Jervois Base Metals Mine Groundwater Impact Assessment Supplement

DRAFT version 0.3

PREPARED FOR NITRO SOLUTIONS ON BEHALF OF KGL RESOURCES BY CLOUDGMS

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Executive summary

Introduction

CloudGMS completed the groundwater impact assessment for the draft EIS for the Jervois Base Metal Project. The assessment presented the impacts of groundwater extraction from the mining activities and abstraction from the Jervois Project borefield during mine operation and closure. As part of the impact assessment a conceptual groundwater model based on regional data was developed and a fit for purpose groundwater model was developed and calibrated to assess dewatering the pits and underground mines and process water supply impacts on groundwater resources.

A Groundwater Management Plan for the Jervois Project was also completed as part of the draft EIS for the Jervois Base Metal Project by CloudGMS.

These two reports were submitted as an appendix in the draft EIS and comments from various stakeholders were received in regard to groundwater assessment.

The draft EIS for the Jervois Base Metal Project was submitted to Northern Territory Environment Protection Authority (NT EPA) in October 2018. The comments on the draft EIS from various stakeholders were received in December 2018. The NT EPA has directed KGL Resources to prepare a Supplement Report to the draft EIS to address all matters that were raised in the submissions during the exhibition period.

Subsequent to the draft EIS submission, CloudGMS completed Phase 1 of the groundwater supply study on Lucy Creek station to demonstrate borefield yields suitable for the Jervois Mine processing supply. The Project requires a water supply of up to 63L/s for ore processing for a projected mine life of 10 years. The process water supply borefield is located on Lucy Creek Station around 20km to the north of the Project.

The groundwater supply study used information from the drilling program by Tomlin Drilling over a three week period from 23rd July to 11th August 2018. Phase 1 investigation bores were drilled at nine sites, six sites in Area 1 and three sites in Area 2, including the construction of two test production bores, one in each of the two investigation areas and seven monitoring bores. Further drilling targets were identified to secure sufficient water supply for the Project. The results of this investigation are presented in CloudGMS (2018) Jervois Base Metals Project Lucy Creek Water Supply Investigation v0.1

Additional investigation drilling and installation of monitoring bores was undertaken in October 2018, typically to less than 100 metres depth. Across all investigations, a total of 15 bores were completed and baseline groundwater levels, water quality and estimates of hydraulic parameters determined and presented in CloudGMS (2018) Jervois Base Metals Project Mine Site Groundwater Investigation v0.1.

This document has been prepared to address the identified Scope of Works and specific requirements for the Supplement EIS Report.

CloudGMS Pty Ltd was commissioned by Nitro Solutions Pty Ltd on behalf of KGL Resources Pty Ltd (KGL) to carry out a groundwater impact assessment of the Jervois Base Metal Project (JBMP / the Project), located approximately 270 km east-north-east of Alice Springs, Northern Territory. This work contributes to the Environmental Impact Statement (EIS) for the Project. The objectives of the groundwater impact assessment were to identify issues and opportunities, and clarify implications for groundwater management, as well as to address the specific requirements for the Supplementary EIS Report.

This hydrogeological and modelling report covers the Project mine site and the associated process water supply borefield. The emphasis of this report is the impact assessment of groundwater extraction from the mining activities and abstraction from the borefield during mine operation and closure.

Context

The proposed Jervois Base Metal Project (the Project) involves mining copper and other base metals from at least five deposits.

Ore would be processed onsite using a crushing, grinding and flotation plant, producing copper and lead/zinc concentrate. The process requires up to 2000 megalitres per year of water, for a mine life of 10 years, to be supplied from an existing fresh water catchment dam and a borefield developed near the Project. Waste material would be stored in a tailings dam with two cells and a capacity of up to 20 million tonnes (Mt) and three waste rock storage areas containing approximately 87 Mt. Some waste may be eventually stored in underground and/or open cut residual voids.

The water supply for the Project comprises a borefield completed into the carbonate rocks of the South Georgina Basin (Georgina Basin Carbonate Aquifer - GBCA).

Impact Assessment

The requirements of the EPA Terms of Reference (ToR) for assessment of the project (NTEPA August 2017) are summarised in Table 1 below and addressed briefly. Cross references to the relevant detailed report sections are provided.

