



GRANTS LITHIUM PROJECT

Environmental Impact Statement

Appendix I

Groundwater modelling report

Prepared by EcOz

October 2018

Development of a Groundwater Model for the Grants Lithium Project

Final Version 1.0

**PREPARED FOR CORE EXPLORATION LIMITED
BY CLOUDGMS**

CLOUDGMS PTY LTD
ABN 84 166 886 586

3 Wright Street
Edwardstown SA 5039

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Author

Anthony Knapton and Simon Fulton

CloudGMS Pty Ltd

ABN 84 166 886 586

3 Wright Street, Edwardstown

South Australia, 5039

Phone: 0428798665

Email: anthony.knapton@bigpond.com

Executive summary

Introduction

A numerical model was developed to assess groundwater impacts resulting from the proposed development of an open cut lithium mine (Grants Lithium Project - GLP) situated on MLA31726 approximately 22 km west of Berry Springs. The mine is proposed to run for 25 months with the pit void being left to form a pit lake post closure.

Model Classification

Based on the classification scheme presented by Barnett et al. (2012), the groundwater model presented herein is deemed to be Class 2 for much of the study area. A Class 2 model is suitable for "providing estimates of dewatering requirements for mines and excavations and the associated impacts".

Hydrogeological conceptual model

The GLP is located in the Burrell Creek Formation which typically comprises heavily weathered shale, siltstone and strongly foliated phyllite with lenses of quartz pebble conglomerate. The Burrell Creek Formation is overlaid by a thin veneer of Cenozoic sediments mainly comprising laterite, gravel, sand and clay. The Burrell Creek Formation is the principal aquifer beneath the study area, it is a fractured and weathered rock aquifer with minor groundwater resource. Bore yields are typically less than 0.5 L/s with groundwater intersected in the base of the weathered zone and where drilling intersects fracture zones. Minor aquifers also occur within the Cenozoic sediments, these are more permeable than the Burrell Creek Formation but have limited saturated thickness. Across the GLP site the groundwater flow direction is to the north-east. Groundwater flows away from slightly elevated areas in the south toward lower lying and incised drainage lines in the north. Depth to groundwater ranges from less than 1 m in the wet season up to 5.5 m in the dry season. Seasonal fluctuations in groundwater is in the order of 3 - 5 m. Diffuse recharge, where water is added to groundwater through the percolation of rainfall over a widely distributed area, is expected to be the dominant recharge mechanism. Evapotranspiration and diffuse discharge are likely to be the key groundwater discharge mechanisms. Discharge will also occur to ephemeral

Executive Summary

drainage lines both on and offsite but volumes are expected to be relatively small due to the low hydraulic conductivity of the aquifer. Groundwater quality in the deeper weathered Burrell Creek is typically fresh (<300 EC) with a neutral pH. Groundwater in the shallow laterite and alluvial sediments is very fresh (<25 EC) and has similar chemical characteristics to rainfall.

With the exception of an abandoned mining bore at Observation Hill dam, there are no registered groundwater bores or groundwater users within 13 km of the GLP site. There are no known groundwater dependent ecosystems (GDEs) on MLA31726 with the area mapped as having a low potential for terrestrial GDEs. There are no mapped areas with moderate-high potential for terrestrial GDEs within 2 km of MLA31276.

Model platform

The numerical model has been developed in using FEFLOW (Finite Element subsurface FLOW and transport system v 7.011) modelling code developed by DHI-WASY GmbH (Diersch, 2015). This code is an industry standard groundwater modelling tool used by many jurisdictions to study groundwater level behaviour within groundwater systems.

Parameter estimation

Results of calibrated model parameters (recharge, hydraulic conductivity, specific yield) were consistent with background ranges determined from field studies and literature. Model convergence and the model water balance were within guideline target criteria. The model had acceptable qualitative performance with modelled groundwater levels in reasonable agreement with observed values and longer term groundwater trends generally reproduced. The model reports a final standard error (RMS) of 0.73 m, the scale root mean squared (SRMS) is 6% and slightly above the guideline target of 5%. The SRMS value is considered reasonable given the dependence of groundwater levels on SRTM ground elevations, which can have considerable error.

Predictive scenarios

Predictive scenarios were modelled to investigate impacts for the life of mine (2 years) and post closure (70 years).

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Life of mine (2 years) 2018 – 2020 - Numerical model scenarios were run to assess groundwater impacts and pit inflows over the 25 month mining period. At the end of the mining dewatering from the base of the pit results in the development of a drawdown cone in the surrounding Burrell Creek Formation aquifer. The predicted drawdown cone extends approximately 1 km from the pit lake. It is not predicted to affect groundwater levels beneath ephemeral drainage lines or impact groundwater levels outside the mining lease.

Groundwater inflow into the pit is expected to peak at 2000 kL/day (23 L/s) during the 2019 wet season before declining to around 1600 kL/day (18.5 L/s) for the remainder of the life of the mine.

Post Closure (70 Years) 2020 – 2090 - Numerical modelling of the mine site post closure predicts that the pit lake will fill slowly over a period of roughly 50 years before the water level stabilises at 12 - 13 mASL or around 7 - 8 m below the existing land surface. The pit lake is categorised as a groundwater sink using the classifications in the Western Australian interim guidance on pit lake assessments (DMP, 2015). A pit lake operating as a groundwater sink has an average lake level that is lower than the surrounding watertable resulting in the creation of groundwater gradients toward the pit lake and groundwater discharge into the pit lake. As the pit lake will predominantly operate as a groundwater sink the water quality in the lake is not expected to influence the groundwater quality in the surrounding aquifer.

The formation of the pit lake will alter the groundwater flow regime around the mine site resulting in a decline in the watertable of around 5 m in the pit area and a decline of 0.5 m at 500 m distance from the pit lake. The area where groundwater levels are predicted to change is largely coincident with the proposed mine footprint. No change in the watertable surface is predicted at the ephemeral water courses that drain the mine site or beyond the boundary of the mining lease.

Mass balance modelling based on the pit lake water budget from the numerical modelling predicts that 70 years after mine closure the Electrical Conductivity (EC) of the pit lake water will be between 50 - 300 $\mu\text{S/cm}$. The final pit lake EC is heavily dependent on the water quality of the groundwater inflow. Water quality samples from neighbouring Observation Hill Dam and an abandoned BHP pit 5 km south of

Executive Summary

the GLP range from 19 - 26 $\mu\text{S}/\text{cm}$ and suggest the final pit lake EC is likely to be at the lower end of the predicted range.

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Abbreviations and acronyms

DENR	Department of Environment and Natural Resources
GIS	geographical information system
GL	gigalitre (10 ⁹ litres)
kL	kilolitre (10 ³ litres)
km	kilometre
km ²	square kilometre
L/s	litres per second
m ² /d	metres squared per day
m ² /d	metres squared per day
m ³	cubic metre
m ³ /d	cubic metres per day
m ³ /s	cubic metres per second
ML	megalitre (10 ⁶ litres)
ML/a	megalitre per year
mAHD	metres above Australian Height Datum
mBGL	metres Below Ground Level
mm	millimetre
mm/d	millimetre per day
pF	log scale for representing soil matric potential
RMS	root mean square
SRMS	scaled root mean square
SRTM	Shuttle Radar Topographic Mission
T	Transmissivity (metres squared per day)

1 Introduction

1.1. Background

Core Exploration Limited proposes to develop Grants Lithium Project (GLP), an open-cut lithium mine targeting pegmatite deposits on Mining Lease (Application) (MLA) 31726 located 24 km south of Darwin. The ore will be either crushed, screened and shipped directly or processed through a water based Dense Media Separation to produce a higher lithium concentration. The proposed life of the mine is two to three years with operations planned as follows: pre-strip (months 1-7), operation (months 8-25), rehabilitation and closure (months 26-30).

EcOz Environmental Consultants (EcOz) were engaged by Core Exploration to develop the Mining Management Plan and obtain Mining Authorisation through the Northern Territory Department of Primary Industries and Resources (DPIR). Part of the MMP process required the development of a “comprehensive groundwater model for the site, at an appropriate scale so as to identify potential impacts, including regional/off site impacts” . In January 2018 Simon Fulton and Anthony Knapton (CloudGMS) were engaged to develop a numerical groundwater model to address the MMP requirements. On May 3, the Northern Territory Environmental Protection Agency (NTEPA) decided the GLP proposal required assessment at the Environmental Impact Statement (EIS) level. Draft terms of reference (ToR) for the development of the EIS were released in June, 2018. The draft ToR require that the EIS describe the groundwater aquifers and hydrological properties, and provide a predicted hydrological classification of the mine pit lake.

This report documents the development of conceptual and numerical groundwater models for the GLP and the use of this model to assess potential groundwater impacts from the proposed mining development as required under the MMP process. It also provides guidance on specific impacts, information and processes required under the EIS terms of reference.

1.2. Modelling objectives

The objective of the GLP groundwater model is to identify potential impacts to the groundwater system and associated environmental receptors resulting from the development of the proposed lithium mine.

1.3. Modelling study scope of works and modelling process

The modelling study will be completed as a staged approach in accordance with the 2012 Australian Groundwater Modelling Guidelines (Barnett, et al., 2012). A flow diagram of the modelling process is presented in Figure 1-1.

A model should be constructed according to the design, and documented as built. It is reasonable and sometimes essential for the design and construction to change as more is learned about the system and the way it can be represented.

The scope of the groundwater modelling study will include the following major components in accordance with the 2012 Australian Groundwater Modelling Guidelines:

- Collation of available data for the Grants Lithium Mine site;
- Data review and conceptualisation of the groundwater system;
- Groundwater model design and configuration;
- Transient model development and calibration;
- Predictive scenario modelling to assess the potential for mining impacts;
- Predictive uncertainty analysis.

Background

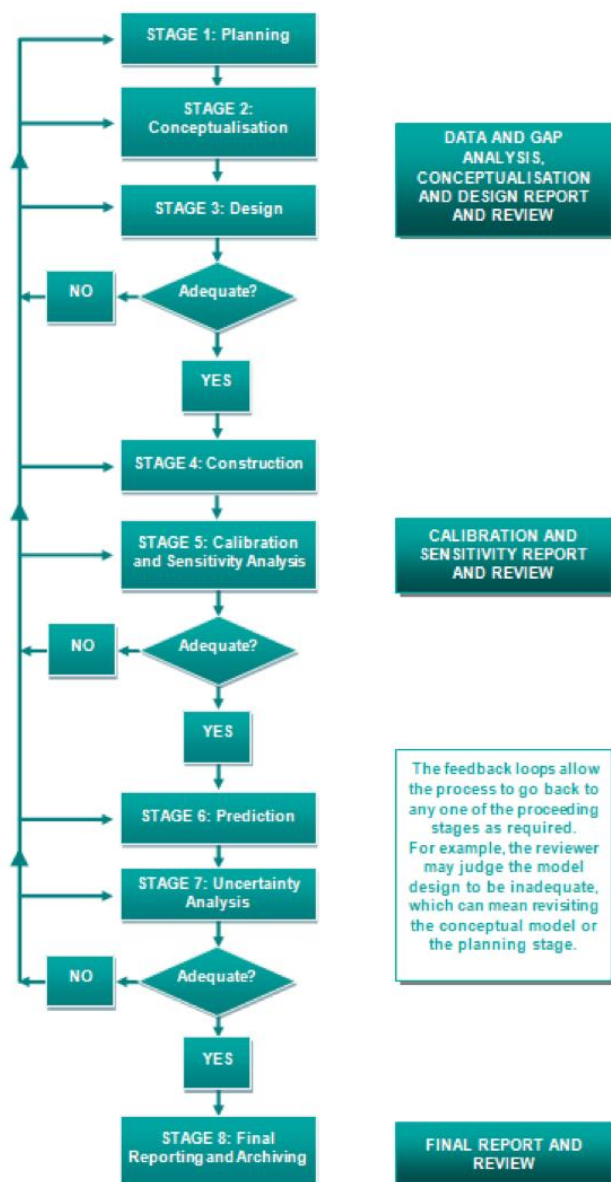


Figure 1-1 Groundwater modelling process after Barnett et al, (2012)

1.4. Model classification

Under the latest national best practice guidelines (Barnett, et al., 2012), the groundwater model presented herein is deemed to be Class 2 with components that are Class 1 and Class 3.

A Class 2 model is suitable for "providing estimates of dewatering requirements for mines and excavations and the associated impacts" (Barnett, et al., 2012). Table 1-1 identifies the classification criteria met by the current model.

Background

Table 1-1 Model classification criteria (after Barnett, 2012)

	Data	Calibration	Prediction	Key indicator	Example of use
Class 3	Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.	Scaled RMS error or other calibration statistics are acceptable.	Length of predictive model is not excessive compared to length of calibration period.	Key calibration statistics are acceptable and meet agreed targets.	Suitable for predicting groundwater responses to arbitrary changes in applied stress or hydrological conditions anywhere within the model domain.
	Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry.	Long-term trends are adequately replicated where these are important.	Temporal discretisation used in the predictive model is consistent with the transient calibration.	Model predictive time frame is less than 3 times the duration of transient calibration.	Provide information for sustainable yield assessments for high-value regional aquifer systems.
	Reliable metered groundwater extraction data is available.	Seasonal fluctuations are adequately replicated where these are important.	Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.	Stresses are not more than 2 times greater than those included in calibration.	Evaluation and management of potentially high-risk impacts.
	Rainfall and evaporation data is available.	Transient calibration is current, i.e. uses recent data.		Temporal discretisation in predictive model is the same as that used in calibration.	Can be used to design water-allocation plans.
	Aquifer-testing data to define key parameters.	Model is calibrated to heads and fluxes.		Mass balance closure error is less than 0.5% of total.	Simulating the interaction between groundwater and surface water bodies to a level of reliability required for dynamic linkage to surface water models.
	Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation. Reliable land-use and soil-mapping data available.	Observations of the key modelling outcomes dataset is used in calibration.		Model parameters consistent with conceptualisation. Appropriate computational methods used with appropriate spatial discretisation to model the problem.	
Class 2	Groundwater head observations are available but may not provide adequate coverage throughout the model domain.	Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domain(s).	Transient calibration over a short time frame compared to that of prediction.	Key calibration statistics suggest poor calibration in parts of the model domain.	Prediction of impacts of proposed developments in medium value aquifers.

Grants Lithium Mine Groundwater Model

Background

Class 1	Bore logs are available but may not provide adequate coverage throughout the model domain.	Long-term trends not replicated in all parts of the model domain.	Temporal discretisation used in the predictive model is different from that used in transient calibration.	Model predictive time frame is between 3 and 10 times the duration of transient calibration.	Evaluation and management of medium risk impacts.
	Metered groundwater-extraction data may be available but spatial and temporal coverage may not be extensive.	Transient calibration to historic data but not extending to the present day.	Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.	Stresses are between 2 and 5 times greater than those included in calibration.	Providing estimates of dewatering requirements for mines and excavations and the associated impacts.
		Seasonal fluctuations not adequately replicated in all parts of the model domain.		Temporal discretisation in predictive model is not the same as that used in calibration.	Estimating distance of travel of contamination through particle-tracking methods. Defining water source protection zones.
	Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information.	No calibration is possible.	Predictive model time frame far exceeds that of calibration.	Model is uncalibrated or key calibration statistics do not meet agreed targets.	Design observation bore array for pumping tests.
	Observations and measurements unavailable or sparsely distributed in areas of greatest interest.	Calibration illustrates unacceptable levels of error especially in key areas.	Temporal discretisation is different to that of calibration.	Model predictive time frame is more than 10 times longer than transient calibration period.	Predicting long-term impacts of proposed developments in low-value aquifers.
	No available records of metered groundwater extraction or injection.	Calibration is based on an inadequate distribution of data.	Transient predictions are made when calibration is in steady state only.	Stresses in predictions are more than 5 times higher than those in calibration.	Estimating impacts of low-risk developments.
	Climate data only available from relatively remote locations.	Calibration only to datasets other than that required for prediction.	Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.	Stress period or calculation interval is different from that used in calibration.	Understanding groundwater flow processes under various hypothetical conditions.
	Little or no useful data on land-use, soils or river flows and stage elevations.			Transient predictions made but calibration in steady state only.	Provide first-pass estimates of extraction volumes and rates required for mine dewatering.
				Model parameters outside the range expected by the conceptualisation with no further justification.	As a starting point on which to develop higher class models as more data is collected and used.
				The model has not been reviewed.	

Criterion met.	Criterion met by current model study at the relevant class
Criterion met through higher model classification.	Criterion met in higher class
Criterion partially met.	Criterion not met by current model study

2 Site Characterisation and Data Sources

2.1. Location

The Grants Lithium Project (GLP), referred to as the study area in this report, is located on MLA31726 approximately 22 km west of Berry Springs and 24 km south of Darwin (see Figure 2-1). MLA31726 covers an area of 770 ha of vacant crown land, the GLP will encompass around 15% (117 ha) of MLA31726.



Figure 2-1 Location of the Grants Lithium Project on MLA31726.

2.2. Climate

Climate data for the GLP study area has been sourced from SILO data drill (<https://www.longpaddock.qld.gov.au/>), a national scale database of climate records for Australia. The SILO data set has been used in preference to individual

Available Data

weather stations in the Darwin area because it provides a continuous rainfall and evaporation record for the study. The SILO data site was located at Latitude, Longitude: -12.65 130.80 (Decimal Degrees), 12°39'S 130°48'E Elevation: 59m.

The study area has an average annual rainfall of 1570 mm and average annual potential evaporation of 2340 mm. Average maximum temperature ranges from 34.1 degrees Celsius (°C) in October and November to 30.8°C in July (Figure 2-2a). July is the coolest month with an average minimum temperature of 18.3°C. Rainfall is concentrated in the wet season (November to March) with around 90% of precipitation occurring over this period. The wettest months are typically January and February with average monthly totals of 382 and 339 mm respectively. Peak potential evaporation generally occurs between September and October, with potential evaporation being lowest during February and March (Figure 2-2b). Average monthly rainfall only exceeds potential evaporation during the wettest months (December-March).

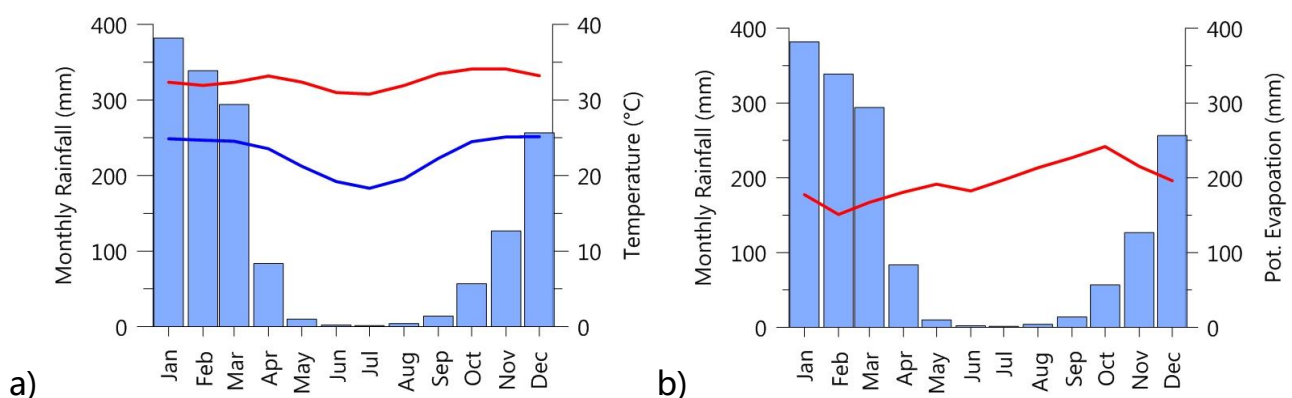


Figure 2-2 (a) Average monthly rainfall compared to average max and min temperatures and (b) average monthly rainfall compared to monthly potential evaporation for the period 1900-2018 (SILO Data Drill).

The rainfall data is presented in Figure 2-3 as annual totals with a trace of mass residual to show long-term trends in the rainfall record.

Available Data

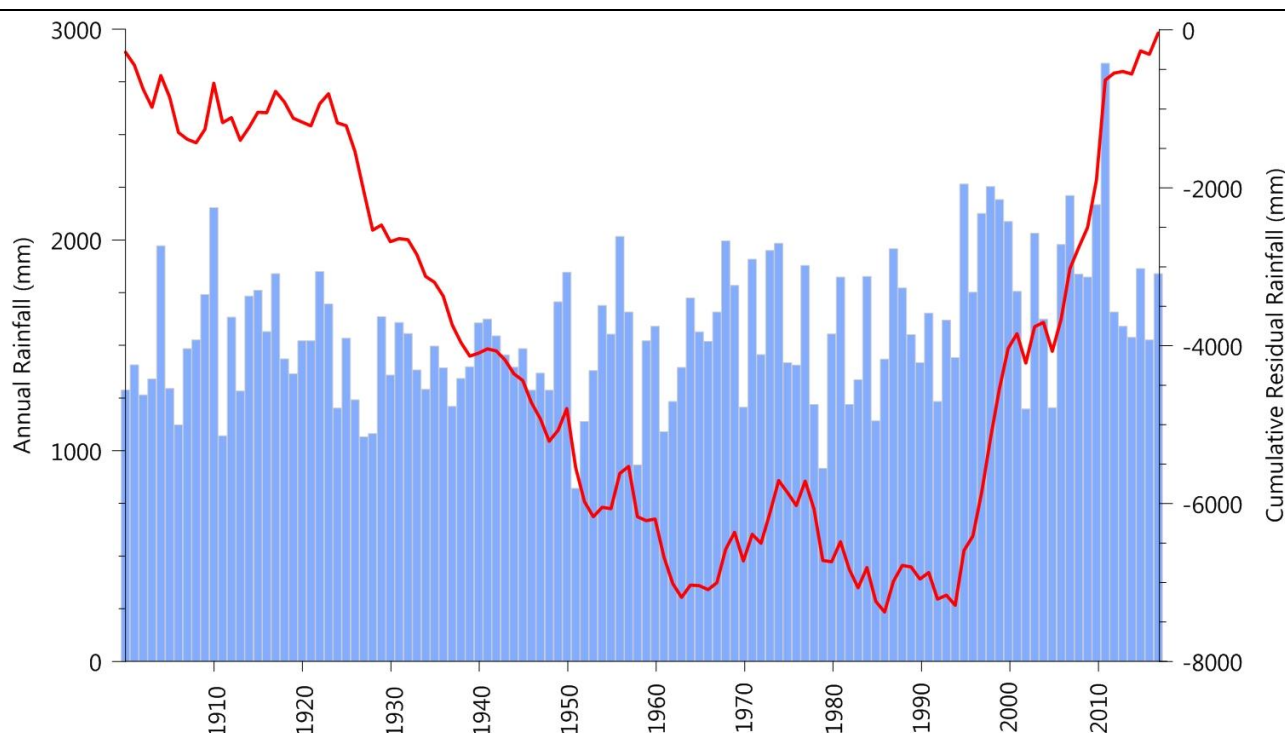


Figure 2-3 Annual SILO rainfall totals with a trace of mass residual to show longer term trends in the rainfall (1900-2018).

