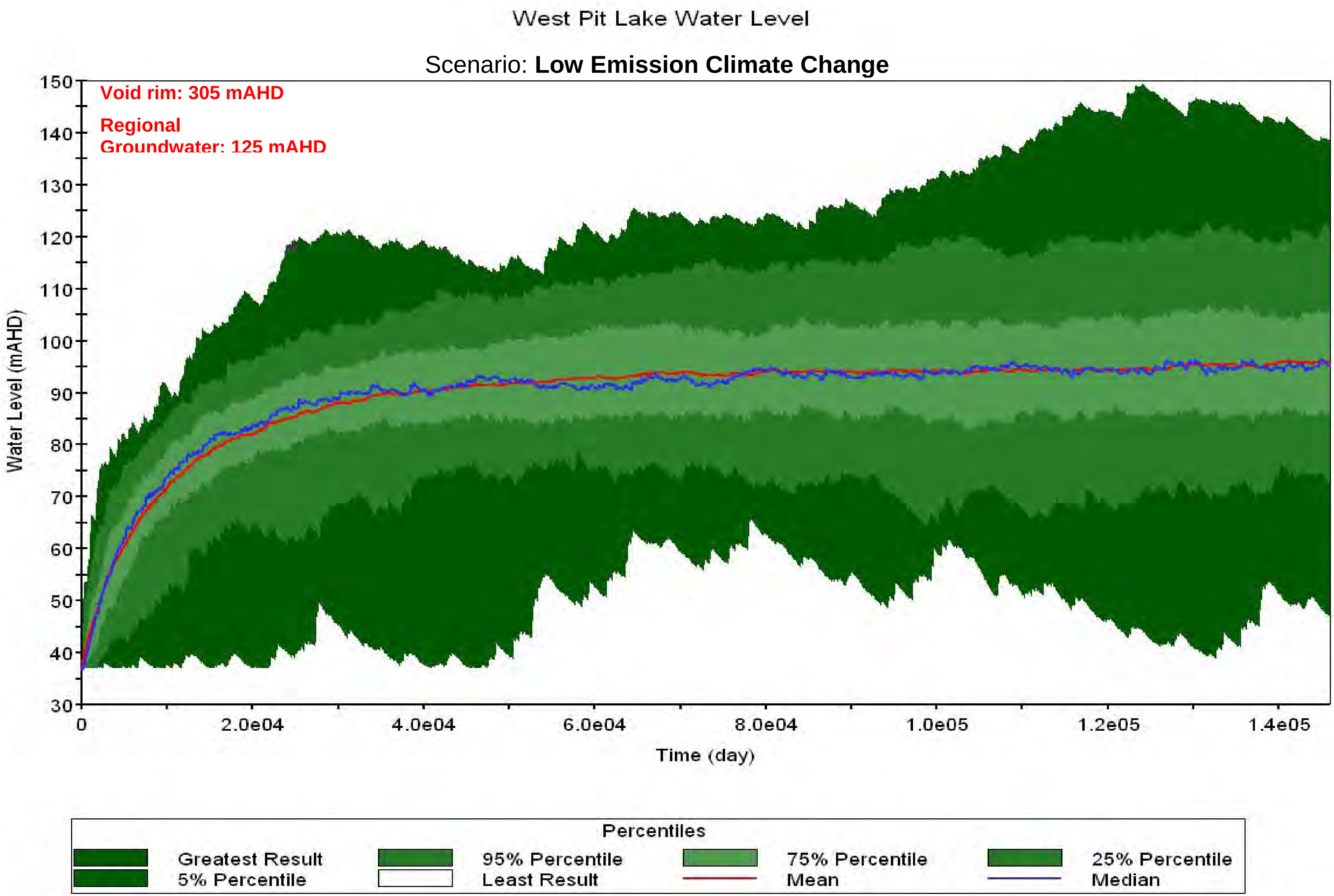

West Pit Lake Water Level
Scenario: High Hydraulic Conductivity
Void rim: 305 mAHD
Regional Groundwater: 125 mAHD
Water Level (mAHD)
150
140
130
120
110
100
90
80
70
60
50
40
30
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median