The main operational groundwater impact of the Project is the drawdown of groundwater levels due to pumping from the process water supply borefield and dewatering at the mine site during mining activities, with post-mining effects relating to the recovery of groundwater levels and the effects of residual pit voids and underground workings.

The proposed extraction at the process water supply borefield is within the capacity of the aquifer and removes a very small fraction of the immense volume in storage. Water table drawdown impacts at the nearest sensitive receptors (Lucy Creek domestic water supply and stock watering bores) are unlikely to exceed 3 m. This drawdown will not reduce water availability for these users due to the very significant available drawdown at each site. There are no mapped Groundwater Dependant Ecosystems identified within the zone of drawdown, although there is the presence of deep-rooted species along Arthur Creek which may be considered facultative GDE species..

The groundwater impacts associated with mine dewatering are relatively localised around the mining activities and the forecast drawdowns at the closest identified existing users Maperte and Orrtipa Thurra.

Waste rock dump seepage is expected to be non-acid forming. Particle tracking indicates that the ultimate fate of groundwater affected by WRDs seepage will be captured by the local sink features associated with the pits and underground workings during life of mine and the pit-lakes post closure.

During operations the process water will dominate seepage quality, and will be alkaline (PH around 9). After closure, once the process water has eventually seeped away, the tailings will oxidise and start producing acid. The TSF cover reduces the transport of the oxidation products, but does not stop the oxidation, just greatly reduces the load reporting to the groundwater system. The TSF will be designed to intercept tailings liquor. Seepage that is not intercepted and recycled will slowly flow to the water table and is likely to cause groundwater rises (although this will be dependent on the efficiency of the underdrainage system) and change groundwater quality beneath the TSF. Particle tracking indicates that the ultimate fate of groundwater affected by TSF seepage will be captured by the local sink features associated with the pits and underground workings during life of mine and the pit-lakes post closure.

Table 1 EPA terms of reference

EPA ToR	Description	Section Reference
Existing Environment		
Groundwater Regionally	Southern Georgina Basin Regional scale sedimentary basin aquifer system	3.5
Groundwater Locally	Fractured rock groundwater system with limited water resources	3.5
Extent	The Southern Georgina Basin Carbonate Aquifer is part of the regionally extensive Georgina Basin that underlies approximately one quarter of the Northern Territory and extends beneath the northwest of Queensland.	3.5
Connectivity	Georgina Basin Carbonate Aquifer connected to the underling fractured rock in areas where the basin sediments on-lap the fractured rock	3.5
Catchment	Regional scale catchment with flow converging to the Georgina Basin Carbonate Aquifer then eastward	3.5
Flow paths	Groundwater flow divide to the west of the project	3.9
Volumes/capacities	Regional scale, extensive and transmissive aquifer. Estimated drainable groundwater volume of 160 – 320 cubic kilometres	3.5
Depths	Ranges from pinch out at the margins to >1000m deep in thick parts of the basin	3.5
Types	Regionally un-confined connected basin aquifer system comprising carbonate sediments	3.5
Chemistry	Groundwater is generally fresh to brackish (500-3000 mg/L TDS). The salinity is suitable in many instances for potable use (<1000 mg/L), and most bores report water suitable for stock watering	3.10
Areas of recharge	Direct infiltration to outcropping or thinly covered aquifers and stream flood- outs. Rate estimates range from 0.2 to 12 mm/year.	4.5
Environmental Values	Potable use in most instances including around the mine site and pastoral use for stock watering at the borefield site.	3.10.3
Uses and third party users	Pastoral bores (nearest 1km from borefield). Domestic water supply (nearest Lucy Creek homestead bores, 17km from the process water supply borefield and 25km from the mine site) Outstation water supply (Maperte 17km NE of mine and 18km SE of the process water supply borefield) Community water supply (Orrtipa-Thurra, 18km to SW of mine).	3.12
Pre-mining Hydrogeological Model	Numerical model constructed consistent with guidelines.	5
Prepared by qualified person	Modelling by Anthony Knapton CloudGMS Pty Ltd	5
Risk Assessment		
Environmental objective	Extraction of water within sustainable limit of aquifer without social or environmental impact	
Water table drawdown	Unlikely that a drawdown of more than 3 m will result at any receptor including Pastoral users, Communities and GDEs.	
Seepage from stockpiles including tailings	Low risk at waste rock dumps are non-acid forming (NAF) Seepage is not saline. Tailings are potentially-acid forming (PAF) Seepage is not saline.	
Spills	Low risk to deep water table. Will be considered a soil contamination risk Standard storage and handling methods must be applied.	