2.3. Topography

The topography across the site is subdued and largely flat-lying (Figure 2-4). Subtle rises occur in the south and south-west with the topography falling away gently toward drainage lines in the north and north-east of the study area. Ground elevations range from 35 mAHD in the south to 10 mAHD in the drainage lines in the north of the study area.

The topography for the study area was derived from the National Digital Elevation Model (DEM) 1 Second Hydrologically Enforced product, derived from the National DEM SRTM 1 Second and National Watercourses, Lakes and Reservoirs.

(<http://www.ga.gov.au/elvis/>). The Shuttle Radar Topography Mission (SRTM) Digital Terrain Elevation Data (DTED) are used with the consensus view that it has a minimum vertical accuracy of 9 m absolute error at 90% confidence world-wide and the minimum vertical accuracy for Australia is 6m (Farr, et al., 2007).

The SRTM elevations will impact on the model by introducing uncertainties into the ground elevation in areas where surface water / groundwater interactions occur, particularly as these areas are often associated with dense vegetation. The ground

Available Data

elevation data impacts the areas of surface water / groundwater interaction as the ground surface limits the groundwater level rises in the wet season. Given the inaccuracies in the elevation data it is likely that there may be poor performance regarding matching modelled groundwater elevations with field observed groundwater elevations. However, uncertainties in the SRTM elevation data set will not affect relative water level predictions such as modelled drawdown.

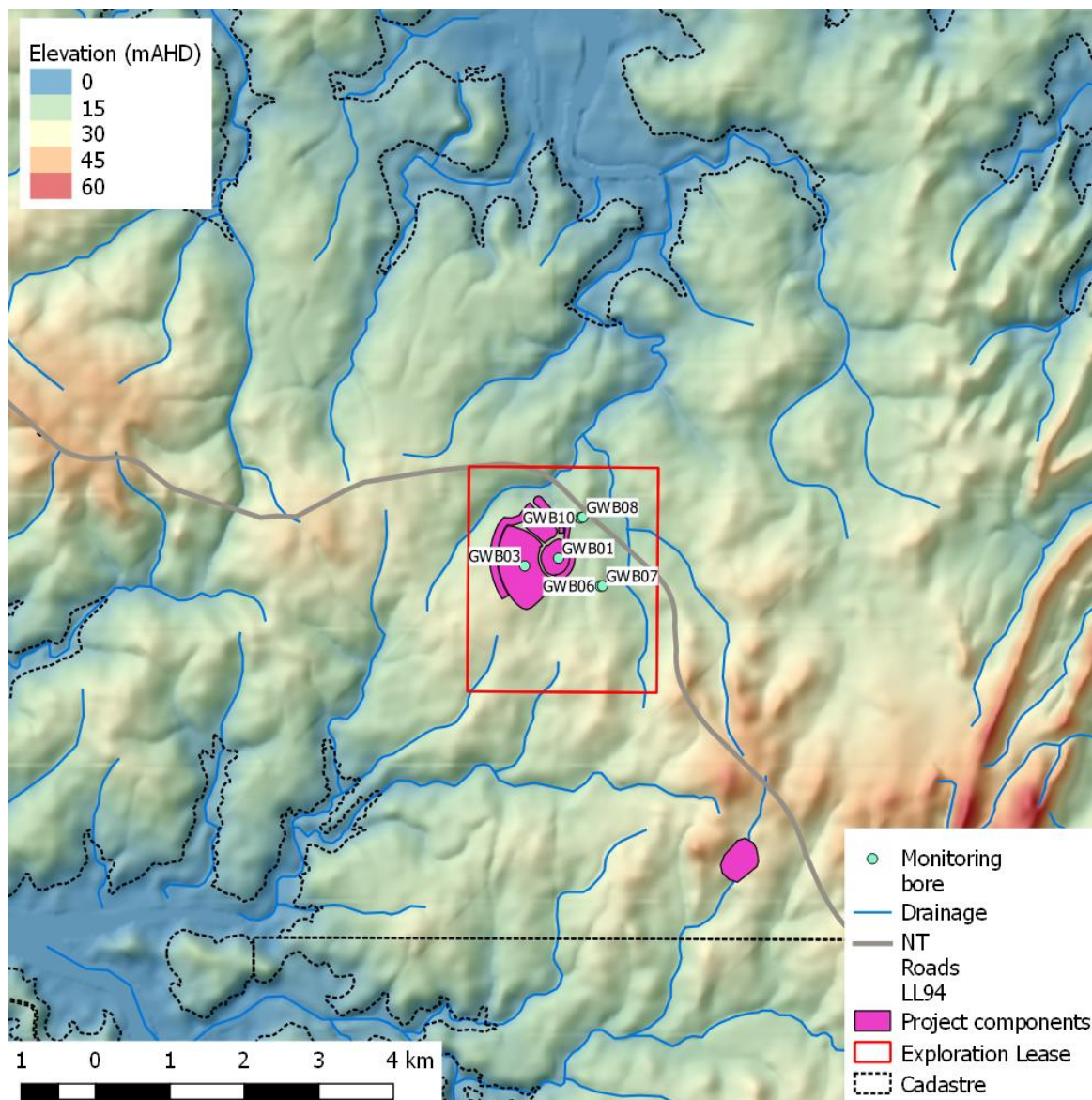


Figure 2-4 Topography of the study area with surface water drainage

2.4. Hydrology

The study area is located in the Finnis River drainage basin within the Timor Sea drainage division and straddles a catchment boundary between the Darwin

Harbour and Bynoe Harbour catchments. There are no permanent water courses in the study area, all drainage lines are relatively small and cease to flow early in the dry season. Runoff from the majority of the site drains north to the Darwin Harbour while a small area in the south-west drains to Bynoe Harbour (Figure 2-4). Drainage within the Darwin Harbour Catchment is to the north via three ephemeral water courses that meet a perennial water course around 1 km north of the study area that drains to Darwin Harbour. All proposed mining activities are located within the Darwin Harbour catchment and do not intersect any drainage lines. Drainage in the south-west is via two ephemeral drainage lines that flow into a tidal inlet in Bynoe Harbour.

2.5. Geology

2.5.1. Regional geology

Regionally, the study area is located within the north-western part of the Pine Creek Geosyncline, a thick sequence of Proterozoic metasediments that overlies Archean basement rocks and underwent extensive folding and uplift between 1870 - 1780 Ma (Pietsch, 1986). After a long hiatus during which significant weathering and erosion occurred a drape of flat bedded Cretaceous and Cainozoic sedimentary formations were deposited over the Proterozoic rocks.

The study area covers most of the northern extremity of a swarm of complex zoned rare element pegmatites which comprise the 55km long by 10km wide West Arm – Mt Finniss pegmatite belt. The main pegmatites in this belt are: Mt Finniss, Grants, BP33, Bilato's (Pickett's), Hang Gong and Bells Mona are up to 300m long and 100m wide.

The Finniss pegmatites have intruded early Proterozoic shales, siltstones and schists of the Burrell Creek Formation which lies on the northwest margin of the Pine Creek Geosyncline. To the south and west are the granitoid plutons and pegmatitic granite stocks of the Litchfield Complex. The source of the fluids that have formed the intruding pegmatites is generally accepted as being the Two Sisters Granite to the west of the belt. The Two Sisters Granite outcrops approximately 3 km to the

west of the study area and is thought to underlie the entire area at a depth of 5-10 km.

2.5.2. Lithology

The surface geology for the study area and surrounding region is presented in Figure 2-5. This coverage is a simplified version of 1:250 000 scale maps published by Geoscience Australia and the Northern Territory Geological Survey.

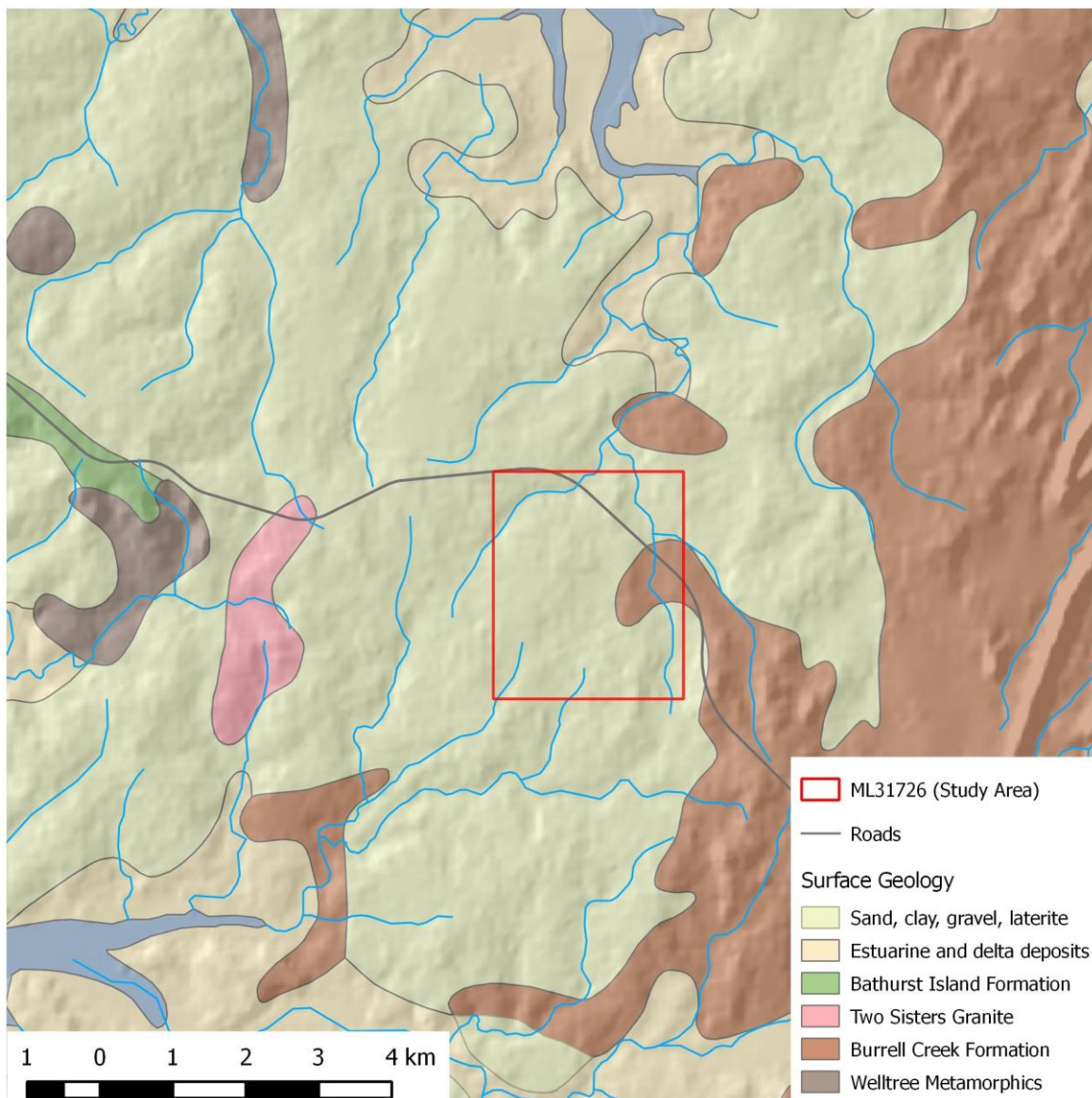


Figure 2-5 Surface geology derived from the 1:250000 scale geology coverage.

The majority of the study area is covered by a thin veneer of Cainozoic sediments - mainly composed of laterite gravel, sand and clay and typically less than 5 m in thickness. The Burrell Creek Formation outcrops in the east of the study area and

sub-crops at shallow depths across the rest of the site. The Burrell Creek Formation is mainly composed of very weathered light grey to dark grey, buff, mauve and weakly colour-banded shale, siltstone and phyllite typically brown, strongly foliated with lenses of quartz pebble conglomerate. The weathering profile on the Burrell Creek Formation ranges from around 30 – 50 m across the study area. The geology shows the following typical horizons associated with a lateritic weathering profile:

- Soil
- Duricrust – indurated cemented material with various fabrics and cements.
- Mottled zone – composed of mottled (different coloured patches) material generally red/brown within grey/white matrix
- Saprolite - is very highly weathered to moderately weathered rock, easily broken, retains rock fabric
- Saprock - is slightly weathered rock which can't be broken in the hand and retains rock fabric
- Fresh rock - shows no signs of weathering

2.5.3. Geological structure

Phyllite is a foliated rock, and based on the discussion with Core personnel, it is understood that the foliation is striking approximately North-South (~010-015°). This is consistent with bedding trends shown in the Bynoe 1:100 000 surface geology (Pietsch, 1986). An approximate assessment using core photographs and survey data of exploration drill holes indicate that the foliation is sub-vertical (potentially west dipping at 80-90°).

A review of the Bynoe 1:100 000 surface geology does not reveal any mapped faults or significant geological structures in the study area.

2.6. Hydrogeology

The Burrell Creek Formation forms the principal aquifer beneath and in the immediate surrounds of the study area. It is categorised on the Cox Peninsula Hydrogeology Map (NRETA, 2008) as a fractured and weathered rock aquifer with minor groundwater resources. Typical bore yields are less than 0.5 L/s largely due to the lack of primary porosity and open fracturing within the Burrell Creek

Formation – this mapped category has the lowest groundwater resource potential in the Greater Darwin region. Higher yields have been recorded in the Burrell Creek Formation where drilling intersects fracture zones or bands of quartz veining. Groundwater is typically intersected within and at the base of weathering zone. The unweathered Burrell Creek Formation is less permeable, though groundwater intersections have been observed where drilling intersects discrete fracture zones within the formation. There is also potential for minor aquifers in the Cenozoic Formations (sand, clay, gravel and laterite) in areas with thicker alluvial cover (i.e. along drainage lines) or where the laterite profile is more extensive.

2.6.1. Previous studies

No hydrogeological investigations or detailed groundwater studies have been conducted in the study area with the exception of the preliminary groundwater investigation for the GLP undertaken by GHD in 2017. The investigation program involved the drilling and construction of six monitoring bores, hydraulic testing (recovery and slug tests) and water quality sampling.

The GLP site falls within regional hydrogeological and water resource mapping completed by DENR Water Resources Division on the Bynoe 1:100 000 map sheet in 2004 and the Cox Peninsula in 2008 (DIPE, 2004; NRETA, 2008). There are several groundwater investigations in the Greater Darwin region that provide context on groundwater occurrence in the Burrell Creek Formation, these include:

- Karp (2010) - In 2010 the current DENR Water Resources Division (WRD) reported on results from investigation drilling conducted in the Burrell Creek Formation near the proposed city of Weddell (Karp, 2010). They report a yield range of < 0.1 – 2 L/s (median 0.3 L/s) from seven investigation bores constructed in the Burrell Creek Formation. All bores encountered groundwater within fractured and weathered rocks at the base of the weathering zone. Although two bores recorded yields of 2 L/s, Karp (2010) suggests that 0.5 L/s is more characteristic of the longer term yield for bores constructed in the Burrell Creek Formation.
- Karp (2009) – WRD completed a groundwater investigation in the suburbs of Johnston and Zuccoli to assess water potential in the area. Six bores were drilled targeting a quartz ridge within the Burrell Creek Formation (shown as

Acacia Gap Quartzite on the geology maps), airlift yields ranged from < 0.1 – 9 L/s. The investigation identified a narrow aquifer associated with the fractured quartz ridge, elsewhere only minor and localised aquifers were intersected in siltstones of the Burrell Creek Formation.

- Verma (1982) – WRD completed a groundwater investigation on the Cox Peninsula to the north-west of the GLP site between 1979 and 1982. The study involved a geophysics and investigation drilling program. Two minor aquifers were identified: a shallow aquifer in the Bathurst Island Formation (Cretaceous) which extended into the weathering zone of the underlying Proterozoic rocks and a deep structurally controlled aquifer in the Proterozoic Formations. Bore yields ranged from 0.1 – 1.5 L/s indicating the aquifers have poor water supply potential. The marginal nature of the aquifers is consistent with groundwater drilling observations from Proterozoic rocks (Burrell Creek Formation) at the GLP site.
- Inpex EIS Hydrology and Hydrogeology of Blaydin Point (2009) – URS completed detailed groundwater investigations on the Inpex Gas site at Blaydin point and drilled around 10 investigation bores into the Burrell Creek Formation. All bores were constructed to screen the shallower Cenozoic and Cretaceous sediments so hydraulic testing and monitoring results have limited application to the GLP site.

2.6.2. Previous groundwater modelling studies

No published groundwater studies have been identified that cover the study area.

2.6.3. Hydrostratigraphic units

The geological formations within the study area have been combined into three hydrostratigraphic units (HSU) for inclusion in the groundwater model. An HSU is a geological formation or part of a formation with similar hydrogeological properties or characteristics. The hydrostratigraphic units defined for the GLP site are presented below in Table 2-1.

Table 2-1 Hydrostratigraphic units

Age	Name	Lithology	Hydrogeology	HSU
Quaternary		Silty sand and gravels	Permeable, but mostly above water table.	
Proterozoic	Highly to moderately weathered Burrell Creek Formation	Saprolite (Phyllite) Mostly silt, clayey and minor sand.	Mostly low permeability.	1
Proterozoic	Slightly weathered Burrell Creek Formation	Saprock (Phyllite) mostly clayey silt with rock fragments.	Mostly low permeability. A few fractured aquifers, but yields less than 2 L/s.	2
Proterozoic	Fresh Burrell Creek Formation	Blue grey fresh Phyllite.	Low permeability, locally fractured rock.	3

The HSUs have been incorporated into a hydrostratigraphic model which was developed using the Leapfrog Hydro geological modelling software. Leapfrog Hydro provides a flexible platform for incorporating lithological information and generating hydrostratigraphic contacts from a variety of sources including surface geological mapping, lithological logs and surfaces generated from geophysical surveys. Each HSU in the Leapfrog model is represented as a three-dimensional object that can be continuous or discontinuous within the model domain. The hydrostratigraphic model forms the basis of FEEFLOW model grid geometry, this is discussed further in Section 4.3.

2.6.4. Aquifer hydraulic properties

The available aquifer parameters relevant to the development of the groundwater model are discussed in the following sections.

AQUIFER TRANSMISSIVITY / HYDRAULIC CONDUCTIVITY

Six monitoring bores were constructed on site in 2017 with four bores constructed in slightly weathered to fresh Burrell Creek Formation (HSU3) and two shallow bores constructed in laterite and highly weathered Burrell Creek Formation (HSU1). Recovery and slug tests were completed on the installed monitoring bores, hydraulic conductivity results from GHD (2017) are summarised in Table 2-2.

Table 2-2 Summary of monitoring bore hydraulic conductivity test results (source GHD, 2017)

BORE ID	SCREENED INTERVAL (mBGL)*	SCREENED FORMATION	K (m/day) RECOVERY TEST	K (m/day) SLUG TEST
GWB01	88 - 154	Fresh Burrell Creek Formation	0.03	0.004
GWB03	50 - 62	Fresh Burrell Creek Formation	0.012	0.003
GWB06	6 – 12	Clay/highly weathered shale	0.005^	0.009^
GWB07	49 – 61	Fresh Burrell Creek Formation	0.009	0.024
GWB08	47 – 59	Slightly weathered to fresh Burrell Creek Formation	0.16	0.022
GWB10	0.5 – 6	Laterite	1.7	0.068

^ Test results for GWB06 are not considered representative of the laterite/highly weathered zone as this bore was not adequately developed.

* metres below ground level

The hydraulic conductivity (K) for the bores constructed in the lightly weathered to fresh Burrell Creek range from 0.003 – 0.16 m/day. The K for the bore constructed in the laterite ranges from 0.07 – 1.7 m/day, note that the test results for shallow monitoring bore GWB06 have been excluded as the bore was not adequately developed. The results of the tests indicate that the upper weathered rocks are more permeable than the fresh rocks.

STORAGE COEFFICIENTS

Specific yield is defined as the volume of water that will drain under gravity from a unit volume of rock over a long period of time. The specific yield is best estimated from the response to long-term pumping, however, no such information is available for the Burrell Creek Formation. Values typical of weathered and fractured rocks have been adopted (~0.01), these are consistent with values adopted for the numerical modelling of the Mt Todd Gold Project (GHD, 2013) which is also located in the Pine Creek Geosyncline and models the Burrell Creek Formation.

2.6.5. Depth to Groundwater and Water Level Fluctuation

Manual groundwater level monitoring has been undertaken on the GLP observation bores since they were installed in the dry season of 2017. Shallow laterite bore GWB10 has also had a logger installed since June 2017. Hydrographs for all bores are provided in Appendix A.

Groundwater levels in the deeper weathered Burrell Creek Formation (GWB01, GWB03, GWB07, GWB08) range from 0.5 to 2.1 mBGL in the wet season and from

3.1 – 5.5 mBGL in the dry season (see Figure 2-6). All bores show an increase in groundwater level in response to wet season rainfall and a gradual decline in water levels through the dry season. The seasonal change in water levels in the Burrell Creek Formation ranges from 2.3 – 3.4 m.

Groundwater levels in the shallow laterite aquifer (GWB10) range from close to 1 m artesian during the wet season to 3.5 m during the dry season (Figure 2-6). GWB10 is located in a swamp area subject to inundation over the wet season and rapidly to rainfall suggesting the laterite aquifer it is highly connected with surface drainage at this location. The response in GWB06, constructed in weathered clay to 18 m, is similar to the deeper Burrell Creek Formation bore with a seasonal water level fluctuation in the order of 3 m.