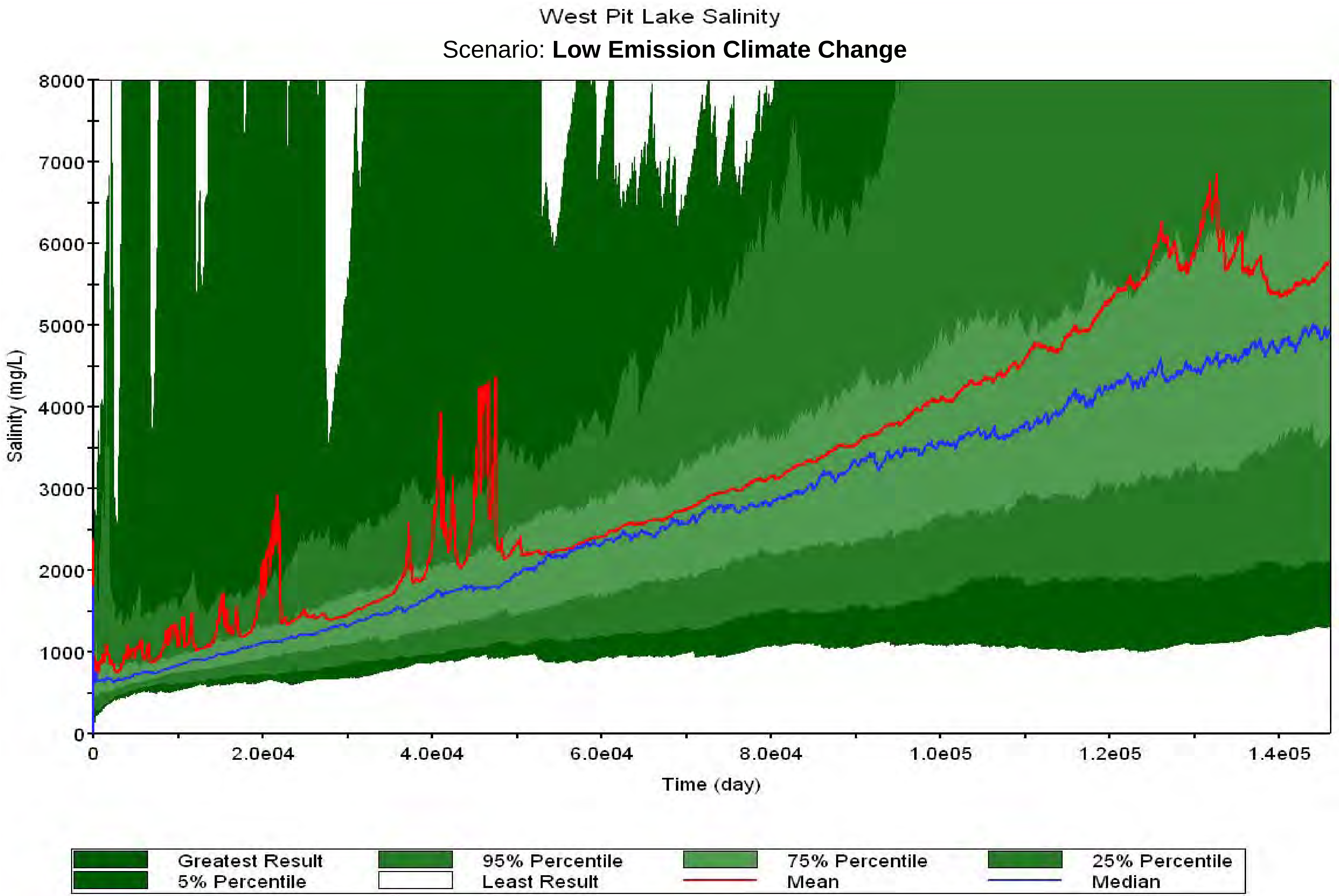

West Pit Lake Salinity
Scenario: High Hydraulic Conductivity
Salinity (mg/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median



West Pit Lake Water Level
Scenario: High Emission Climate Change
Void rim: 30 mAHD
Regional
Groundwater: 125 mAHD
Water Level (mAHD)
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


West Pit Lake Salinity
Scenario: High Emission Climate Change
Salinity (mg/L)
5000
4000
3000
2000
1000
0
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


West Pit Lake Water Level
Scenario: Low Emission Climate Change
Void rim: 305 mAHD
Regional Groundwater: 125 mAHD
Water Level (mAHD)
150
140
130
120
110
100
90
80
70
60
50
40
30
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Percentiles
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median


West Pit Lake Salinity
Scenario: **Low Emission Climate Change**
Salinity (mg/L)
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2.0e04
4.0e04
6.0e04
8.0e04
1.0e05
1.2e05
1.4e05
Time (day)
Greatest Result
5% Percentile
95% Percentile
Least Result
75% Percentile
Mean
25% Percentile
Median