Table of Contents

List of Figures

List of Tables

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 Background

1.1. Introduction

CloudGMS completed the groundwater impact assessment for the draft EIS for the Jervois Base Metal Project. The assessment presented the impacts of groundwater extraction from the mining activities and abstraction from the Jervois Project borefield during mine operation and closure. As part of the impact assessment a conceptual groundwater model based on regional data was developed and a fit for purpose groundwater model was developed and calibrated. The model was used to assess dewatering the pits and underground mines and the process water supply impacts on groundwater resources.

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This document has been prepared to address the identified Scope of Works and specific requirements for the Supplement EIS Report.

KGL Resources are in the planning and approval stage of developing a base metals project at Jervois, located approximately 270 km north-east of Alice Springs. The proposed Jervois Base Metal Project (JBMP / the Project) involves mining copper and other base metals from at least five deposits.

Ore would be processed onsite using a crushing, grinding and flotation plant, producing copper and lead/zinc concentrate. The process requires approximately 2000 megalitres per year of water, to be supplied from an existing fresh water catchment dam and a borefield to be developed near the Project. Waste material would be stored in a tailings dam with two cells and a capacity of up to 20 million tonnes (Mt) and three waste rock storage areas containing up to 87 Mt. Some waste will eventually be stored in underground and/or open pit residual voids.

The NT EPA decision (NT EPA Statement of Reasons March 2017) that the Jervois Base Metal Project required formal assessment in the form of an Environmental Impact Statement was based on the following potential environmental risks and impacts relating specifically to groundwater resources:

- Risks to the quality of and accessibility/availability to shared regional groundwater resources from the development, operation and closure of the Project
- The Project has the potential to deplete the groundwater aquifers and impact on the recovery potential of regional groundwater aquifers. In an area of water scarcity, restricted or diminished access to water by existing water users has the potential to have broader social, economic and cultural impacts that have yet fully be scoped by the Proponent. The NT EPA considers that the water requirements support the altered Project are still significant and that the potential social, and cultural impacts from the altered Project are consistent to those initially referred the NT EPA.

The NT EPA Terms of Reference for the Preparation of an Environmental Impact Statement Jervois Base Metal Project KGL Resources (August 2017) sets out the requirements of the EIS and this document specifically addresses the groundwater component of these requirements. This study presents a hydrogeological (groundwater) characterisation study, groundwater impact assessment and groundwater management plan for the Jervois Base Metal Project (JBMP) Environmental Impact Statement (EIS).

1.2. Modelling objectives

The objective of the JBMP groundwater model is to identify potential impacts to the groundwater system and associated environmental receptors resulting from the development of the proposed base metals mine and associated process water supply. That objective information is then used to develop the principles for the groundwater management plan.

1.3. Scope of works and modelling process

This hydrogeological and modelling report has been prepared to address the original requirements of the EIS and the specific requirements for the supplemental groundwater impact assessment :

1. The requirements of the NT EPA Environmental Impact Statement Terms of Reference for assessment of the Jervois Base Metal Project KGL Resources (NTEPA, 2017).

2. Development of a groundwater management and monitoring plan (GMMP) for planning and operation of the JBMP.

The proposed supplemental groundwater impact assessment also addresses the following specific requirements with reference to the collated comments submitted in response to the draft EIS (Table 2 Scope of Works):

- Update the conceptual groundwater model to include local groundwater bore data, to demonstrate a sound understanding of groundwater levels and water quality, and to investigate the implications for pit water quality and associated management strategies; Provide details on the bores at the mine site and borefield area(s) that are used to inform groundwater investigations and modelling;
- Provide objective information on uncertainties and the level of confidence of the model;
- The groundwater impact assessment will satisfy the requirements of the Jervois Project ToR, and to address the following specific comments:
    - Impacts to groundwater during operation, closure and post-closure,
    - Identify water demand, water abstraction and predicted effects on local and regional drawdown (including Maperte) and other impacts;

  - Provide a clear understanding on long term drawdown impacts beyond 200 years;
  - Impacts to Red Gum community and other groundwater dependant ecosystem (GDE);
  - Impacts on stygofauna;

- Establish a groundwater monitoring program to satisfy the requirements of the Jervois Project ToR and to address the specific comments relating to the EIS including a regional and local monitoring program for GDE, AMD and final voids post closure; including contingency plans for unexpected groundwater results;
- Mitigation measures to address the impacts and update the Groundwater Management Plan with all the findings and mitigation strategy;
- Risk assessment approach to be undertaken in identifying and analysing the environmental impacts outlined in Section 4.1 of the ToR, including:
  - the assessment of cumulative impacts outlined in Section 4.3 of the ToR; and
  - a post-closure risk assessment.