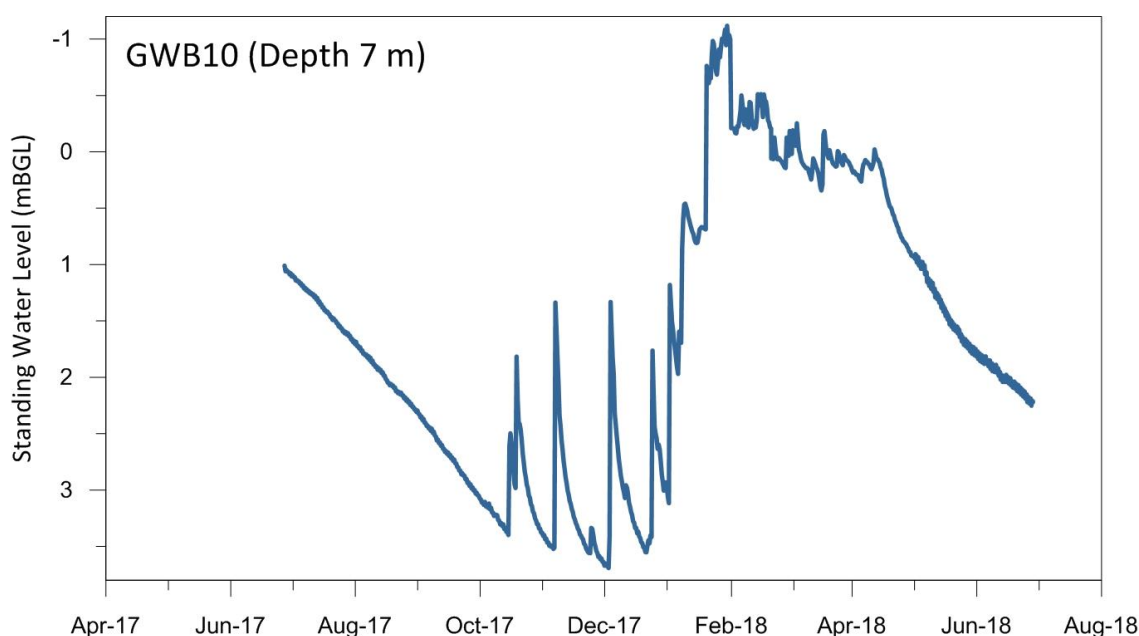


Figure 2-6 Hydrograph for shallow laterite bore GWB10

2.6.6. Groundwater Flow Direction

Routine groundwater level monitoring has been undertaken on the GLP observation bores since they were installed in the dry season of 2017. The bores were surveyed to mAHD (metres Australian Height Datum) using a Trimble RTX Differential GPS. The survey heights have a horizontal precision ranging from 0.01 – 0.18 m and a vertical precision of 0.03 – 0.34 m. Water levels from 20 February 2018 (wet season) and 28 June 2018 (dry season) are presented in Table 2-3 along with the reduced groundwater level (RWL). This data has been used to generate wet

Available Data

season and dry season potentiometric surfaces for the immediate area around the pit and proposed project components (Figure 2-7). Note that the potentiometric surface excludes the shallow nested bores GWB06 and GWB10.

Table 2-3 GLP monitoring bore groundwater levels: 20 Feb 2018 and 28 June 2018

BORE ID	SCREENED INTERVAL (mBGL)*	Elevation Ground Level (mAHD)	SWL 20/02/18 mBGL	SWL 28/06/18 mBGL	RWL 20/02/18 mAHD	RWL 28/06/18 mAHD
GWB01	88 - 154	21.80	2.12	5.54	19.56	16.14
GWB03	50 - 62	23.60	0.5	3.19	22.97	20.29
GWB06	6 – 12	19.29	0.14	2.99	19.02	16.18
GWB07	49 – 61	19.58	0.98	3.66	18.47	15.80
GWB08	47 – 59	15.30	0.77	3.08	14.45	12.10
GWB10	0.5 – 6	14.96	0.21	2.12	14.61	12.72

Figure 2-7 shows that the local flow direction is north to north-east across the site. Groundwater levels are 2-3 metres higher in the wet season surface, however, the general groundwater flow pattern does not change seasonally. There is no information (bore data) to determine regional groundwater flow directions. However, the watertable aquifer typically represents a subdued reflection of the land surface so it can be expected that regionally groundwater will flow to the north toward Darwin Harbour, and locally will flow from the more elevated rises toward the lower lying incised drainage lines.

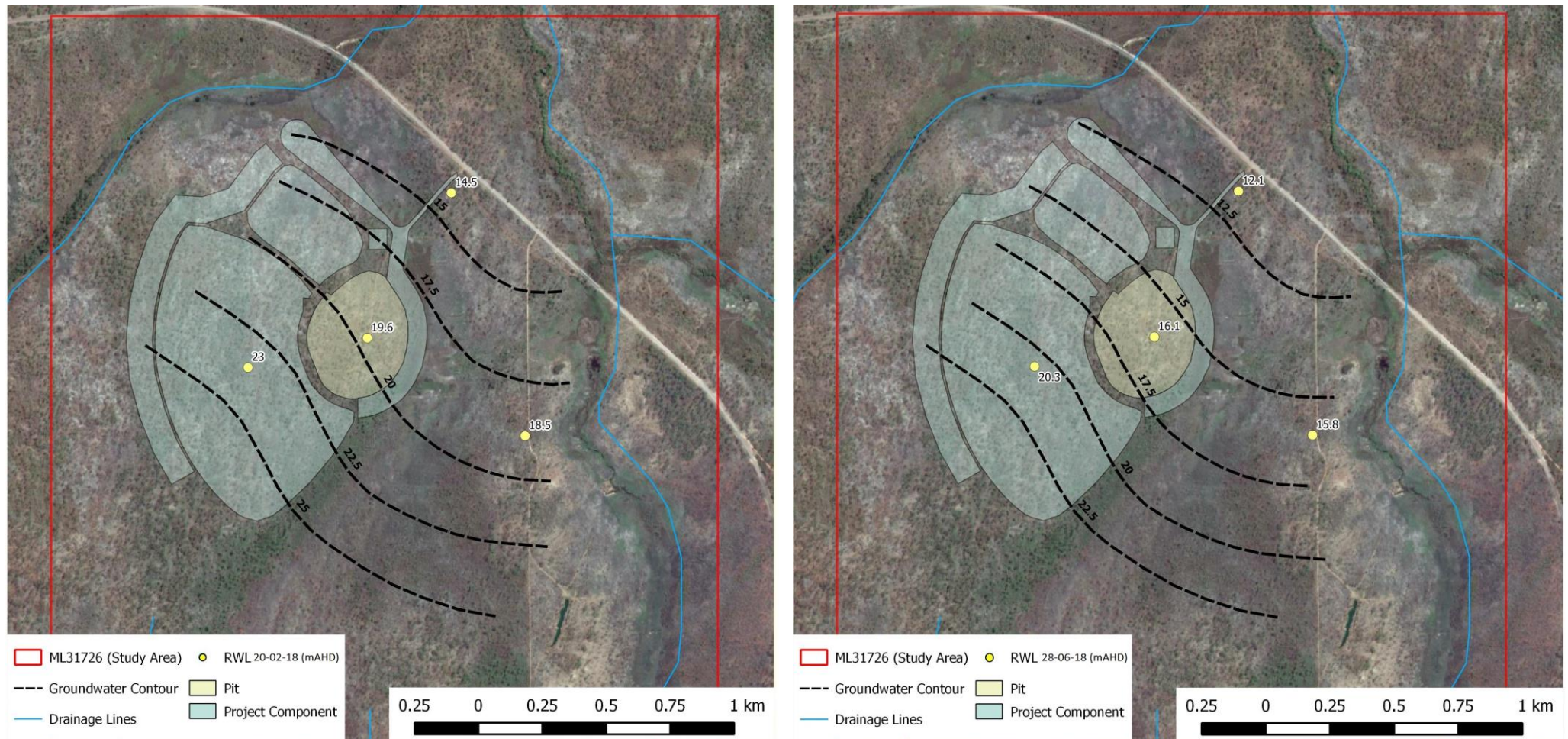


Figure 2-7 GLP mine site potentiometric surfaces relative to mAHD (a) Wet season (20/02/2018) (b) Dry season (28/06/2018)

2.6.7. Vertical groundwater gradients

Two nested bore sites were installed during the initial GLP groundwater investigation (GHD, 2017):

- Observation bores GWB06 (shallow) and GWB07 (deep) are located south-east of the proposed pit with screened intervals at 6 - 12 mbgl and 50 - 62 mbgl respectively.
- Observation bores GWB10 (shallow) and GWB08 (deep) are located north of the proposed pit with screened intervals at 0.5 – 6 mbgl and 47 – 59 mbgl respectively

Both nested sites display a downward gradient of 0.4 – 0.6 metres head difference between the shallow bores and the deep bores. Although the magnitude changes slightly the direction of the groundwater gradient remains constant throughout the year.

Vertical gradients provide insight into groundwater flow processes and downward gradients within the watertable aquifer are indicative of a recharge zone, which is consistent with the GLP conceptual model of distributed diffuse recharge occurring across the site in response to wet season rainfall.

Nested site GWB10/GWB08 is located in a lower lying area that is subject to inundation during the wet season. The constant downward groundwater gradient indicates that the ponding that occurs at this site during the wet season is driven by overland flow and poorly developed surface drainage rather than groundwater discharge.

2.6.8. Groundwater quality

Three groundwater sampling rounds have been undertaken on the six GLP monitoring bores: an initial event after bore construction (June 2017) followed by wet season and dry season sampling events in January and May 2018 respectively.

The groundwater quality in the deep monitoring bores (screening slightly weathered to fresh Burrell Creek Formation) is neutral to slightly acidic (pH 6.4 – 7.2)) and fresh with an EC range of 168 – 280 $\mu\text{S}/\text{cm}$. There are no apparent spatial trends in EC between the bores or temporal trends between sampling events.

Groundwater quality in the two shallow bores screening laterite/weathered Burrell Creek varies significantly. The groundwater quality in GWB10 is very fresh (EC 20 – 25 $\mu\text{S}/\text{cm}$) and mildly acidic (5 – 5.2 pH), results are characteristic of rainfall. The bore has a very shallow screened interval (0.5 – 6 m) which suggests the shallow groundwater is well connected with surface drainage at this location - though the bore construction may also be influencing the water quality results as the surface casing is only installed to a depth of 0.5 m. Monitoring bore GWB06 is constructed in clay with a screened interval of 6 – 12 m, groundwater quality in this bore is slightly brackish with an EC of 2000 – 2560 $\mu\text{S}/\text{cm}$, is unusually alkaline with a pH of 11.5 and has elevated calcium and alkalinity. A review of the completion report (GHD, 2017) indicates that this bore was not adequately developed and is contaminated with cement, as such water quality results from GWB06 are not considered representative of the broader groundwater quality across the site.

Water quality samples for the 2018 sampling events have been analysed against the ANZECC 2000 water quality guideline for 95% freshwater ecosystem protection. The arsenic concentration exceeds guideline values in all four deeper bores (GWB01, GWB03, GWB07, GWB08), copper and zinc concentrations exceed guideline values in GWB10. All bores (excluding GWB06) exceed nutrients guidelines for Ammonia and Total Phosphorus, GWB10 also exceeds the Nitrate and Nitrite guideline for 2018 dry season sampling event. All other dissolved metal and nutrient concentrations are below guideline values.

2.7. Existing groundwater users

All existing bores and groundwater users within 15 km of the GLP proposed pit were identified using NRMaps (DENR, 2018), results are summarised in Table 2-4. No existing groundwater users have been identified within 13 kilometres of the GLP pit. The only registered bore in the vicinity of the study area is RN023177 located 4 km to the south-east of the proposed GLP pit. RN023177 is an abandoned production bore located 600 m north of Observation Hill dam. The bore was drilled in the 1984 as a water supply for the Greenex Observation Hill tin and tantalite treatment plant. The closest groundwater users (active bores) are located on the Cox Peninsula Road approximately 13 km east of the GLP pit.

Table 2-4 Registered bores in the vicinity of the GLP study area

BORE ID	Easting GDA94 Z52	Northing GDA94 Z52	Distance from GLP Pit (km)	Use	Comment
RN023177	695330	8595810	3.9	Production	Abandoned Greenex mine bore
RN038217	688884	8586501	13.2	Production	Domestic
RN024936	704730	8592610	13.3	Production	Domestic
RN021574	685830	8610310	13.4	Investigation	NTG investigation bore
RN024254	687130	8586960	13.4	Production	Dogs Mine Bore
RN036421	688271	8586122	13.8	Production	Domestic
RN030887	703516	8589291	14.3	Production	Agriculture and domestic
RN035753	705585	8591673	14.5	Production	Agriculture

2.8. Groundwater dependent vegetation

Groundwater dependent ecosystems have been identified using the Groundwater Dependent Ecosystems Atlas (Bioregional Assessment Programme (2016) National Groundwater Dependent Ecosystems (GDE) Atlas. Bioregional Assessment Derived Dataset. Viewed 22 May 2018,

<http://data.bioregionalassessments.gov.au/dataset/e358e0c8-7b83-4179-b321-3b4b70df857d>).

The terrestrial GDE layer expresses the potential for groundwater and mapped vegetation communities to interact. It shows the vegetation communities that interact with groundwater from the watertable or in the capillary zone. GDE classes in the study area are presented below in Figure 2-8. The terrestrial GDE layer shows that there is low potential for GDE to occur within the study area.

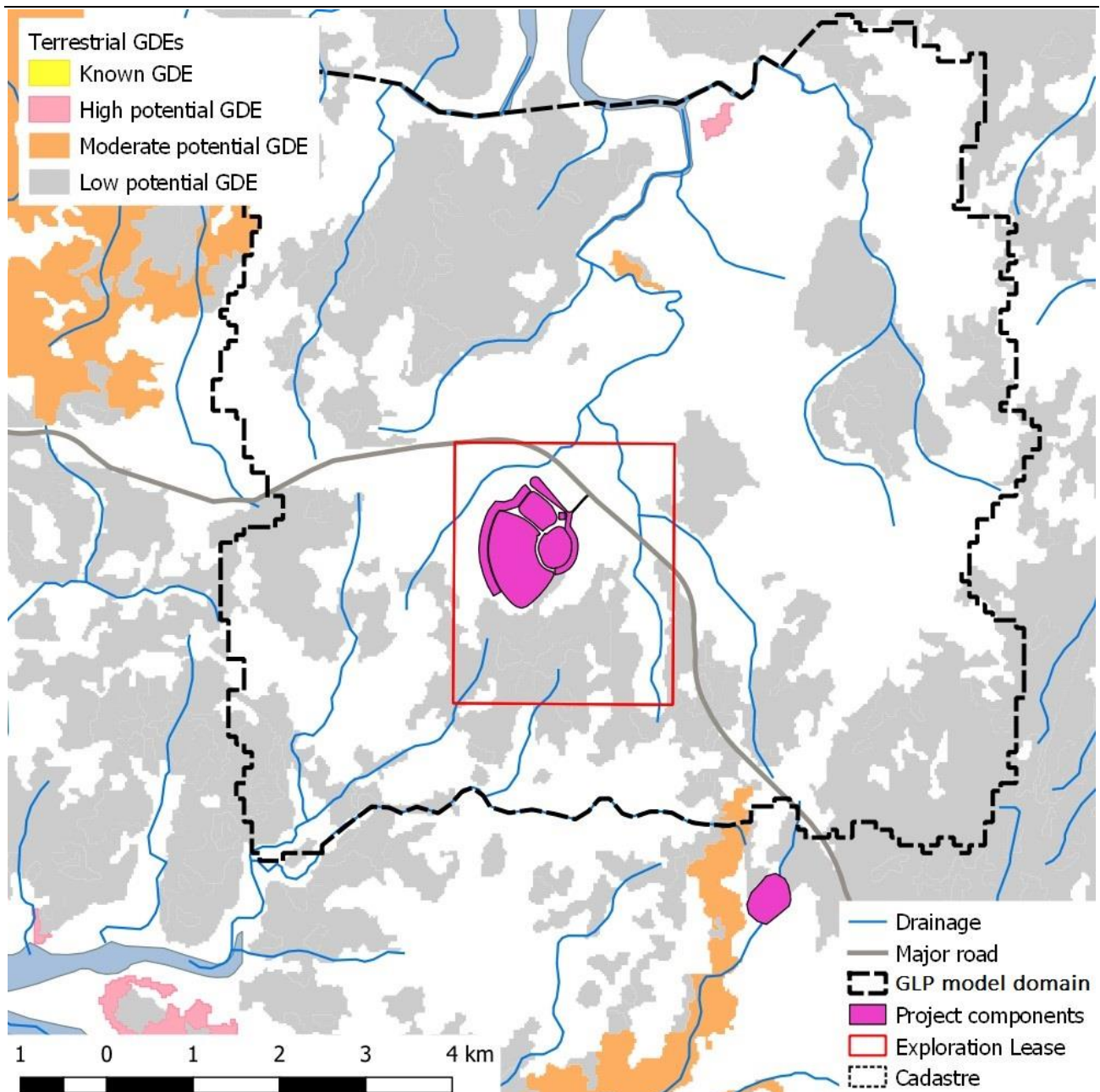
Conceptual Model

Figure 2-8 GDE classes within and surrounding the study area.

2.9. Mining Activities

2.9.1. Final pit shell geometry

Core are proposing to mine the lithium ore via an open cut mine. The approximate dimensions of the final pit are 500m x 350m x 150m (L x W x D) (source GLP NOI, 2017), with a projected a planar area of 14 Ha. At the end of the life of the mine the pit will left intact to form a pit lake.

2.9.2. Pit excavation schedule

The Life of Mine (LoM) is expected to be 2-3 years. A preliminary top down mine schedule has the pit being mined over a period of 25 months (refer Figure 2-9). Ore is expected to be intercepted at month eight in the schedule. Mining will occur in three phases:

- The Pre-strip months 1-7 removal of oxide waste and oxidised pegmatite waste
- Operation: months 8-25 Mining of pegmatite ore body and adjacent 'fresh' waste and processing / transport of product.
- Rehabilitation & closure: months 26-30 Rehabilitation & closure



Figure 2-9 Grants Lithium mining schedule (source GLP NOI, 2017)

Based on the mining schedule (Figure 2-9) a schedule of pit shells was developed. The pit shells are applied to the model in monthly steps. They were developed using the final pit shell as a starting point and assigning an elevation for the base of the pit at each monthly time step - these elevations are extrapolated from the extracted volume identified in the mine schedule. This results in a pit that initially covers the entire footprint of the final mine before developing downwards to the

Conceptual Model

final pit shell in monthly time steps. The pit shell schedule is presented below in Table 2-5.

Table 2-5 Grants Lithium pit schedule

MONTH	PIT BASE RL [mAHD]	MONTH	PIT BASE RL [mAHD]
1	16.0	13	-41.0
2	11.5	14	-45.0
3	7.0	15	-49.0
4	2.0	16	-54.0
5	-3.0	17	-59.0
6	-9.0	18	-65.0
7	-15.0	19	-72.0
8	-22.0	20	-80.0
9	-25.5	21	-89.0
10	-29.0	22	-100.0
11	-33.0	23	-117.0
12	-37.0	24	-150.0

2.9.3. Pit void volume / area relationships

The IfmLake module, which is used to model the pit lake development post closure (see Section 4.3.5), requires an elevation-volume relationship describing the pit void volume for a given pit-lake water level. The elevation – volume and elevation – area relationships for the GLP pit is presented in Figure 2-10 a) and Figure 2-10) respectively.

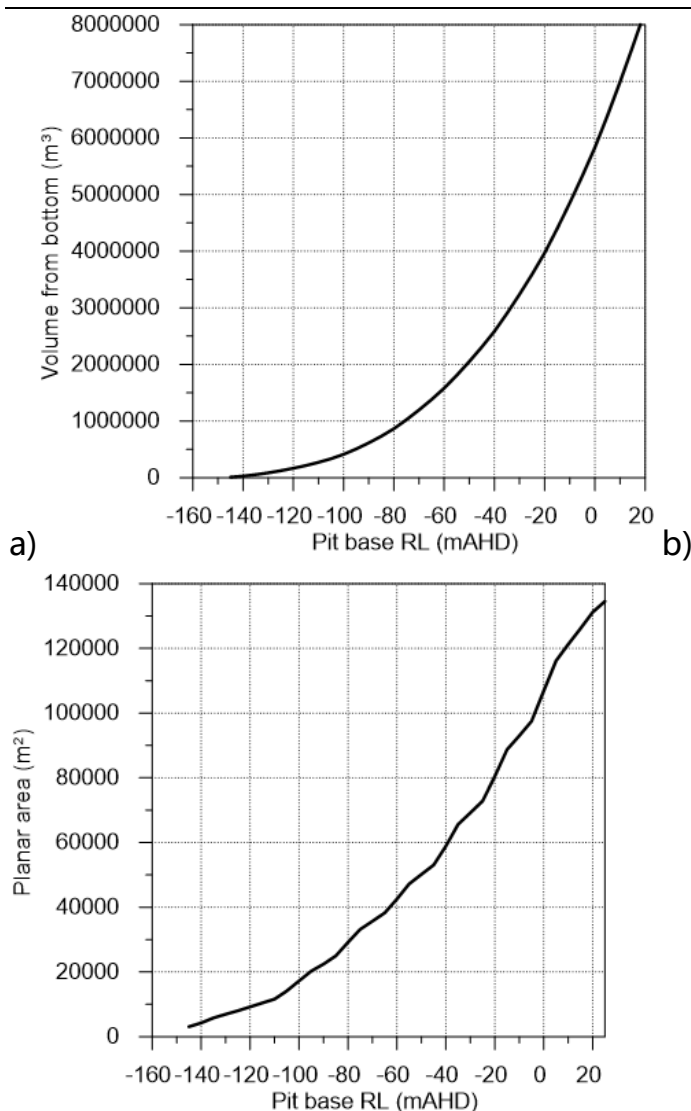
Conceptual Model

Figure 2-10 Grants Lithium pit void a) volume vs pit-lake water level relationship and b) area vs pit-lake water level relationship.

2.9.4. Preliminary pit groundwater inflow estimate

Dewatering volumes from the pit are expected to be relatively low given the initial groundwater assessment (GHD, 2017) identified bore yields of less than 2 L/s in the centre of the proposed pit at a depth of 150 m. Inflow rates of less than 1 L/s were recorded at the monitoring bores installed at depths ranging between 6 m to 63 m.