The groundwater modelling study has been undertaken using a staged approach and reviewed by a competent groundwater modelling professional 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. Modelling studies are usually an iterative process, and this study is the second stage in the ongoing development of a model suitable for operational planning and benchmarking of monitoring targets.

The modelling guidelines identify that a model should be constructed according to the conceptualisation and design, and documented as built. It is reasonable and sometimes essential for the conceptualisation, design and/or construction to change as more is learned about the system and the way it can be represented.

The current document details the following steps in the process:

- A collation of available data for the Project site is presented;
- The available data is then assessed and interpreted to provide a conceptual model of the groundwater system; and
- The initial design and configuration of the groundwater model that will be used in the calibration stages is then described;
- Calibration of the steady state ('long term average') and transient (time-varying) groundwater flow model
- Predictive scenario modelling to assess the potential for mining impacts;
- Predictive uncertainty analysis.

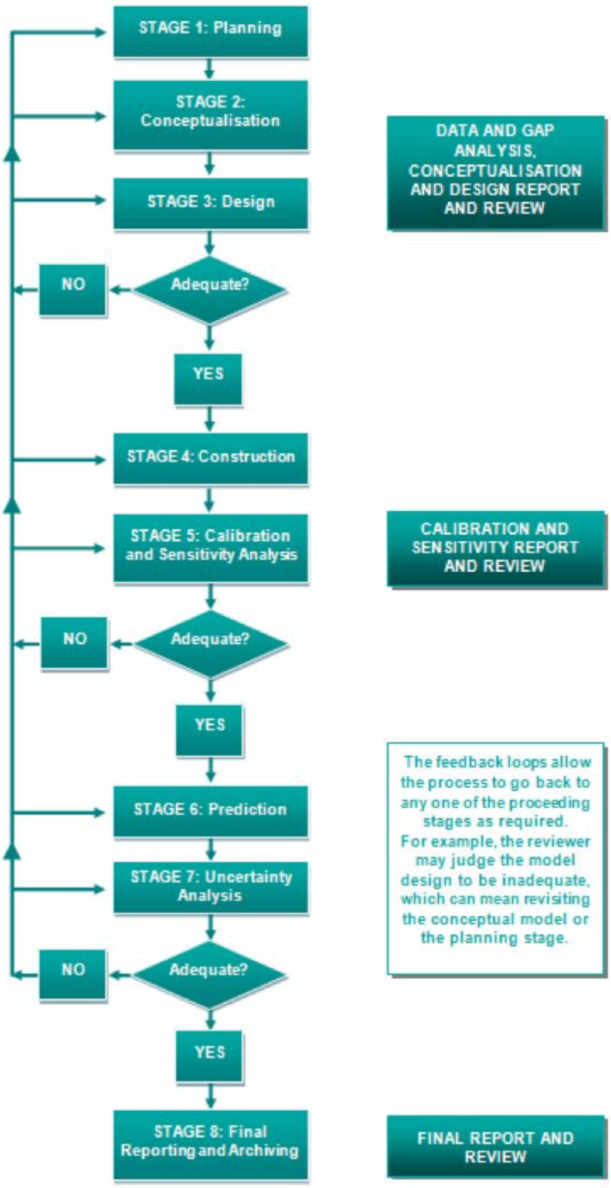


Figure 1-1 Groundwater modelling process after Barnett et al, (2012)

1.4. Model classification

The Australian Groundwater Modelling Guidelines (Barnett et al., 2012) introduced the concept of confidence level classification to characterise the confidence in the model to simulate potential future effects. This depends primarily on whether or not:

- Future stresses to be predicted by the model are similar to those of the past
- Predictions are required for a period of time similar to that of historical observations
- Available data sufficiently characterises hydrological features of most relevance to model predictions
- The model can be calibrated to available data.

Most groundwater models do not satisfy all characteristics of a particular confidence level class outlined in the guidelines. The main challenge for mining project models is that future changes to groundwater systems are often large compared with those observed in the past, which can suggest relatively low confidence in the cause and effect relationships simulated by the model. On the other hand, careful model design and sensible parameterisations ensures the model outputs are mathematically sound and provides an appropriate basis for informing potential project-related impacts on groundwater.

For the Jervois project, the indicators suggesting a low confidence level include the length of the predictive timeframe that exceeds the calibration timeframe and the magnitude of future stresses that is large compared with the past. Characteristics indicating higher confidence levels include acceptable calibration statistics, low mass balance error (<0.1 per cent), sensible parameterisation consistent with the conceptual model and appropriate model design/spatial discretisation for the intended model use. Based on the consideration of the above, the groundwater model developed for the Jervois project is considered to have the characteristics of a Class 2 confidence level mainly, with a few components that are Class 1 and Class 3. That is, a moderate model confidence level, 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.

Table 1-1 Model confidence classification (Barnett, et al., 2012).

Class		Data		Calibration		Prediction		Quantatative Indicators
1 Simple		Not much / Sparse coverage		Not possible		Timeframe >> Calibration		Timeframe > 10x Calibration
	✓	No metered usage		Large error stats		Large stresses / periods		Stresses > 5x
		Low resolution DEM		Inadequate data spread		Poor / no validation		Mass balance > 1% (or one off 5%)
		Poor aquifer geometry		Target incompatible with model purpose	✓	Transient prediction using steady-state calibration		Properties <> field values
		Basic/Initial conceptualisation						No review by hydrogeologist / modeller
2 Impact assessment	✓	Some data / Ok coverage		Weak seasonal match	✓	Timeframe > Calibration		Timeframe 3 - 10X
		Some usage data / low volumes		Some long term trends wrong		Long stress periods		Stresses 2 - 5x
		Baseflow estimates		Partial performance (eg some stats / part record / model measure offsets)		Ok validation		Mass balance < 1%
	✓	Some K + S measurements	✓	Head & flux targets used to constrain calibration		Calibration & forecast consistent (transient or steady-state)		Some properties <> field values. Review by hydrogeologist
	✓	Some high res topo DEM and /or some aquifer geometry		Non-uniqueness and qualitative uncertainty partially addressed	✓	Significant new stresses not in calibration		Some coarse discretisation in key areas of grid or at key times
	✓	Sound conceptualisation, reviewed and stress tested	✓	Good performance stats		Timeframe ~ Calibration		Timeframe < 3x
3 Complex simulator		Plenty data, good coverage		Most long term trends matched		Similar stresses & periods		Stresses < 2x
		Good metered usage data		Most seasonal matches Ok		Good validation	✓	Mass balance < 0.5%
		Local climate data		Present day head / flux targets, with good model validation		Transient calibration and forecast	✓	Properties ~ field values
		Kh, Kv and storage from range of tests		Non-uniqueness minimised, qualitative uncertainty justified		Similar stresses to those in calibration	✓	No coarse discretisation in key areas (grid or time)
		High res topo DEM all areas and good quality aquifer geometry					✓	Reviewed by experienced modeller
		Mature conceptualisation						

1.5. Key Limitations

Assumes no surface water runoff into the pits.

The magnitude of future pumping stresses are large compared with those applying in the past.

2 Physical setting

2.1. Location

The planned Jervois Base Metals Mine (the Project) is located approximately 270 km north-east of Alice Springs in the Northern Territory (-22.65°, 136.27°). Access is via the Plenty Highway, which passes within 15 km of the project (Figure 2-1).

There are two Aboriginal communities within 20 kilometres of the Project. The Orrtipa-Thurra (Bonya) Community is approx. 18 kilometres to the south-west and the Maperte Outstation is approx. 17 kilometres to the north-east.

The closest homestead is at Lucy Creek station located approx. 25km to the north of the mine site.

The location of the Project relative to the communities and pastoral properties is presented below in Figure 2-1.