An estimation of the steady state groundwater inflow to the pits has been made using the method of Marinelli and Niccoli (2000). This analytical solution is useful in situations where rainfall recharge is the principal factor in groundwater flow. The method is based on the Dupuit – Forchheimer approximation and the flow into the pit is divided into two zones as shown below in Figure 2-11. Zone 1 represents flow

Conceptual Model

through the pit walls. Zone 2 represents the inflows from the base of the pit. In this case it is assumed Zone 1 is the weathered zone and Zone 2 is fresh rock (although both are assumed to have similar permeabilities).

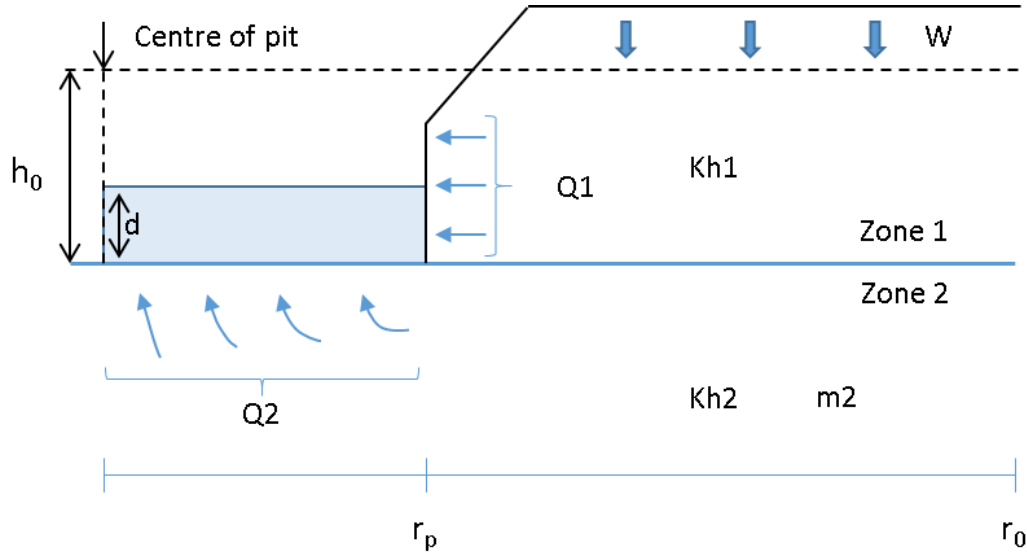


Figure 2-11 Pit inflow model adapted from Marinelli and Nicoli (2000).

Steady state flow into the pit or sump $Q_T = Q_1 + Q_2$,

Where:

$$Q_1 = W\pi(r_0^2 - r_p^2)$$

$$Q_2 = 4r_p \left(K \frac{K_{h2}}{m_2} \right) (h_0 - d)$$

$$h_0 = \left(h_p^2 + \frac{W}{K \left[\left(r_0^2 \ln \left(\frac{r_0}{r_p} \right) \right) - \left(\frac{r_0^2 - r_p^2}{2} \right) \right]} \right)^{\frac{1}{2}}$$

$$m_2 = \left(\frac{K_{h2}}{K_{v2}} \right)$$

Conceptual Model**Where:**

W is the distributed recharge flux (Annual rainfall expressed as m/s)

r_0 is the radius of influence (extent of cone of depression) [m]

r_p is the pit radius at half the total depth [m]

h_0 is the initial regional water level [m]

h_p is the saturated thickness above Zone 1 [m]

d is the depth of water in the pit above Zone 1 [m]

K_{h1} is the horizontal hydraulic conductivity in Zone 1 [m/s]

K_{h2} is the horizontal hydraulic conductivity in Zone 2 [m/s]

K_{v2} is the vertical conductivity in Zone 2 [m/s]

The input parameters and final pit inflows for three different hydraulic conductivity values (1.0, 0.1 & 0.01 m/d) are presented below in Table 2-6. Recharge is estimated at between 30 – 160 mm/year (see Section 3.5 for further detail), an annual recharge of 100 mm has been adopted for the pit inflow calculations.

Table 2-6 GLP input parameters and estimated final pit inflows for $K_h = 1.0, 0.1$ & 0.01 m/d.

Variable	$K_{h1} = K_{h2}$ [m/d]			notes
	1	0.1	0.01	
W [m/s]	3.17e-09	3.17e-09	3.17e-09	This is equivalent to 100 mm/year
r_0 [m]	4630	1740	820	Iteratively solved
r_p [m]	100	100	100	The pit is not cylindrical and the planar area converted to an equivalent radius.
h_0 [m]	140	140	140	This is calculated as above the base of the pit, and is approximated from WL readings in the observation bores at the start of the project (~2 – 3mbgl near the pit).
h_p [m]	0	0	0	The thickness of saturated ground above the base of the pit; assumed to be the pit depth.
d [m]	0	0	0	Depth of water in the pit above Zone 1 and is assumed to be 0 (ie dry) during LoM.
Q1 [m ³ /s]	0.21	0.030	0.013	Inflow from zone 1
Q2 [m ³ /s]	0.65	0.065	0.019	Inflow from zone 2
Qt [m ³ /s]	0.86	0.095	0.032	Combined inflow

Based on the expected hydraulic parameters of the rocks in the study area groundwater inflows to the pit at the end of mining are expected to be between 30 to 100 L/s.

2.9.5. Preliminary pit dewatering volume estimates

Dewatering requirements will be higher during the wet season as rain will mean larger volumes of stormwater entering the pit. The flood diversion bund construction will largely eliminate surface flows into the pit and only rainfall directly into the pit will require dewatering. Based on a maximum pit area of 12.6 ha and an average daily rainfall of 4.49 mm, dewatering requirements are estimated at 206 700 m³/yr. However, maximum pit inflows of up to 1,640 m³ per day (19 L/s) can be expected due to individual rain events during the wet season (January average = 13 mm/d).

Assuming the components of the pit water balance during LoM are:

1. rainfall incident on the pit area (126 100 m²) at 1 642 mm/yr = 207 060 m³/yr; and
2. groundwater seepage into the pit of 912 500 m³/yr based on analytical estimates assuming a $K_h = 0.01$ m/d (2 500 m³/d).

The total annual dewatering requirements are expected to be approximately 1 120 000 m³, with peak dewatering requirements expected to be 4 320 m³/d (~50 L/s) during the wet season and 2 500 m³/d (~30 L/s) in the dry season.

2.10. Data uncertainty

Sources of uncertainty can be simply differentiated as either intrinsic or epistemic.

Intrinsic uncertainties are concerned with apparent random variability and can be treated directly in probabilistic terms. Epistemic uncertainties (from the Greek for knowledge or science), on the other hand, arise from lack of knowledge and understanding and, it is often suggested, could be reduced in principle by having more or better measurements; or by new science. Epistemic uncertainties may not be treated easily in probabilistic terms, but it will not usually be clear what other uncertainty framework could be used usefully to represent them. Epistemic errors are often treated in terms of probabilities as if they were intrinsic, but the probabilities are much more likely to be incomplete, imprecise, or nonstationary in nature. Consequently, any representation will require subjectively chosen

Conceptual Model

assumptions (actually, by definition, since if we had the knowledge to describe them properly, they would no longer be epistemically uncertain).

Table 2-7 Intrinsic and epistemic uncertainties associated with the groundwater modelling.

UNCERTAINTY FROM	INTRINSIC COMPONENT	EPISTEMIC UNCERTAINTIES
Topographic data	Measurement errors associated with signal from vegetation canopy	
Recharge estimates		Choice of assumption in process representation Neglect of local factors / processes
Aquifer properties	Point observations Measurement errors	Errors associated with lack of knowledge of spatial heterogeneity and laterally continuous preferential flowpaths Errors arising from neglect of or inappropriate handling of scale effects
Head observations	Point observations Measurement errors	Errors arising from neglect of or inappropriate handling of scale effects

2.11. Limitations

It is assumed that the majority of the study area has limited vegetation cover and errors in elevations derived from the SRTM data, due to vegetation, are minimal.

3 Conceptual model

3.1. Introduction

The development of a conceptual model is one of the most important steps in groundwater modelling (Barnett et al, 2012). The conceptual model establishes the basic design principles for a groundwater model and identifies any key knowledge gaps to guide future investigations.

At this stage of the modelling process, a decision is made on what processes to include (or exclude) and what simplifying assumptions should be made to achieve the modelling objective(s). These decisions will strongly influence the mathematical model and ultimately the modelling outcome.

3.2. Groundwater system extents

Similar geological / hydrogeological conditions (Burrell Creek Formation) extend well beyond the expected impact of the Grants Lithium Project, therefore in order to build a functional numerical groundwater model, the modelled groundwater system extents have been taken from hydrological features such as surface water catchment divides and surface water drainage features.

The extents of the groundwater model are presented below in Figure 3-1. The model domain has adequate lateral extents to prevent the interaction between areas showing potential changes to the groundwater system due to mining activities and the model boundaries (approximately 3 – 4 km separation).

The geometry and layering of the groundwater model are based on the following criteria:

- The western and eastern boundaries correspond with surface water drainage divides, assuming that the groundwater surface is a subdued reflection of the topography, then these will correspond to groundwater divides.
- The northern boundary coincides with drainage features, which are assumed to be tidal and forms a constant head.
- The southern boundary coincides with the ephemeral drainage features and is likely to form a local no-flow boundary.

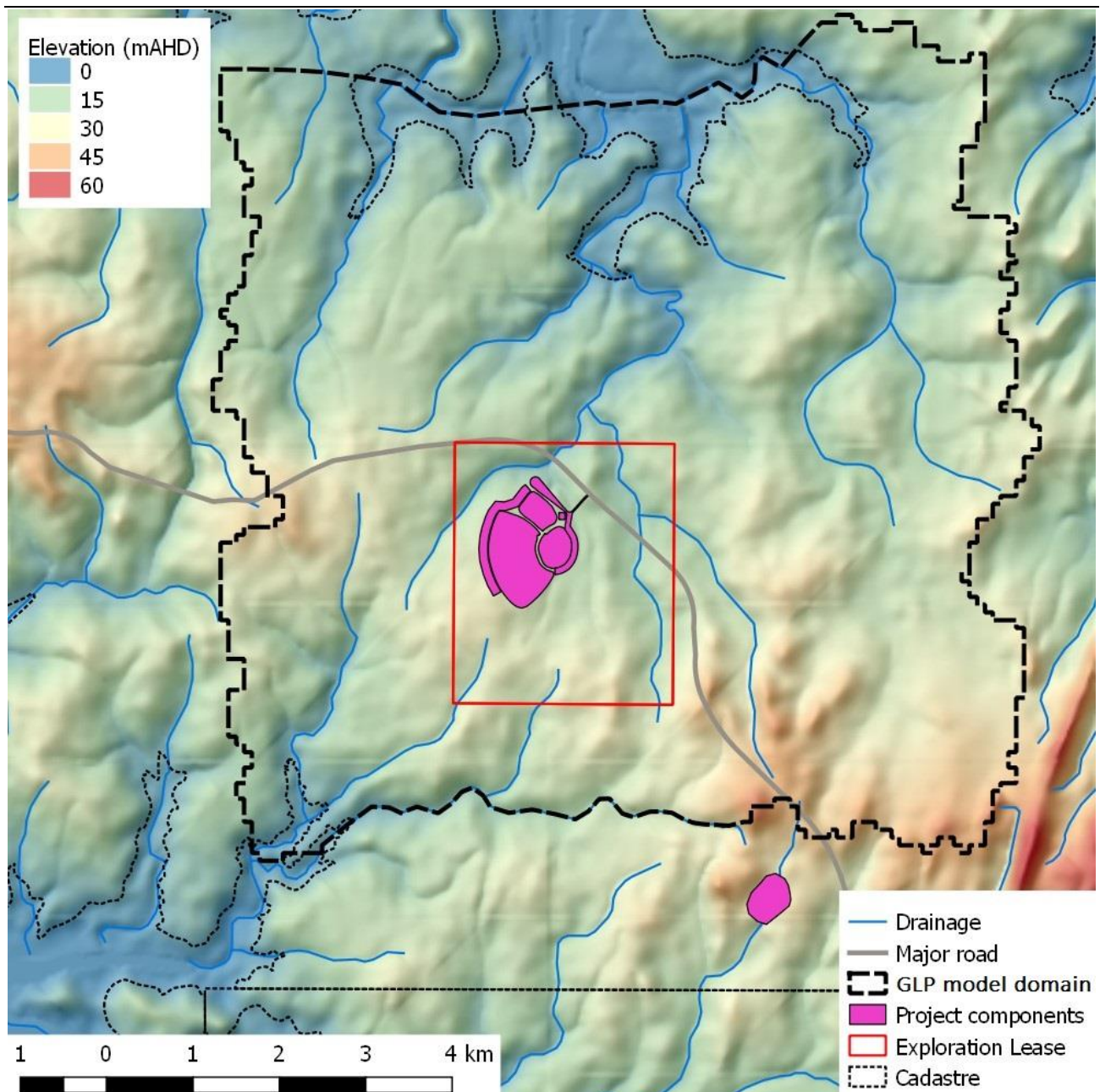
Conceptual Model

Figure 3-1 Grants Lithium groundwater model domain.

3.3. Hydraulic characteristics

In the study area, the Burrell Creek formation typically comprises heavily weathered shale, siltstone and strongly foliated phyllite with lenses of quartz pebble conglomerate. All groundwater investigation bores encountered a thin cover of Cainozoic sediments over the Burrell Creek Formation, mainly comprising laterite gravel, sand and clay.

Only sparse low yielding localised fractured and weathered aquifers are present in the Burrell Creek Formation typically occurring at the base of the weathered zone.

Discrete aquifers also occur where drilling intersects discrete fracture zones within the fresh Burrell Creek Formation. The most permeable sediments are likely to occur in the Cenozoic sands and gravels, and the laterised top of the Burrell Creek Formation. However, the potential of these deposits to store and transmit groundwater is not significant due to their limited saturated thickness. The permeability of the Burrell Creek Formation is relatively low with hydraulic testing indicating hydraulic conductivity values of around 0.1 m/d. The storage characteristics are unknown, however, the specific yield is expected to be low and in the order of 0.01. In the absence of site data the specific yield is based on typical values for weathered and fractured rocks and is consistent with values adopted for other groundwater modelling studies undertaken in similar hydrogeological environments (i.e. the Burrell Creek Formation).

Groundwater in the Burrell Creek Formation in the study area is fresh with a low electrical conductivity ($EC < 280 \mu\text{S}/\text{cm}$) and is mildly acidic to neutral. Groundwater quality in the shallow laterite and Cenozoic deposits is very fresh ($EC < 25 \mu\text{S}/\text{cm}$) and slightly acidic with water quality characteristics similar to rainfall.

3.4. Groundwater flow dynamics

In the immediate area around the proposed mine pit and infrastructure groundwater flows in a north to north-easterly direction, moving from the more elevated rises in the south of the study area toward the lower lying areas and incised drainage lines in the north. The groundwater flow pattern does not vary significantly between the wet and dry seasons. Regionally, there is limited groundwater level and elevation data, but the watertable around the study area is expected to mirror the topography - flowing generally from south to north toward Darwin Harbour and locally from areas of higher topography to areas of lower topography such as drainage features and discharging as small seepages adjacent to the rivers and lowlands. Groundwater discharge to surface features will be relatively low as the aquifer has a low hydraulic conductivity.

3.5. Recharge

Two mechanisms provide recharge to the aquifers of the study area:

- Direct (or diffuse) recharge – this is defined as the water added to the groundwater in excess of soil moisture deficits and evapotranspiration, by direct vertical percolation of precipitation through the unsaturated zone and is typically distributed over large areas; and
- Indirect (or local) recharge – this results from the percolation of water to the water table following runoff as ponding in low-lying areas or through the beds of surface water courses (Lerner et al., 1990).

Estimates of recharge rates are based on the watertable fluctuation method.

Assuming an annual 3 – 4 m variation in groundwater levels and a specific yield of between 0.01 and 0.04 gives an estimated annual recharge range of 30 – 160 mm.

3.6. Groundwater Discharge

Natural mechanisms for groundwater leaving the aquifers in the study area are thought to be via:

- Evapotranspiration and diffuse discharge where groundwater is relatively close to the surface (including from the surface of the pit-lake post closure);
- Discharge to streams and creeks; and
- Underflow to the north;

Evapotranspiration can be estimated from studies conducted in similar vegetation types and climatic conditions. Cook et al (1998) provided an annual estimate of evapotranspiration from the unsaturated zone of 1 110 mm for an annual rainfall of 1 720 mm. The volume and rate of groundwater discharge to surface features (streams and creeks) is expected to be relatively low as the aquifer has a low hydraulic conductivity.

3.7. Water budget

3.7.1. Catchment water budget

The saturated water balance should satisfy the following flux equation:

$$REg - \Delta Ly - \Delta D - EVT - A = \Delta S$$

Where:

Conceptual Model

- REg = gross recharge to the saturated zone
- ΔLy = net horizontal flow of groundwater across the model boundaries
- ΔD = net drainage from groundwater to surface water
- EVT = evapotranspiration from the groundwater
- A = groundwater abstraction
- ΔS = change in groundwater storage

That is the sum of the fluxes is equal to the change in groundwater storage in the aquifer. All fluxes vary in space and time. Some values can be measured directly, for example, the discharge from extraction wells, whereas other values have to be indirectly evaluated by appropriate methods or models.

The absolute value of these fluxes is likely to contain error due to spatial lumping, parameter estimation and various assumptions used in the calculations. However, the input parameters such as aquifer geometry, transmissivity and specific yield are considered to be reasonable and the underflow and storage values determined are also reasonable. However, due to the nature of the recharge processes analytical estimates are likely to be accurate to only an order of magnitude and expressed as long-term averages.

3.7.2. Pit-lake water budget and final level

The water level in the pit will recover if inflows are greater than outflows. Assuming that rainfall is the only inflow to the pit, the pit will recover to about -20 mAHD (using the pit area – volume relationship in section 2.9.3).

- Inflows due to rainfall incident on the pit area ($126\,100\text{ m}^2$) at $1\,642\text{ mm/yr} = 207\,060\text{ m}^3/\text{yr}$
- Outflows the equivalent area assuming an evaporative flux of $2\,340\text{ mm/yr}$ is $88\,490\text{ m}^3$
- the corresponding pit RL will be -20 mAHD.

However, there will be some groundwater inflow to the pit. For the pit-lake to recover to the pre-mining groundwater levels, additional groundwater inflows are required to balance the losses due to evaporation from the greater surface area of the pit-lake assuming the pit is full:

- evaporation from the surface of the pit-lake assuming the pit is full ($126\,100\text{ m}^2$) at $2\,340\text{ mm/yr} = -295\,070\text{ m}^3/\text{yr}$

The required groundwater flow into the pit is the difference between the inflow to the pit from rainfall and the evaporative losses when the pit is full:

- inflows = 207 060 m³/yr
- outflows = -295 070 m³/yr
- groundwater flow into the pit = 88 010 m³/yr (241 m³/d or 2.8 L/s)

The water balance implies that if groundwater inflows into the pit are greater than approx. 3 L/s the pit water level will recover to a level commensurate with the pre-mining level. Based on this analytical water balance analysis, the post-mining water level will recover relatively quickly to a level greater than -20 mAHD and then recover more slowly (over decades). The pit-lake level is likely to stabilise at a level slightly lower than the pre-mining conditions.

3.8. Summary hydrogeological conceptualisation

The conceptual model of groundwater flow is a fractured rock aquifer with a thick weathered zone. In general, flow in the aquifer is away from slightly elevated areas in the south and toward lower lying and incised drainage lines in the north. For the most part, streams in the area act as the discharge points, and topographic highs and anthropogenic surface water impoundments (dams, water storages) act as recharge areas. Groundwater recharging in the vicinity of the mine and its infrastructure would be expected to migrate offsite, likely as discharge to surface water features.

The path groundwater follows through the project area is influenced by the regional groundwater gradient and the hydraulic conductivity of the materials in the area. The local flow direction is influenced by differences in recharge, local topography, and local hydraulic conductivity. In addition, any project-related pumping will influence the local flow direction. The regional groundwater gradient in the project area is toward the north and the groundwater flow direction generally mimics the topography.

The primary fractured rock unit through which groundwater flow occurs in the project area is the Burrell Creek Formation (BCF). The Pit is located in metamorphosed (hornfelsed) BCF, hence, there is expected to be limited groundwater recharge or discharge through the walls of the pit.

Conceptual Model

The weathering profile is hydrogeologically important in the project area. Based on examination of numerous boring logs, the top 3m of material is generally completely weathered, very highly fractured, or unconsolidated. Alluvium often extends somewhat deeper than 3m below streambeds. Weathering of the bedrock is generally observed down to 25 to 30m below land surface. In bore logs, weathering is often associated with increased fracturing, infilling of fractures with clay or mineralisation, or oxidation. The degree of weathering decreases with depth.

The alluvium and uppermost weathered portion of bedrock have the potential to transmit reasonable volumes of groundwater, especially during rain events. However, they are generally unsaturated except in the immediate vicinity of the local streams and surface water bodies. Also, the infilling and mineralisation along fractures in the weathered zone above 30m depth has the potential to cause a decrease in their transmissivity.

Table 3-1 Summary of key features of the hydrogeological conceptualisation

ASPECT FEATURE(S)	DESCRIPTION
Hydrostratigraphy	Groundwater is present in the weathered Burrell Creek Formation.
Flow dynamics	Groundwater generally flows from south to north and locally from areas of higher topography to areas of lower topography such as drainage features.
Recharge processes	Recharge primarily occurs as diffuse recharge. This hypothesis implies that preferential recharge is not significant.
	Total recharge fluxes were estimated at 7.7 GL/year, which (for an assumed total recharge area of 77.2 km ²), equate to rates of approximately 100 mm per year, or 2.7×10^{-4} m/d.
Discharge processes	Diffuse discharge also occurs via streambed seepage (unquantified) and via evapotranspiration from shallow groundwater. The fluxes were estimated at 4 GL/year respectively.
	Total discharge fluxes were estimated to range from 7 to 8 GL/year, which (for an assumed total discharge area of 77.2 km ²), equate to rates of approximately 90 – 104 mm per year, or 4×10^{-4} to 7×10^{-4} m/d.

4 Numerical Model Design & Construction

4.1. Model design strategy

The model has been designed to meet the following criteria:

- Designed to run as quickly as practical to allow for uncertainty analysis;
- Refined in the pit area; and
- Refined in the areas that may be impacted by the mine pit such as the surface water features.

4.2. Model platform

The FEFLOW (Finite Element subsurface FLOW and transport system v 7.011) modelling code developed by DHI-WASY GmbH (Diersch, 2015). This code is an industry standard groundwater modelling tool used by many jurisdictions to study groundwater level behaviour within groundwater systems.

FEFLOW handles a broad variety of physical processes for subsurface flow and transport modelling and simulates groundwater level behaviour indirectly by means of a governing equation that represents the Darcy groundwater flow processes that occur in a groundwater system.

FEFLOW provides the capability to explicitly model recharge processes and surface water/groundwater interactions. Rejected recharge is an important mechanism in Top End groundwater systems and adequately characterising this process is critical if the model is to accurately assess the impacts from the mining development. The ability of FEFLOW to explicitly model rejected recharge and surface water/groundwater interactions are major reasons for its selection as the preferred modelling code for the GOP model.

4.2.1. Saturated zone governing equations

3D Finite Element Method

The mathematics of the Finite Element (FE) method is less straightforward than the Finite Difference (FD) method. In the FE method, the problem domain is subdivided into elements that are defined by nodes. The dependent variable (e.g., head) is

defined as a continuous solution within elements in contrast to the FD method where head is defined only at the nodes and is considered piecewise constant between nodes. The FE solution is piecewise continuous, as individual elements are joined along edges.

The governing flow equation for three-dimensional saturated flow in saturated porous media is:

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) - Q = S \frac{\partial h}{\partial t}$$

where K_{xx} , K_{yy} and K_{zz} are the hydraulic conductivity along the x, y and z axes of the model, which are assumed to be parallel to the principle axes of hydraulic conductivity tensor, h is the hydraulic head, t is time, Q represents the source/sink terms, and S is the storage coefficient.

Two special features of this apparently straightforward elliptic equation should be noted. First, the equations are non-linear when flow is unconfined and second, the storage coefficient is not constant but switches between the specific storage coefficient for confined conditions and the specific yield for unconfined conditions.

4.3. Model domain and grid

4.3.1. Model domain

The 3D finite difference model domain is roughly centred on the GLP pit and covers an area of 77.2 km². The mesh has been refined along the drainage lines and within the pit footprint. The model domain is discretised into a mesh consisting of 12089 elements per layer.

The final FEFLOW mesh extents are summarised in Table 4-1 and the model domain is presented below in Figure 4-1.

Table 4-1 Grants Lithium project numerical flow model domain specifications.

X min	689065
X max	698640
Y min	8594870
Y max	8606595
Model area	77.2 km ²
Map projection	GDA94 / MGA zone 52

3D Model Design & Construction

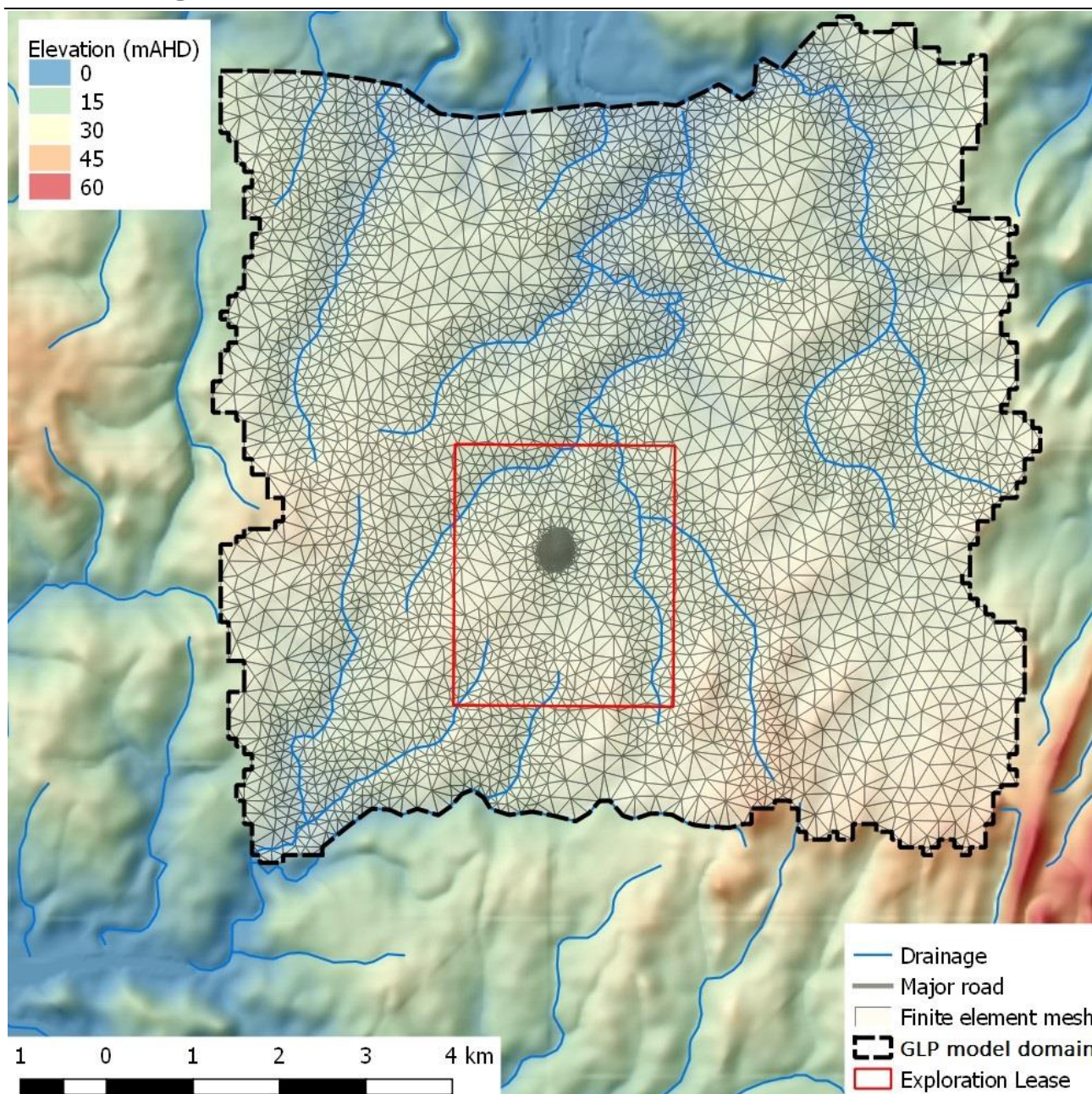


Figure 4-1 Grants Lithium Project FEFLOW groundwater model domain and grid.

4.3.2. Boundary conditions

The boundary conditions are defined at nodes along the boundary or within the model domain. There are four main boundary conditions available in FEFLOW.

- Fixed Head BCs - this boundary prescribes a head in the boundary node. The head can be fixed at a prescribed value or assigned to a time series file.
- Flux BCs - this boundary condition describes a constant or time varying flux across the outer boundary of the model. A time varying flux can be

specified as a mean step-accumulated discharge (e.g. m³/d). A positive value implies an inflow to the model cells.

- Well BCs - this boundary condition is applied to nodes and represent a time-constant or time-varying local injection or abstraction of water at a single node or at a group of nodes.
- Zero flux - This is a special flux no-flow boundary, which is the default.

The locations of the boundary conditions at the extents of the model domain are depicted in Figure 4-1.

4.3.3. Areal flux distributions (recharge and ET)

The recharge is applied to the model as a Parameter Expression using the In / outflow on top / bottom areal flux distribution.

The Parameter Expression is a user-defined expression linking the time- varying values of recharge to the In / outflow on top / bottom parameter, based on the dependencies of other parameters, in this case the recharge reference distribution, maximum evapotranspiration flux, extinction depth and reference distribution. Scaling factors are applied to the time- varying rainfall values using the recharge zones, which are attributed to the different soil types. Soils in this study have been defined using the surface geology (Section 2.5.2) and the distribution of ET based on the LAI and vegetation mapping.

The ET function is determined using an estimate of the potential evaporation rate, an estimate of root depth or depth of capillary rise where vegetation is absent and the extent of persistent vegetation

The ground surface is represented by seepage face boundary conditions.

4.3.4. Representation of the pit during mining

Dewatering of the pit during excavation is simulated using seepage face boundary conditions that are activated sequentially in time. A seepage face is a specific Dirchlet (specified hydraulic-head) boundary condition with a zero-flux inflow constraint applied. This means the boundary condition can discharge groundwater from the model domain, but no inflow to the model domain can occur. The

implication of using seepage face boundary conditions to represent the pit is that the inflow to the pit is a predicted output of the modelling.

The seepage face requires a reference elevation, which in this case has been determined from the planned progression of the pit-levels over the life of mine discussed in Section 2.9.2.

4.3.5. Post closure pit-lake representation

The development of the pit-lake post mine closure is represented by the IfmLake module developed by DHI.

IfmLake is an IFM plug-in which allows the incorporation of lakes within a FEFLOW model. The plug-in calculates the development of water levels from internal fluxes (received or discharged by the lake from the groundwater model) and/or external fluxes (such as rainfall and evaporation defined by the user). The plug-in dynamically adjusts the horizontal extent of the lake depending on water level and surface elevation.

IfmLake uses the pit-lake bathymetry ("IfmDTM"), the external net inflow into the lake ("InflowExtMM" such as evaporation and rainfall) and a function describing the water level vs the lake volume $f(\text{Volume})$.

If the water level in the lake is higher than the surface level at a node, a third kind boundary condition is set at this node with a value identical to the lake water level (in masl). Additionally, a head boundary constraint is set with a value identical to the nodal value of the reference distribution "IfmDTM". This constraint limits the value ($h_{ref} - h_{gw}$) to the actual water depth at the node ($h_{ref} - dtm$). This is useful if the groundwater level drops below the bottom of the lake.

InflowExtMM represents an external net inflow into the pit-lake (such as evaporation and rainfall). This rate is given in mm/d and the area of the lakes is taking into account during the simulation (in principle the area of the lake is determined at the beginning of each time step).

The level of the lake is calculated using an empirical function $f(\text{Volume})$ relating lake water level to pit-lake storage volume. The Volume stored in the pit-lake at the end of the time step is calculated by $Volume_{end} = Volume_{begin} + (Inflow_{GW} + Inflow_{ExtMM}) * dT$.

4.3.6. Vertical discretisation / model layers

A total of three model layers were used to represent the groundwater flow system. The layers coincide with the upper completely weathered / laterised horizon, the moderately /highly weathered zone to 30-40 metres below ground levels and the slightly weathered / fresh rocks.

A west - east cutaway of the numerical model showing the layers is presented below in Figure 4-2.

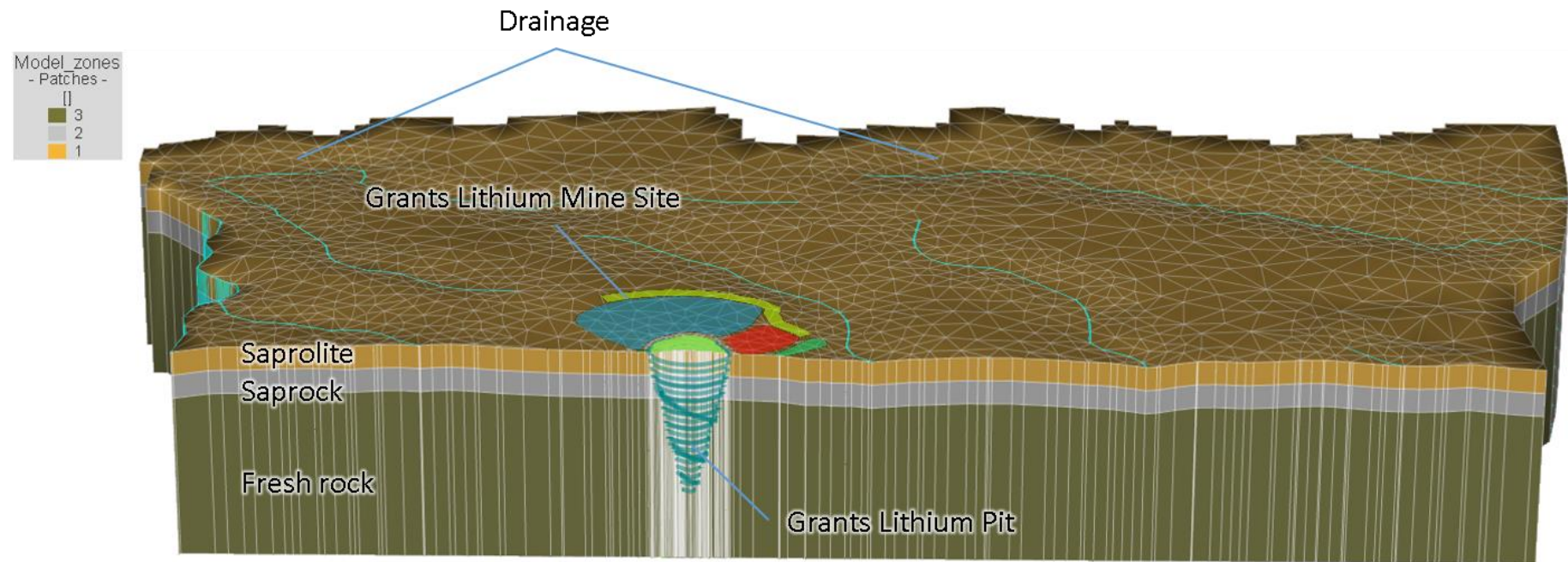


Figure 4-2 South to north cross-section of the model domain through the pit showing layering.

4.4. Transient model design & construction

4.4.1. Simulation period and time stepping

The period from 01/01/2012 to 01/01/2018 (40909 – 43101d) was selected as the period for parameter estimation. This period was selected because it provides a warm-up period prior to the period of available groundwater levels. The FEFLOW simulation time, equation solver and numerical settings are presented in Table 4-2.

Table 4-2 FEFLOW simulation specification settings

Model code	FEFLOW
Software version	7.1.05 (x64)
Mesh	
Element geometry	Triangle prism
Free surface	3D phreatic surface (fixed mesh)
Head limits for unconfined conditions	
Top of model domain	Unconstrained head
Storage change in phreatic top layer	Extend storage of unconfined layer to water table
Bottom of model domain	Unconstrained head
Numerical parameters	
Time stepping	Adams-Bashforth/Trapezoid rule (AB/TR) predictor-corrector
Error tolerance	
Euclidian L2 integral (RMS) norm	1e-03
Maximum number of iterations per timestep	12
Equation System Solver	Preconditioned conjugate-gradient method

4.4.2. Error tolerance

The Error tolerance (units: 10^{-3}) is defined as the averaged absolute error (change in the primary variable) divided by the maximum value occurring in initial or boundary conditions. For the averaging process over all nodes, the default Euclidian L2 integral (RMS) norm was used and set to a value of 1. As a dimensionless normalized error tolerance is used in FEFLOW, the absolute tolerated error depends on the elevation of the model. Two otherwise identical models with maximum heads of 10 m and 500 m will produce more precise results at 10 m if the same error tolerance is applied. Therefore, typically the error tolerance has to be smaller than the default at higher elevations (Diersch, 2015).

4.4.3. Transient model initial heads

Initial heads for the transient model were obtained by running the model for a warm-up period starting 01/01/2010.

5 Parameter estimation

5.1. Parameter Estimation Approach & Criteria

Calibration or parameter estimation is the process, subsequent to model design and construction, of determining a set of parameters, boundary conditions and stresses that produce simulated heads and fluxes in order to match field-measured values within a pre-established range of error, so that the model can be accepted as a good representation of the physical system of interest. Finding this set of values from a set of observed heads amounts to solving the inverse problem.

During the calibration process, important model parameters are adjusted, within realistic limits, to produce the best match between simulated and observed data. The process begins with an initial estimation of parameters (hydraulic conductivity horizontal and vertical, specific yield, recharge, boundary conditions, etc.) for each active element in the model mesh. Adjustment of parameters can be done manually through trial and error or automatically.

Regardless of the technique employed all optimisation methods require:

- selection of a number of parameters to be estimated;
- an objective function, that is, a function of the measured values, defined such that its value is to be minimised; and
- constraints that limit the range of possible values of the estimated parameters.

5.1.1. Measure of 'goodness of fit'

The 'goodness of fit' of the modelled to the observed data is often measured using a simple statistic. Statistics used in this study to describe the fit of final model output values to observed values include:

The root mean squared error (RMS):

$$RMS = \sqrt{\frac{\sum_{i=1}^n (W_i * (y_i - f(x_i)))^2}{n}}$$

Where:

W_i is the i 'th observation weighting

y_i is the i 'th observed value

$f(x_i)$ is the i 'th predicted value

The scaled root mean squared error (SRMS) is the RMS divided by the range of measured heads and expressed as a percentage. Weights are sometimes introduced to account for different levels of confidence in different measurements.

$$SRMS = \frac{100}{H} \sqrt{\frac{\sum_{i=1}^n (W_i * (y_i - f(x_i)))^2}{n}}$$

Where:

W_i are weights between 0 and 1; and

H is the range of measured heads across the model domain.

5.2. Parameter estimation results

5.2.1. Recharge

The final scaling factor for the recharge was 0.08 which is an average rate of 128 mm/yr. This value is consistent with the recharge determined in similar environments.

5.2.2. Hydraulic conductivity and specific yield

The hydraulic conductivity and specific yield parameter fields were defined for individual layers representing the hydrostratigraphic units developed in the Leapfrog model (Section 2.6.3). The final hydraulic conductivity values are presented below in Table 5-1:

Table 5-1 Final calibrated model parameters.

LAYER	HSU	HYDRAULIC COND.	SPECIFIC YIELD
1	Zone 1 laterite / completely weathered rocks	0.1	0.02
2	Zone 2 extremely / highly / moderately weathered rocks	0.07	0.02
3	Zone 3 slightly weathered to fresh rocks	0.03	0.01

5.3. Water balance

5.3.1. Total catchment water budgets

The water balance for the entire model domain is presented below in Table 5-2. The imbalance is 342 m³ which is less than 0.001% of the inflows / outflows and several orders of magnitude less than the target criteria of <1%.

The water budget indicates that 6.2 GL/yr enters the model domain as recharge through rainfall. This is equivalent to an annual recharge rate of 80 mm based on a model domain area of 77.2 km². And is consistent with the range of values presented in Section 3.5.

Nearly all of the groundwater leaving the model domain 5.9 GL/yr (or 76 mm/yr) is through interception by evapotranspiration. The evapotranspiration component is less than the estimate provided in Section 3.6 as this includes evapotranspiration from the unsaturated zone above the water table.

Table 5-2 Model domain natural water budget for the period 2010 – 2018

COMPONENT	OUT (-) [M ³]	IN (+) [M ³]	OUT [GL/YR]	IN [GL/YR]
Dirchlet	1.35E+05	1.60E+00	0.0	0.0
Neumann	0.00E+00	0.00E+00	0.0	0.0
Cauchy	0.00E+00	0.00E+00	0.0	0.0
Wells	0.00E+00	0.00E+00	0.0	0.0
Distributed Sink(-) / Source(+)	6.54E+07	6.21E+07	6.2	5.9
Storage Capture(-) / Release(+)	4.67E+07	5.01E+07	4.4	4.8
Totals	1.12E+08	1.12E+08		
Imbalance		3.42E+02		

5.4. Transient model performance

Barnett et al (2012) recommend that the groundwater model acceptance should be based on a number of measures that may not be specifically related to model calibration. These measures are required to demonstrate that a groundwater model is robust, simulates the water balance as required and is consistent with the conceptual model on which it is based. The four measures recommended by Barnett et al (2012) are presented below in Table 5-3. The performance of the Grants Lithium Mine groundwater model is discussed in the following sections.

Table 5-3 Recommended groundwater model performance measures (after Barnett, 2012)

PERFORMANCE MEASURE	CRITERION
Model convergence	
The model must converge in the sense that the maximum change in heads between iterations is acceptably small.	The iteration convergence criterion should be one or two orders of magnitude smaller than the level of accuracy required in head predictions. Typically of the order of centimetres or millimetres.
Water balance	
The model must demonstrate an accurate water balance, at all times and in steady state. The water balance error is the difference between total predicted inflow and total predicted outflow, including changes in storage, divided by either total inflow or outflow and expressed as a percentage.	A value less than 1% should be achieved and reported at all times and cumulatively over the whole simulation. Ideally the error should be much less. An error of >5% would be unacceptable, and usually indicates some kind of error in the way the model has been set up.
Qualitative measures	
The model results must make sense and be consistent with the conceptual model. Contours of heads, hydrographs and flow patterns must be reasonable, and similar to those anticipated, based either on measurements or intuition. Estimated parameters must make sense, and be consistent with the conceptual model and with expectations based on similar hydrogeological systems.	Qualitative measures apply during calibration, when comparisons can be made with historical measurements, but also during predictions, when there is still a need for consistency with expectations. There is no specific measure of success. A subjective assessment is required as to the reasonableness of model results, relative to observations and expectations. The modeller should report on relevant qualitative measures and discuss the reasons for consistency and inconsistency with expectations.
Quantitative measures	
The goodness of fit between the model and historical measurements can be quantified, using statistics such as RMS, SRMS, MSR and SMSR for trial-and-error calibration and the objective function in automated calibration.	Quantitative measures only apply during calibration. Statistics of goodness of fit are useful descriptors but should not necessarily be used to define targets. Targets such as SRMS < 5% or SRMS < 10% may be useful if a model is similar to other existing models and there is good reason to believe that the target is achievable. Even if a formal target is not set, these measures may provide useful guides.

5.4.1. Model convergence

Section 4.4.2 documents that the dimensionless error criterion in FEFLOW is used for the automatic time-stepping process.

On completion of the transient model runs, the model log was queried to ensure all iterations converged to a value less than the error criterion of 1×10^{-3} .

5.4.2. Water balance

The water balance for the entire model domain is presented above in Table 5-2.

The imbalance is less than 0.001% several orders of magnitude less than the Class 2 target criteria of <1%.

5.4.3. Qualitative performance

The final estimated parameters are considered to be consistent with the conceptual model and with expectations based on similar hydrogeological systems.