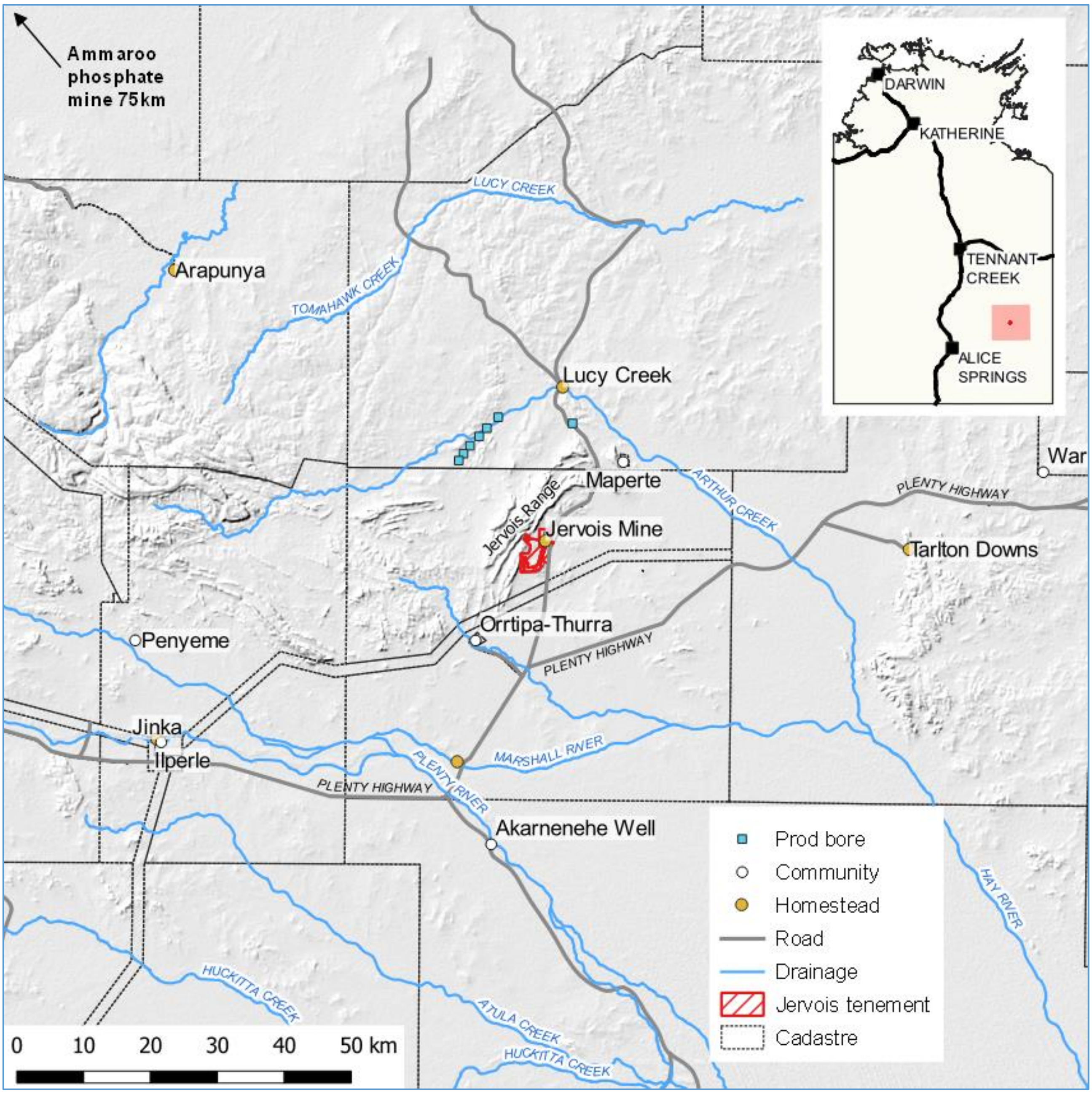


Figure 2-1 Location of the Project and study area.

2.2. Previous studies

Technical reports related to the study area available online from the Department of Environment and Natural Resources Water Resources Division are presented below in Table 2-1.

Table 2-1 Available hydrogeological reports available online by the DENR.

Author	Year	Title
CloudGMS	2018	Jervois Base Metals Mine EIS Groundwater Impact Assessment, Adelaide: Unpublished.
CloudGMS	2019	Jervois Base Metals Project Lucy Creek Water Supply Investigation
CloudGMS	In prep	Jervois Mine Site Groundwater Investigation Field Report

2.3. Previous groundwater modelling studies

2.3.1. Ammaroo phosphate mine

Groundwater modelling studies have been conducted in the area (CloudGMS, 2018), and a numerical groundwater modelling study has been completed for the Ammaroo Phosphate Mine (170km to the northwest of the Jervois mine site) and modelled the carbonate aquifers in the southwestern Georgina Basin area with similar hydraulic properties as those targeted by the Project process water supply borefield. The study considered the impacts of a 140 L/s mine process water supply (12,100 kL/d / 4415 ML/yr) operating for 25 years. The study employed parameter uncertainty to examine the drawdown at identified communities and pastoral bores.