The modelled water budget is also considered to be consistent with the conceptual model.

The contours of heads, hydrographs and flow patterns are reasonable, and similar to those anticipated, based on observed measurements. Generally, the absolute modelled groundwater levels are in reasonably good agreement with the observed values. Long term trends in the groundwater levels are generally reproduced. The modelled vertical gradient between GWB08 / GWB10 and GWB06 / GWB07 are also generally reproduced.

The modelled and observed heads at selected sites are presented below in Figure 5-1.

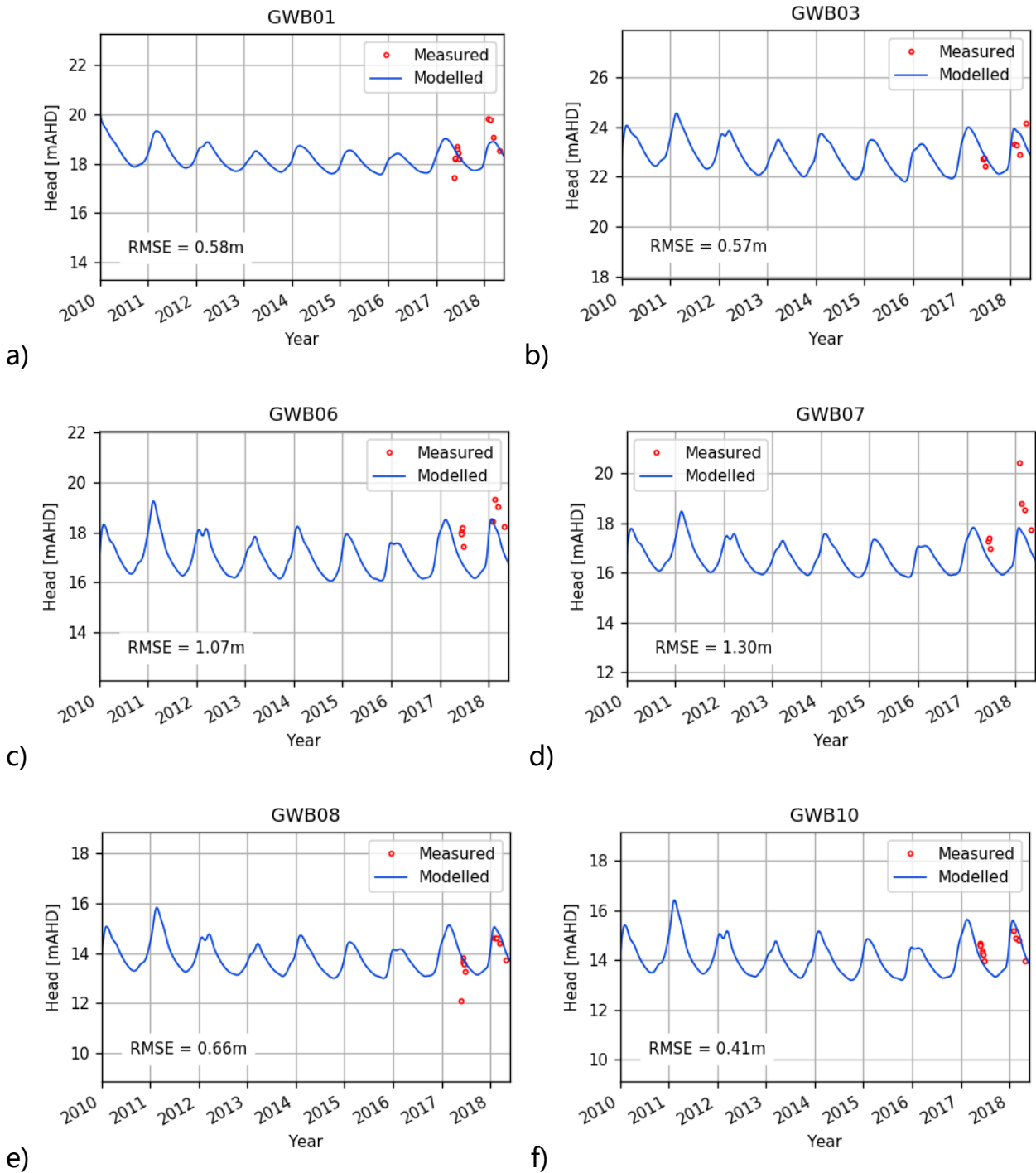


Figure 5-1 Comparison between observed and simulated groundwater levels at a) GWB01 (RN040093) b) GWB03 (RN040094) c) GWB06 (RN040095), d) GWB07 (RN040096), e) GWB08 (RN040097) and f) GWB10 (RN040098).

The modelled and measured heads are also presented as a scatter plot in Figure 5-2. Points below the line indicate the model is underestimating the observed value, whereas points above the line indicate the model is overestimating the groundwater levels.

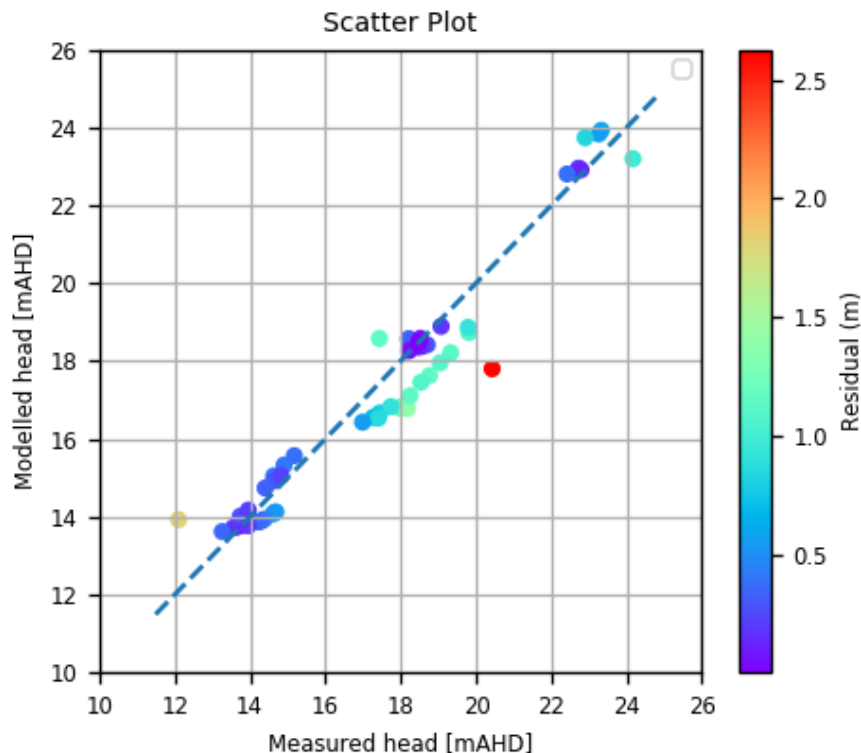


Figure 5-2 Scatter plot of modelled vs measured heads. The point colour indicates the magnitude of the residuals (i.e. the absolute difference between measured and modelled heads).

5.4.4. Quantitative performance

At the conclusion of the parameter estimation process the final standard error (RMS) of 0.73 metres. The maximum head range of the observed heads is 12.1 metres, therefore, the scaled root mean squared (SRMS) is 6% (slightly above the target SRMS of 5%). The SRMS value is considered acceptable given that the groundwater levels are dependent on the SRTM ground elevations, which as indicated in Section 2.3, can have considerable error.

Statistical descriptions of the goodness of fit between the observed and modelled groundwater levels are presented in Table 5-4.

Table 5-4 Analysis of residuals using final estimated parameters.

METRIC	ALL OBS.
Number of residuals with non-zero weight	54
Mean value of non-zero weighted residuals	-0.004
Maximum weighted residual	1.272
Minimum weighted residual	-1.97
Standard variance of weighted residuals	0.53
Standard error of weighted residuals (RMS)	0.73
Scaled standard error (SRMS)	6.0%

5.5. Sensitivity analysis

Sensitivity analysis involves quantifying the variation in the value of one of more output variables (such as hydraulic heads) due to changes in the value of one or more inputs to a groundwater flow model (such as hydraulic properties or boundary conditions).

This section discusses sensitivity in the historic groundwater modelling, through a systematic variation of model input values to:

- Identify those model input elements that cause the most significant variations in model output (list of ranked sensitivities); and to
- Quantitatively evaluate the impact of parameter variability (sometimes referred to as parameter uncertainty) in model input on the degree of calibration and on the model's predictive capability.

The sensitivities are determined from the relative change to the objective function due to a 5% change in the parameter value and are presented graphically below in Figure 5-3. The sensitivities indicate that the groundwater levels are most sensitive to the assumed root depth (rd_1) of the vegetation. The next most sensitive parameter is the hydraulic conductivity of layer 1 (k_1).

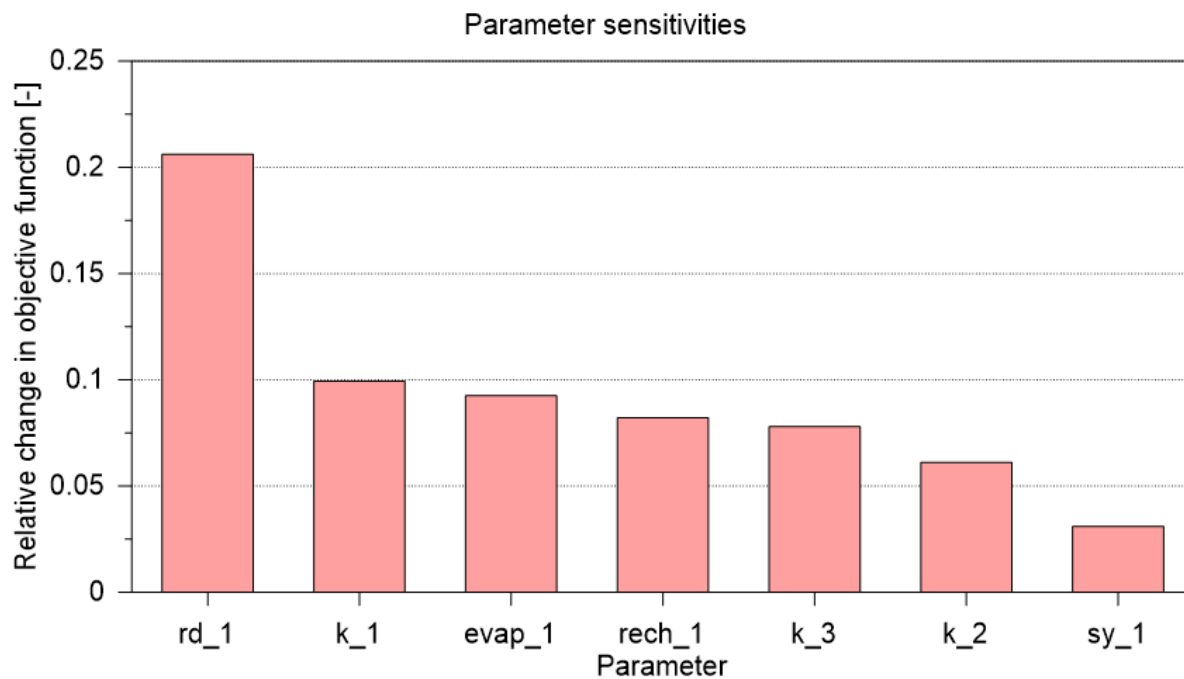


Figure 5-3 Sensitivities (relative change in objective function) determined by adjusting parameter values by 5%. (rd_1 = root depth; rech_1 = recharge scaling factor; k_1, k_2 & k_3 are layer hydraulic conductivities; evap_1 is the ET function scaling factor; and sy_1 = specific yield of layer 1 & 2)

6 Forecast scenarios

This section investigates the impacts of the GLP pit development over the life of the mine and post closure. The scenarios considered are summarised below:

- Life of mine (2 years) 2018 – 2020
- Post closure (50 years) 2020 – 2070

6.1. Life of mine forecast 2018-2020

The LoM forecast scenario was designed to investigate the effect of the pit development on groundwater flow dynamics in the area. The following assumptions were made for the predictive model runs:

- All model parameters were taken from the calibrated model;
- Pit shell elevations were applied to the model as per Section 2.9.2;
- Passive groundwater dewatering via sumps, with no groundwater dewatering from production bores;
- The model was run for a forecast period of 2 years from the end of the calibration period (01/06/2018) to the projected end date of the mine (01/06/2020).
- Initial conditions were taken from the final heads of the calibrated model corresponding to 43282d (01/06/2018);
- The time series climatic inputs from the period 1970 – 2018 were repeated to obtain the 50 year time series used to calculate recharge for the forecast model.

6.1.1. Groundwater levels

The groundwater levels for the life of mine (LoM) from 01/06/2018 to 01/05/2020 compared to the historic model without mining are presented below in Figure 6-1.

Conclusions

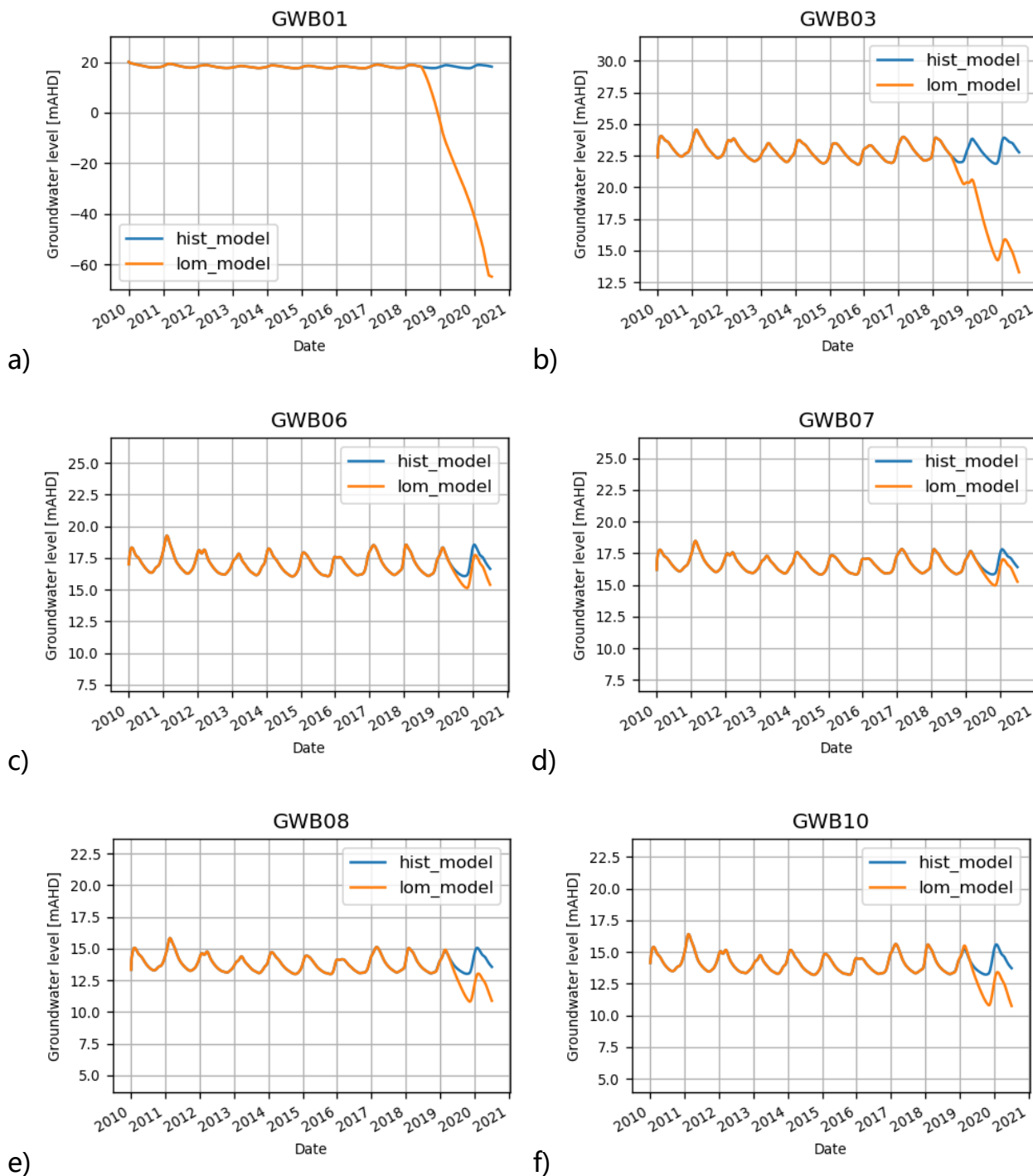


Figure 6-1 Groundwater level response at existing observation bores a) GWB01, b) GWB03, c) GWB06, d) GWB07, e) GWB08 and f) GWB10.

6.1.2. Groundwater drawdown contours

The LoM forecast drawdown impacts at the end of the 2 year mining period are presented below in Figure 6-2. The drawdown at the end of mining does not

Conclusions

extend beyond the exploration lease and also does not intersect any of the ephemeral drainage lines on site.

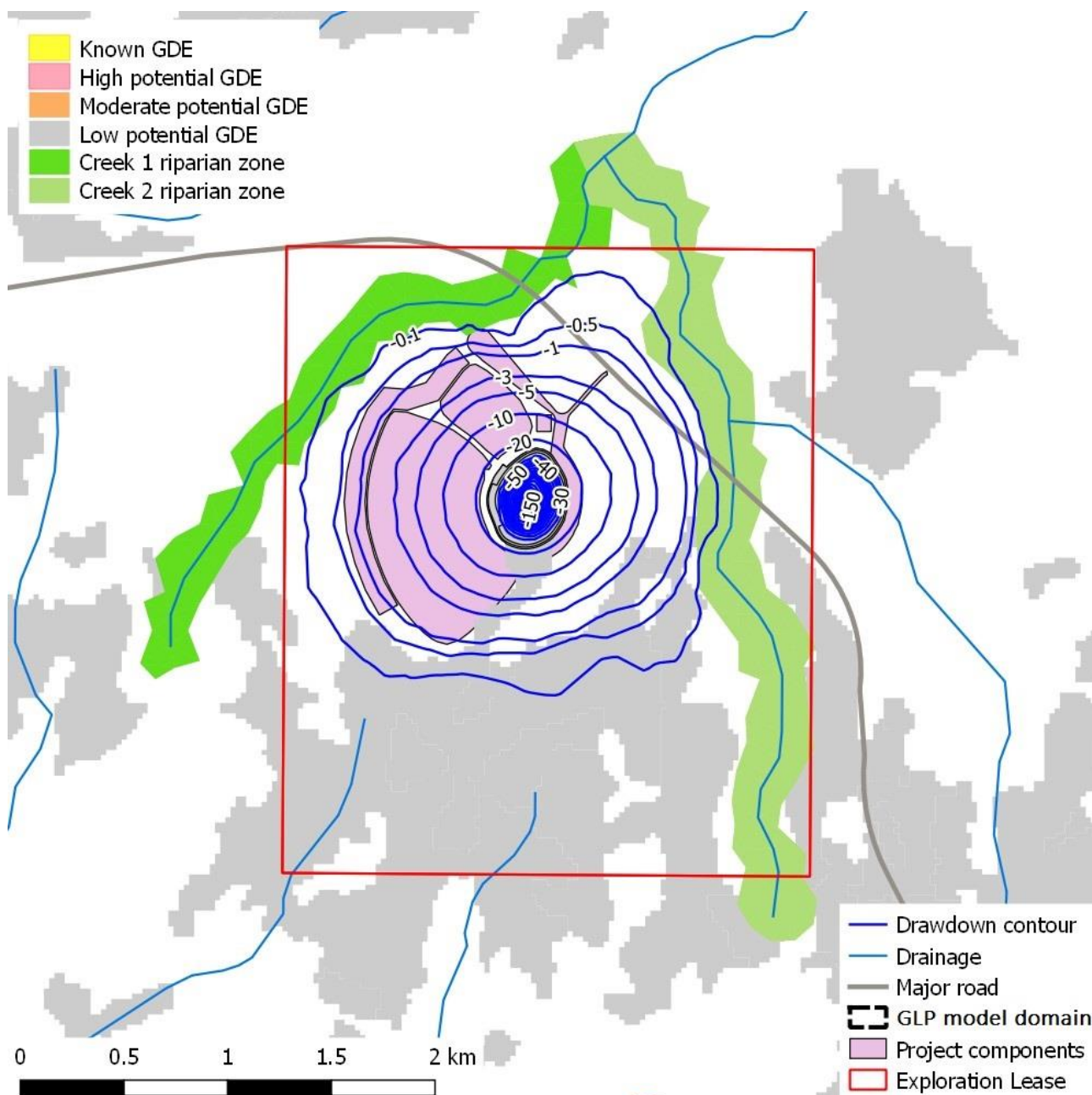


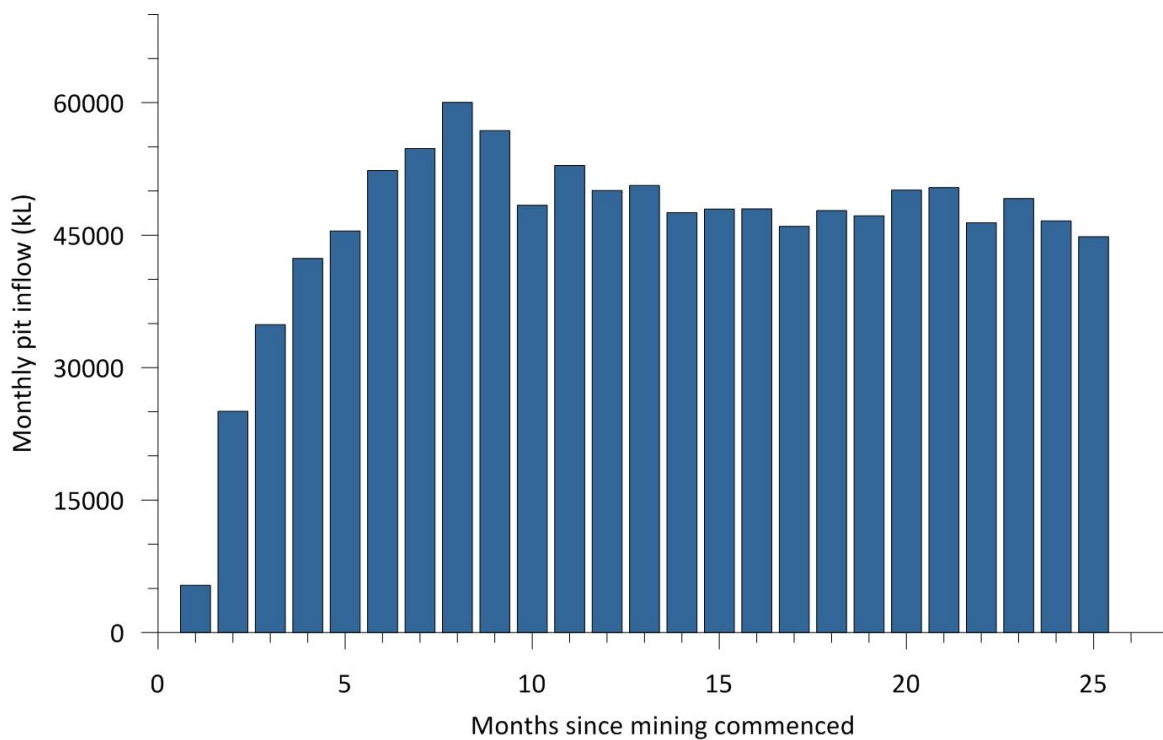
Figure 6-2 LoM final drawdown contours after 2 years of mining at year 2020.

6.1.3. LoM pit inflows

Pit inflows have been determined during the life of mine and are presented below in Table 6-1. Inflows increase from commencement of mining in June 2018 and reach a peak during the wet season of 2019 at about 2 000 kL/d (23 L/s). Pit inflows decline to around 1 600 kL/d (18.5 L/s) for the rest of the life of mine. Pit inflows as kL/month over the LoM are presented graphically in Figure 6-3.

Conclusions**Table 6-1 Monthly life of mine pit inflows**

Month	Inflow [kL/d]	Inflow [kL/month]	Month	Inflow [kL/d]	Inflow [kL/month]
1	178	5353	14	1534	47544
2	808	25051	15	1547	47952
3	1125	34871	16	1599	47982
4	1412	42361	17	1484	45993
5	1467	45478	18	1593	47782
6	1744	52323	19	1522	47195
7	1768	54815	20	1616	50098
8	1936	60029	21	1737	50382
9	2030	56827	22	1497	46396
10	1561	48392	23	1639	49155
11	1763	52891	24	1504	46609
12	1615	50057	25	1494	44835
13	1687	50618			

**Figure 6-3 Predicted pit inflows (kL/month) during life of mine.**

6.2. Post closure forecast 2020 – 2090

The post closure impacts scenario was based on the life of mine scenario with the following additional assumptions / settings:

- Initial heads were taken from the final time step of the LoM scenario 01/07/2020 (44013d);
- The post closure model runs for an additional 10 years with the final time step ending at 01/07/2090 (69580d);
- Removing the seepage face boundary conditions representing the pit; and
- Activation of the IfmLake module (Section 4.3.5) to simulate the filling of the pit void.

The post closure period of 70 years was determined by assuming pit inflows of 500 m³/d. At this rate it will take 50 years to fill the pit and an additional 5 years under dynamic equilibrium.

The seasonal nature of recharge meant that a steady state model of the system was not deemed appropriate to assess the post closure impacts. The model was run to an approximate dynamic equilibrium identified by the stabilisation of groundwater levels and inflows to the pit.

6.2.1. Post closure groundwater levels

The groundwater levels at the existing monitoring sites are provided Figure 6-4. Each plot provides the natural groundwater level response (blue) assuming the pit was not excavated, the life of mine response (orange) and the post closure response (green). The following observations can be made:

- The groundwater levels in GWB01 recover to about 4 – 5 metres below the groundwater levels under baseline (non-mining) conditions.
- The up-gradient bore GWB03 shows a decline of 2.5 metres compared to a non-mining scenario;
- Nested sites GWB06/GWB07 and GWB08/GWB10 essentially return to the natural groundwater levels after approximately 40 years of recovery post close;

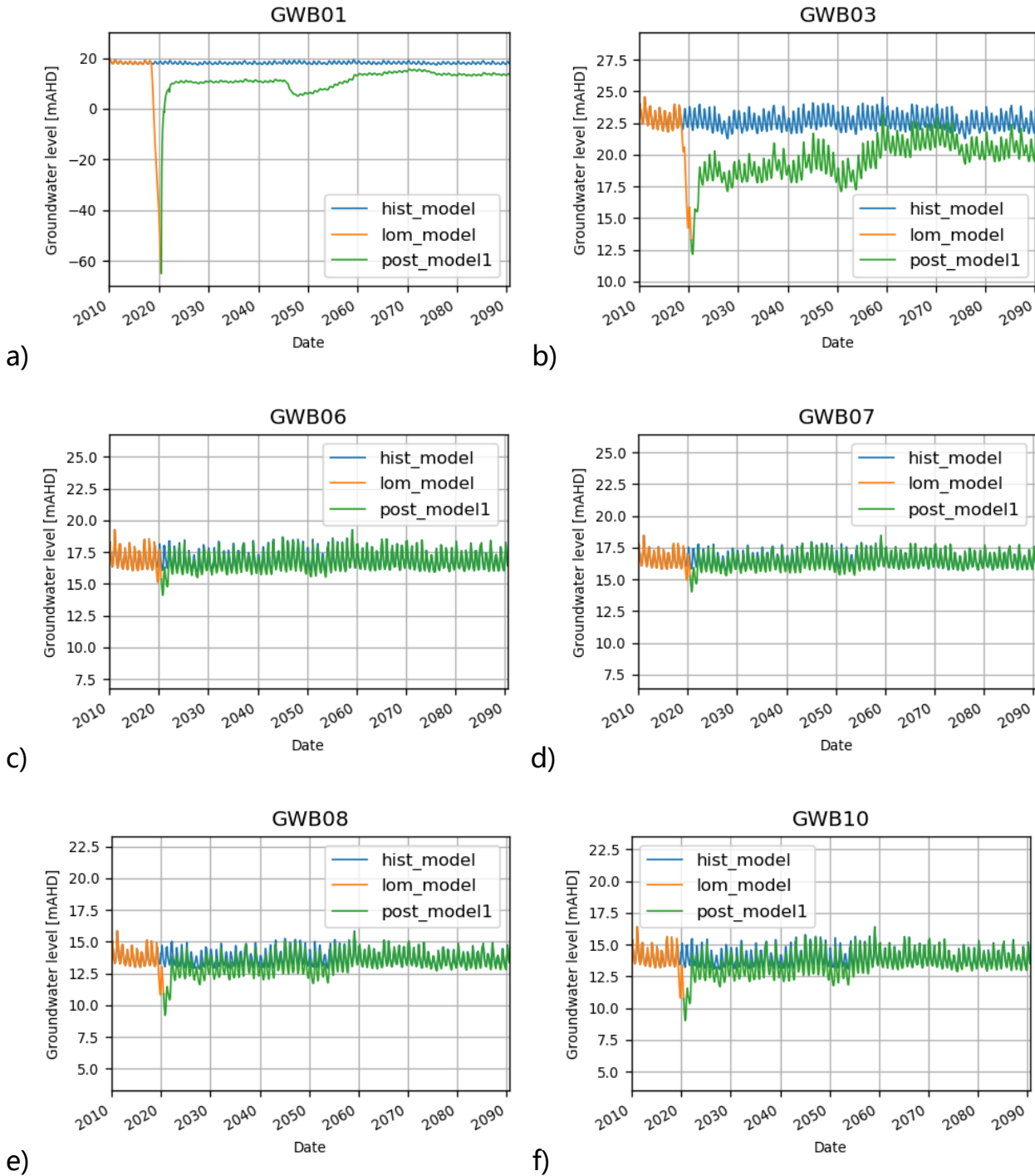
Conclusions

Figure 6-4 Post closure groundwater levels at existing observation bores a) GWB01, b) GWB03, c) GWB06, d) GWB07, e) GWB08 and f) GWB10.

6.2.2. Groundwater drawdown contours

The final post closure drawdown contours are presented in Figure 6-5. This figure shows the drawdown surface after 70 years of recovery post mine closure (year 2090). The pit lake operates as a groundwater sink and will result in 0.5 m

Conclusions

drawdown with a radial extent of approximately 500 m around the pit lake. The change in watertable surface resulting from the mining activities and the pit lake is not expected to extend beyond the mining lease or change groundwater conditions beneath ephemeral drainage lines.

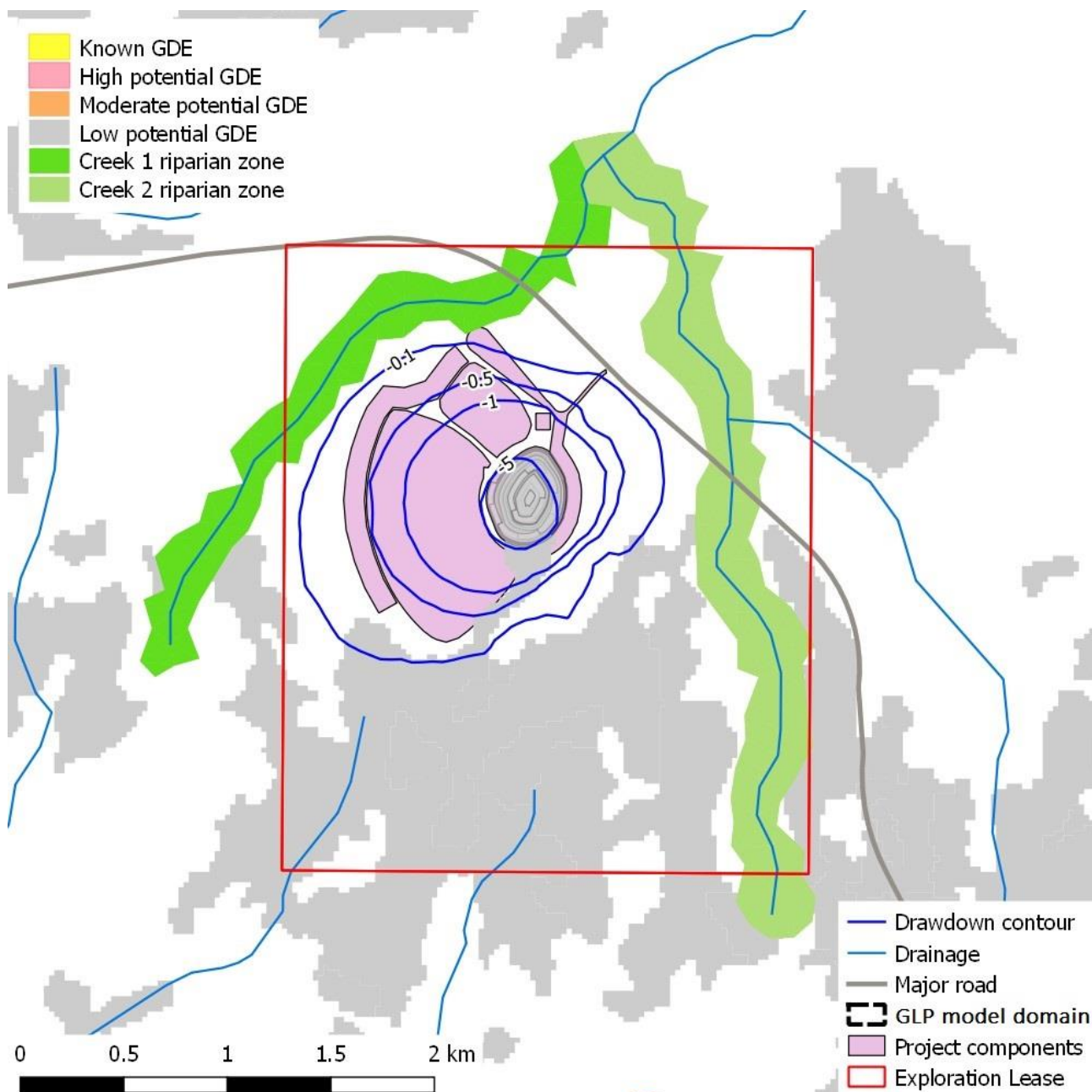


Figure 6-5 Post closure final drawdown contours after 70 years of recovery at year 2090.

6.2.3. Pit-lake formation and water budget

At the completion of mining the pit will infill over a period of approximately 50 years forming a pit-lake with a final water level of 12 – 13 mASL reached around

Conclusions

2070 (see Figure 6-6). With a surface elevation around 20 mASL this corresponds to a pit lake water level in the order of 7 – 8 m below the existing land surface.

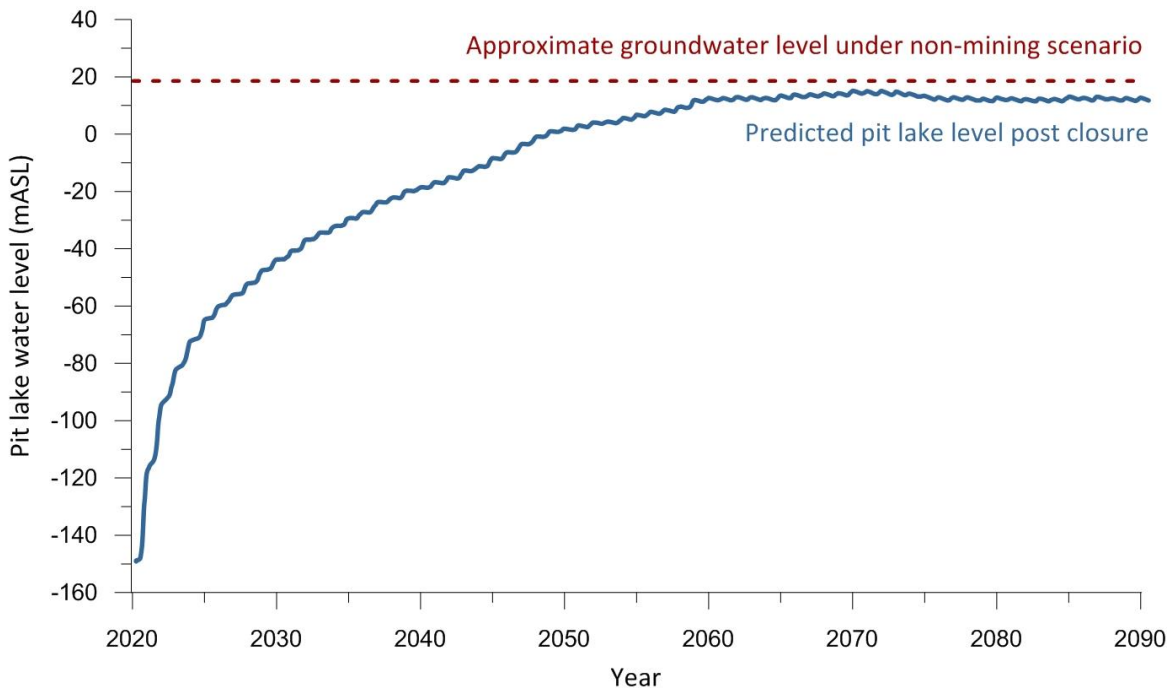


Figure 6-6 Pit lake water level after mine closure in mASL (metres above sea level)

Once dynamic equilibrium is reached (i.e. the pit water level has stabilised) the average annual components (2070 – 2090) of the pit water budget are:

- rainfall incident on the pit area 187 000 m³/yr
- groundwater flow into the pit 99 000 m³/yr (equivalent to 3 L/s)
- evaporation from the surface of the pit-lake 300 000 m³/yr

The pit-lake will only reach a level below the predicted 12 – 13 mASL if the groundwater inflow is less than 260 m³/d (~3 L/s) resulting in a deficit in the annual pit water budget. If groundwater inflows into the pit are greater than approximately 3 to 4 L/s the pit water lake will recover to a level approaching the pre-mining condition.

Under the modelled closure scenario the pit lake is categorised as a groundwater sink using the classifications in the Western Australian interim guidance on pit lake assessments (DMP, 2018). A pit lake operating as a groundwater sink has an average lake level that is lower than the surrounding watertable resulting in the creation of groundwater gradients toward the pit lake and groundwater discharge into the pit lake.

6.2.4. Pit-lake Salinity

The annual water balance components from the post mine forecast scenario have been used as an input into a mass balance model to estimate the water quality of the pit lake. For this model electrical conductivity (EC) has been used as the water quality indicator. The pit lake salinity has been estimated using the following equation:

$$Ps(n+1) = (Vp(n) \times Ps(n) + GWin \times GWs + R \times Rs - GWout \times GWs) / Vp$$

Where:

- $Ps(n)$ = Pit lake salinity at time step (Electrical conductivity in $\mu\text{S/cm}$)
- $Vp(n)$ = Pit Lake volume at time step (m^3)
- $GWin$ = Groundwater inflow into pit (m^3)
- $GWout$ = Groundwater outflow from pit (m^3)
- GWs = Groundwater salinity (Electrical conductivity in $\mu\text{S/cm}$)
- R = Rainwater inflow (m^3)
- Rs = Rainwater salinity (Electrical conductivity in $\mu\text{S/cm}$)

The inflow and outflow volumes are drawn from the model pit lake water balance from 2020 – 2090. The model assumes a groundwater input salinity of $220 \mu\text{S/cm}$ which represents the average EC from the deep monitoring bores across the site. The model assumes a rainfall salinity of $10 \mu\text{S/cm}$ which is consistent with Darwin rainfall EC from the peak wet season months (Crosbie et al, 2012).

The estimated pit lake salinity from mine closure to 2090 is shown in Figure 6-7. The model suggests that the pit lake salinity will rise from an initial value of around $40 \mu\text{S/cm}$ to a final salinity of $290 \mu\text{S/cm}$ in 2090.

Conclusions

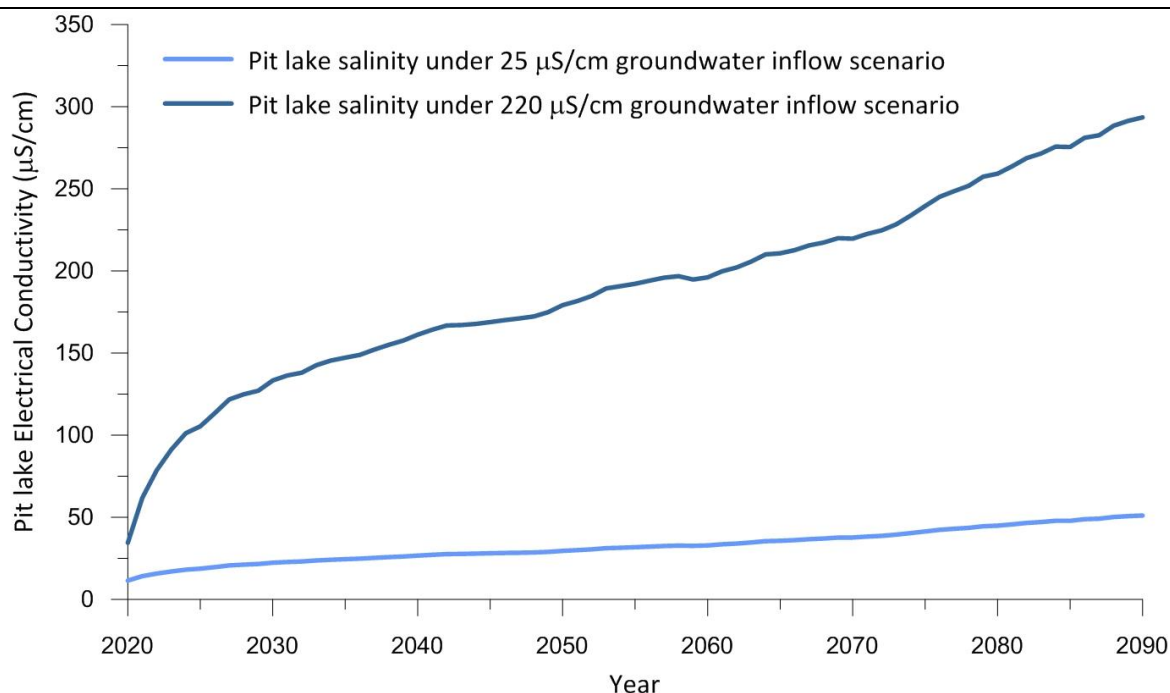


Figure 6-7 Projected pit lake EC under two groundwater EC inflow scenarios

A review of water quality sampling from other similar pit lakes/dams in the vicinity of the GLP shows Observation Hill Dam with an EC of 19 $\mu\text{S}/\text{cm}$ and an abandoned historic BP mining pit 5 km south of the GLP with a salinity ranging from 17 – 26 $\mu\text{S}/\text{cm}$. These results are notably fresher than the modelled salinity for the GLP pit lake and suggest that the mass balance model is overestimating the long term EC in the GLP pit lake. A contributing cause may be the groundwater input salinity, the model assumes a groundwater inflow EC based on the deep observation bores. Once the Lake level has stabilised the majority of groundwater inflow will be drawn from the shallow groundwater system. Water quality sampling results from observation bore GBW10 indicates the shallow groundwater has an EC in the order 25 $\mu\text{S}/\text{cm}$ in contrast to the deeper system with an average salinity of 220 $\mu\text{S}/\text{cm}$. Re-running the mass balance model with a groundwater inflow EC of 25 $\mu\text{S}/\text{cm}$ results in a final pit lake EC of 50 $\mu\text{S}/\text{cm}$, which is more consistent with EC values observed in neighbouring pit lakes/dams.

6.3. Impacts to existing users and environmental receptors

Based on the forecast scenarios, it appears that over the 70 year period considered by the groundwater flow modelling the only impacts will be to the area in the immediate vicinity of the mine footprint. No watertable drawdown impacts are

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predicted beyond the boundaries of the mining lease or underneath the ephemeral water course that drain the GLP site. No impacts are predicted to existing groundwater users - the nearest of which is over 13 km from the site – or groundwater dependent ecosystems from the pit dewatering activities.

6.3.1. Particle tracking

Forward particle tracks or streamlines can simulate the advective transport of solutes and are determined by releasing a number of particles from seeding points (in this case the nodes beneath the waste rock dump), into the groundwater flow field. The particles move along the hydraulic gradient (downgradient) until exiting the model at an outflowing boundary (or ending up in a zone without significant flow velocity). In this way forward particle tracks help visualize groundwater flow and can be used to determine the fate of solutes leaching into the groundwater system. Backward particle tracking can be used to delineate areas of contribution and capture zones. The use of streamlines assumes steady-state flow conditions.

Random-Walk Particle-Tracking (RWPT) solutions can be obtained by incorporating dispersive processes to the standard advective particle tracking. RWPT solutions are theoretically consistent with advection - dispersion equation solutions.

Table 6-2 Random walk particle tracking dispersive parameters.

PARAMETER	VALUE	UNIT
Effective porosity	0.02	[-]
Longitudinal dispersivity	10	[1/m]
Transverse dispersivity	1	[1/m]

6.3.2. End of LoM particle tracking

The fate of particles seeded beneath the waste rock dump (WRD) at the end of LoM are presented below in Figure 6-8. The majority of particles terminate at the pit to the east of the WRD as the groundwater gradient is towards the pit. A small proportion of particles beneath the northern portion of the WRD are not captured and terminate to the north of the proposed mine footprint. Reducing the size of the WRD or shifting the location of the WRD further south will result in a greater proportion of leakage being captured by the pit.

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Note that the analysis assumes that no additional recharge (associated with leakage from the waste rock) is assigned within the footprint of the WRD. Including recharge may result in a mound developing beneath the WRD and a greater proportion of the particles terminating to the north and northeast.

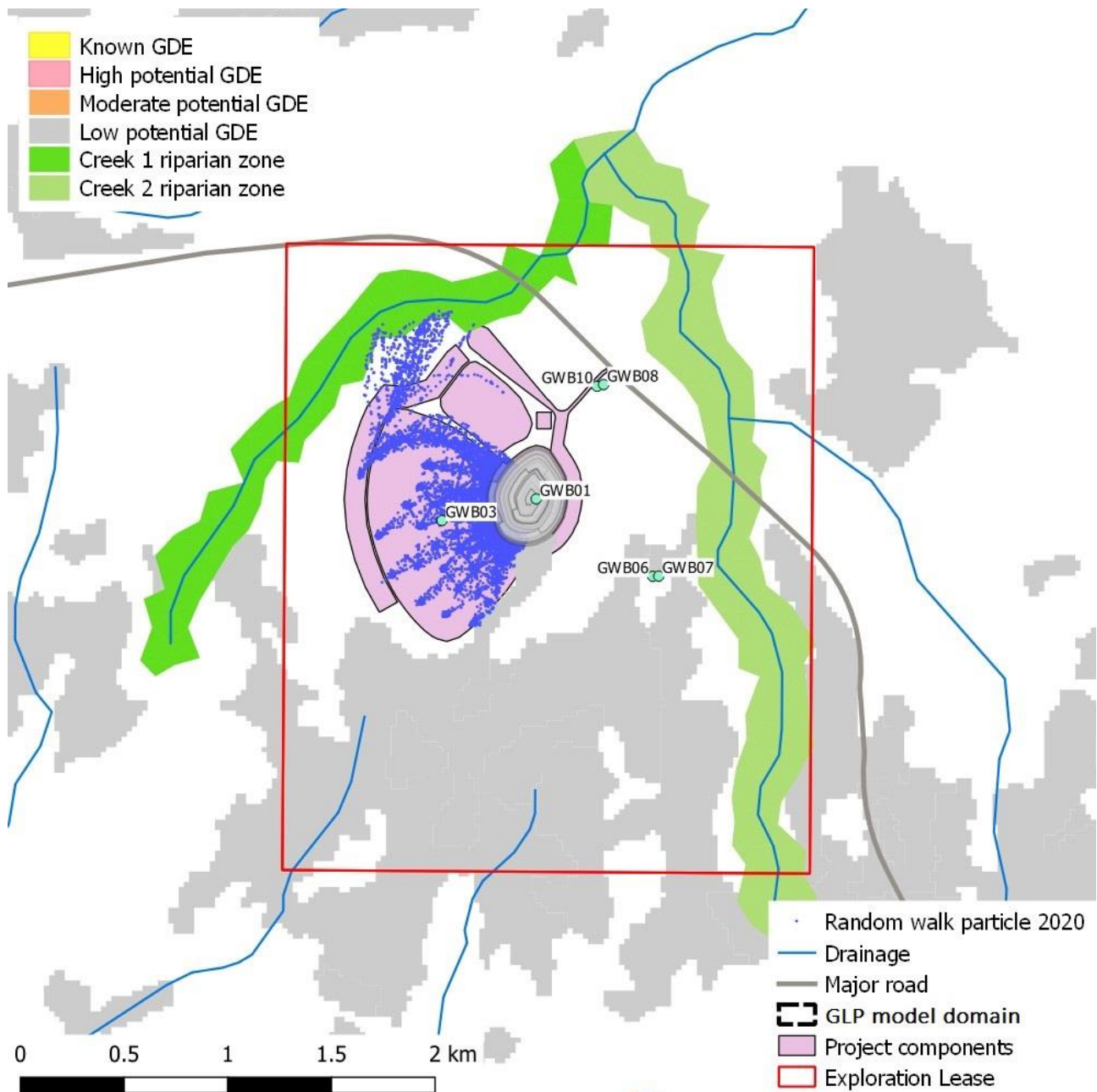


Figure 6-8 Random walk particle tracking at the end of LoM July 2020 (44013d).

6.3.3. Post closure particle tracking

Random walk particle tracking has also been used to investigate the fate of particles beneath the proposed waste rock dumps following closure of the mine

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(Figure 6-9). The parameters used to calculate the particle tracks are consistent with those used to determine particle tracking for end of LoM.

The particle tracks are similar to those determined for the end of LoM with the majority of the particles captured by the pit. However, the filling of the pit with water has reduced the gradient towards the pit-lake resulting in a greater proportion of particles in the northern portion of the WRD not being captured by the pit-lake and terminating north toward the drainage line.

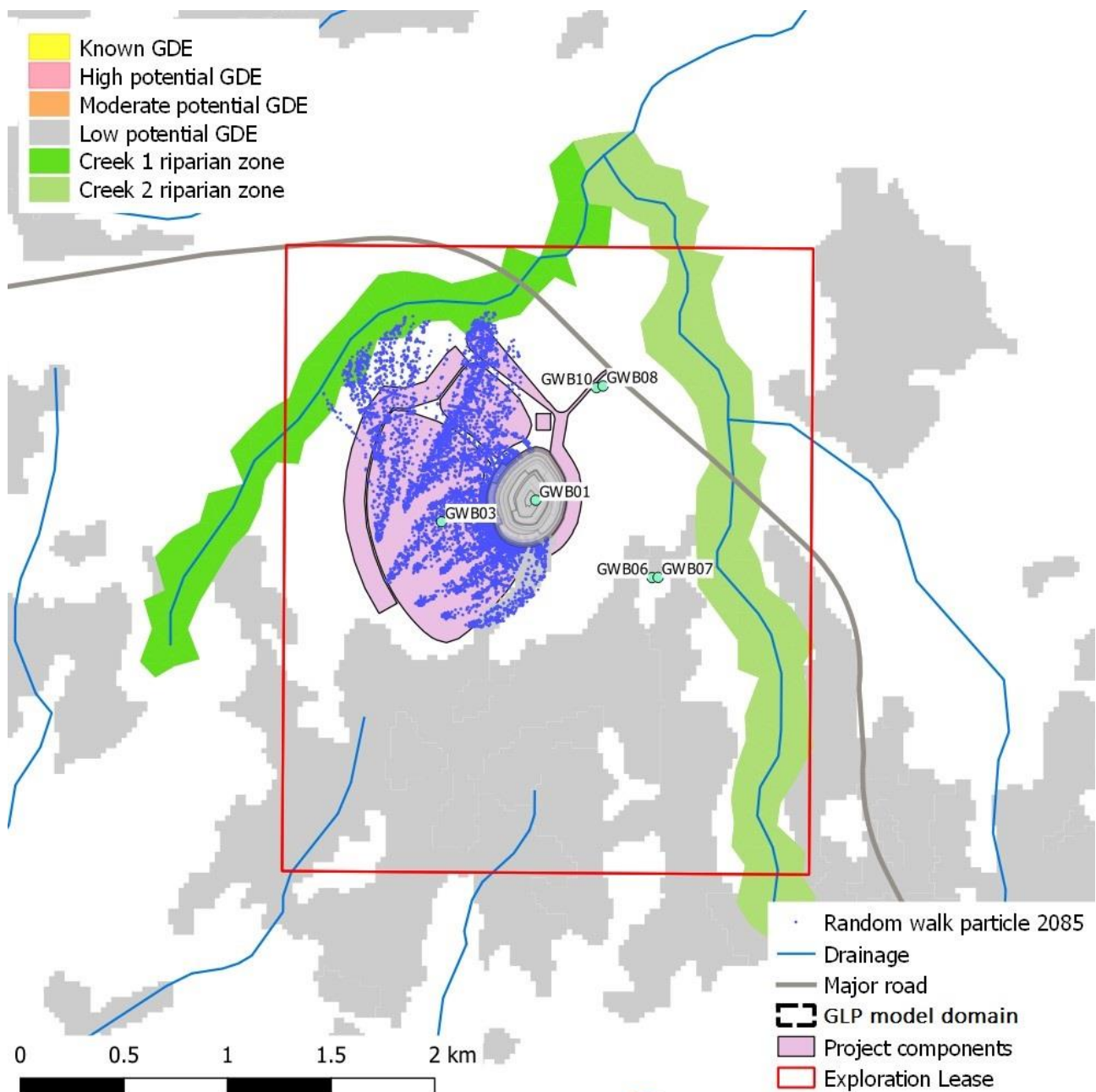


Figure 6-9 Random walk particle tracking at the end of post closure Oct 2090 (69672d).

7 Conclusions

A numerical model was developed to assess groundwater impacts resulting from the proposed development of an open cut lithium mine (Grants Lithium Project) situated on MLA31726 approximately 22 km west of Berry Springs. The mine is proposed to run for 25 months with the pit void being left to form a pit lake post closure.

The numerical groundwater model was developed using the FEEFLOW modelling code and was underpinned by a conceptual groundwater model. Model parameter estimation was undertaken in accordance with best practice guidelines (Barnett et al, 2008). The model is deemed to meet the requirements of a Class 2 model and is suitable for providing estimates of dewatering requirements for mines and the associated impacts.

Predictive scenarios were run to estimate impacts and pit inflows during the life of the mine (25 months) and to estimate impacts and simulate the development of the pit lake post closure (70 years).

Life of Mine Forecasts

Numerical model scenarios were run to assess groundwater impacts and pit inflows over the 25 month mining period. At the end of mining dewatering from the base of the pit will result in the development of a drawdown cone in the surrounding Burrell Creek Formation aquifer. The predicted drawdown cone extends approximately 1 km from the pit lake. It is not predicted to affect groundwater levels beneath ephemeral drainage lines or impact water levels outside the mining lease.

Groundwater inflow into the pit is expected to peak at 2000 kL/day (23 L/s) during the 2019 wet season before declining to around 1600 kL/day (18.5 L/s) for the remainder of the life of the mine.

Post Closure Forecasts

Numerical modelling of the mine site post closure predicts that the pit lake will fill slowly over a period of roughly 50 years before the water level stabilises at 12 - 13 mASL or around 7 - 8 m below the existing land surface. The pit lake is categorised as a groundwater sink using the classifications in the Western Australian interim

Conclusions

guidance on pit lake assessments (DMP, 2015). A pit lake operating as a groundwater sink has an average lake level that is lower than the surrounding watertable resulting in the creation of groundwater gradients toward the pit lake and groundwater discharge into the pit lake. As the pit lake will predominantly operate as a groundwater sink the water quality in the lake is not expected to influence the groundwater quality in the surrounding aquifer.

The formation of the pit lake will alter the groundwater flow regime around the mine site resulting in a decline in the watertable of around 5 m at the centre of the pit and a decline of 0.5 m at 500 m distance from the pit lake. The area where groundwater levels are predicted to change is largely coincident with the proposed mine footprint. No change in the watertable surface is predicted at the ephemeral water courses that drain the mine site or beyond the boundary of the mining lease.

Mass balance modelling based on the pit lake water budget from the numerical modelling predicts that 70 years after mine closure the Electrical Conductivity (EC) of the pit lake water will be between 50 - 300 $\mu\text{S}/\text{cm}$. The final pit lake EC is heavily dependent on the water quality of the groundwater inflow. Water quality samples from neighbouring Observation Hill Dam and an abandoned BHP pit 5 km south of the GLP range from 19 - 26 $\mu\text{S}/\text{cm}$ and suggest the final pit lake EC is likely to be at the lower end of the predicted range.

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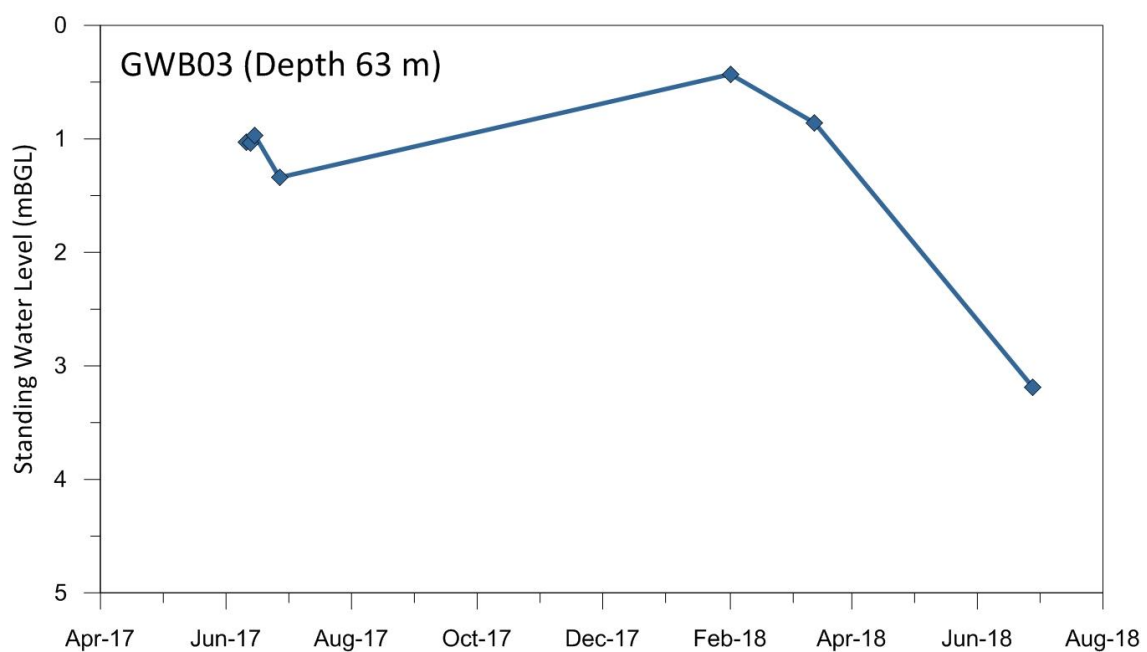
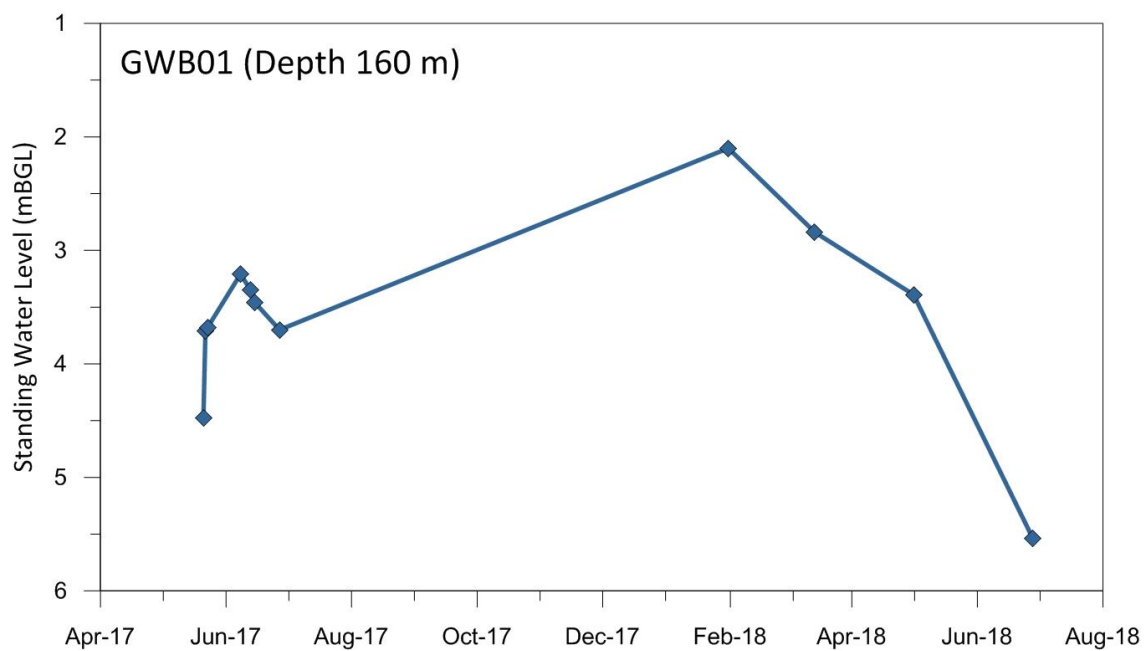
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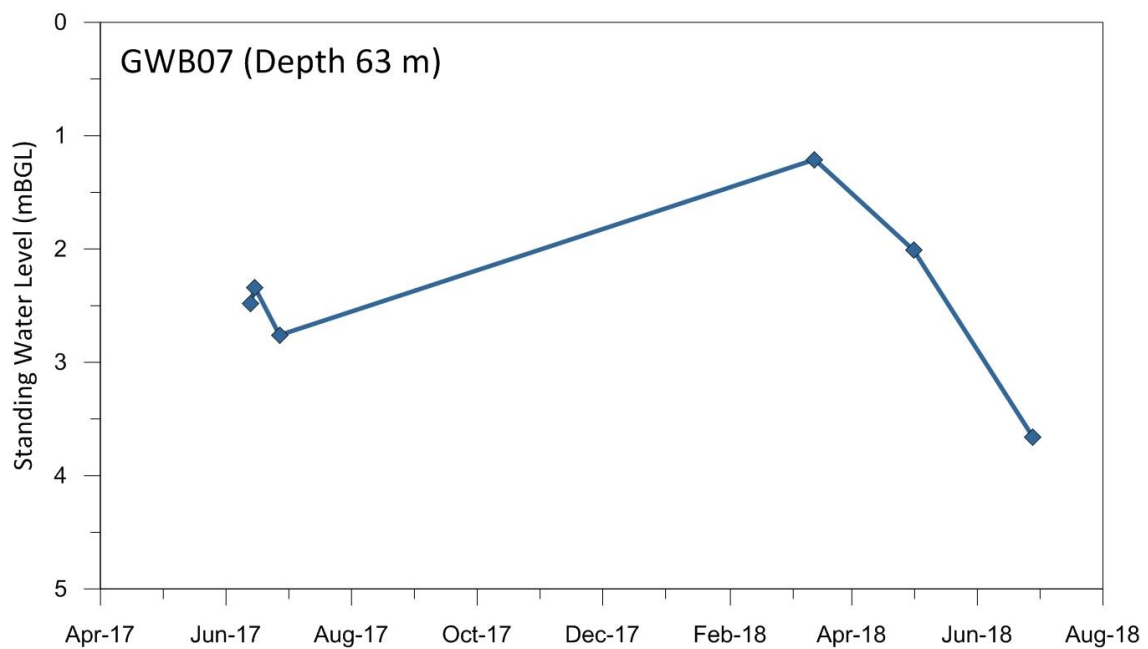
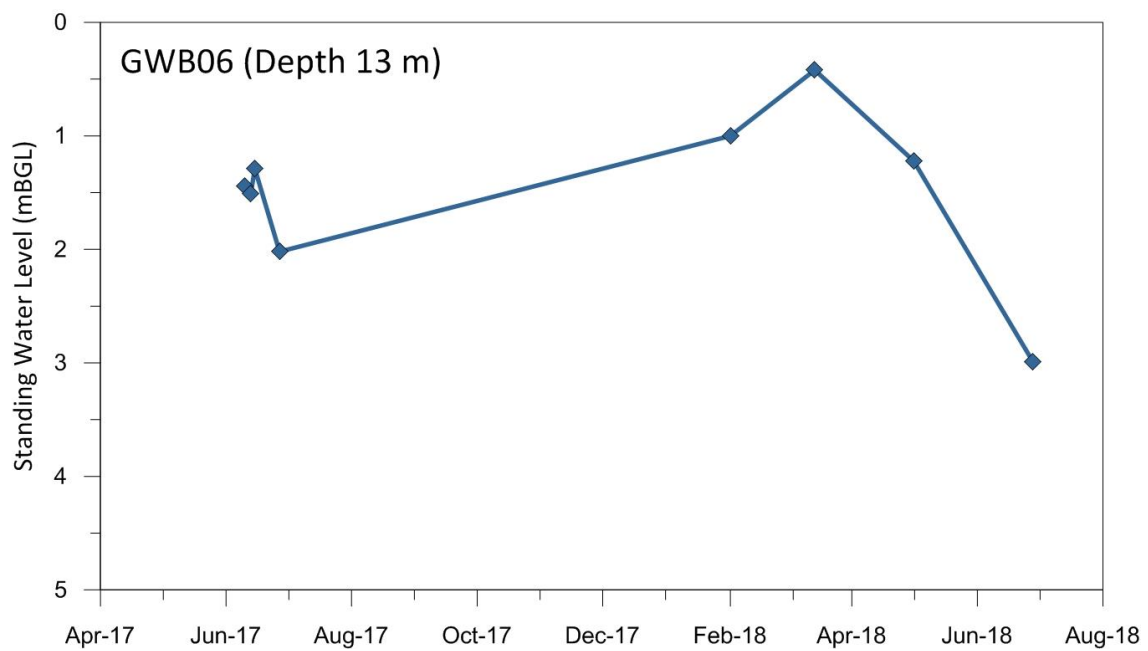
9 Document history and version control

<i>VERSION</i>	<i>DATE RELEASED</i>	<i>APPROVED BY</i>	<i>BRIEF DESCRIPTION</i>
0.1	01/03/2018	AK	Draft containing available data and conceptualisation.
0.2	27/07/2018	AK/SF	Draft report released to EcOz for comment
1.0	20/09/2018	AK/SF	Final

Appendix A Water level hydrographs



Appendix



Appendix