Under the range of hydraulic parameters considered by the Ammaroo modelling study, it was found that, at a distance of approx. 10 km from the borefield (a smaller distance than between the Project process water supply and Lucy Creek homestead), the drawdown can be expected to be between 1 and 5 metres, with 95% of realisations indicating a drawdown of less than 4 metres can be expected. At a distance of approx. 20km from the Ammaroo borefield the drawdown can be expected to be between 0.5 and 4 metres, with 95% of realisations indicating a drawdown of less than 3 metres. It should be noted that the pumping rate considered for the Ammaroo modelling is more than twice that expected for the Project process water supply and 2.5 times the duration of the Project, so the drawdowns due to the Project process water supply borefield are expected to be less than those estimated for the Ammaroo borefield.

3 Available data

3.1. Climatic data

Climatic data are available at several rain gauges in the area. However, to ensure the continuity of data the SILO data drill was used to provide rainfall and evaporation data for this study. The SILO data site was located at Latitude, Longitude: -22.65 136.25 (Decimal Degrees), 22°39'S 136°15'E, and Elevation: 398m. This site is the closest SILO calculation location to the mine site, which has a resolution of 0.05 degrees. The rainfall data is presented in Figure 3-1 as annual totals with a trace of mass residual to show long-term trends in the rainfall record. Average annual rainfall is 224.5 mm and average daily rainfall is 0.6 mm/d. Average annual pan evaporation is 3120 mm and exceeds average annual rainfall by more than 10 times.

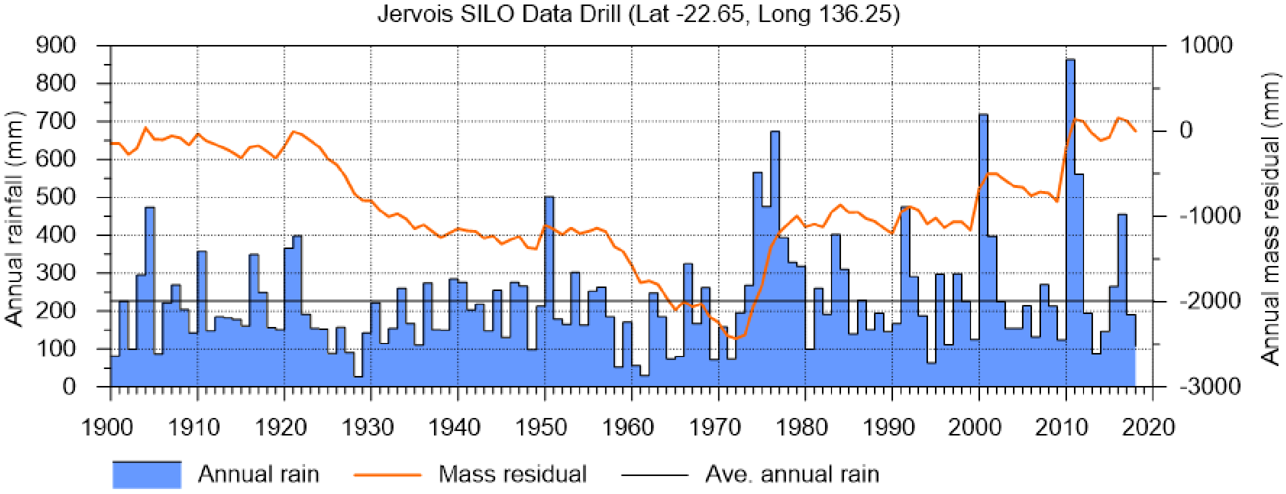


Figure 3-1 Annual SILO rainfall totals with a trace of mass residual to show longer term trends in the rainfall (1900-2018).

3.2. Topographic data

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 horizontal resolution is 1 second (about 90 metres) and the vertical resolution is 1 metre.

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 6 m (Farr, et al., 2007).

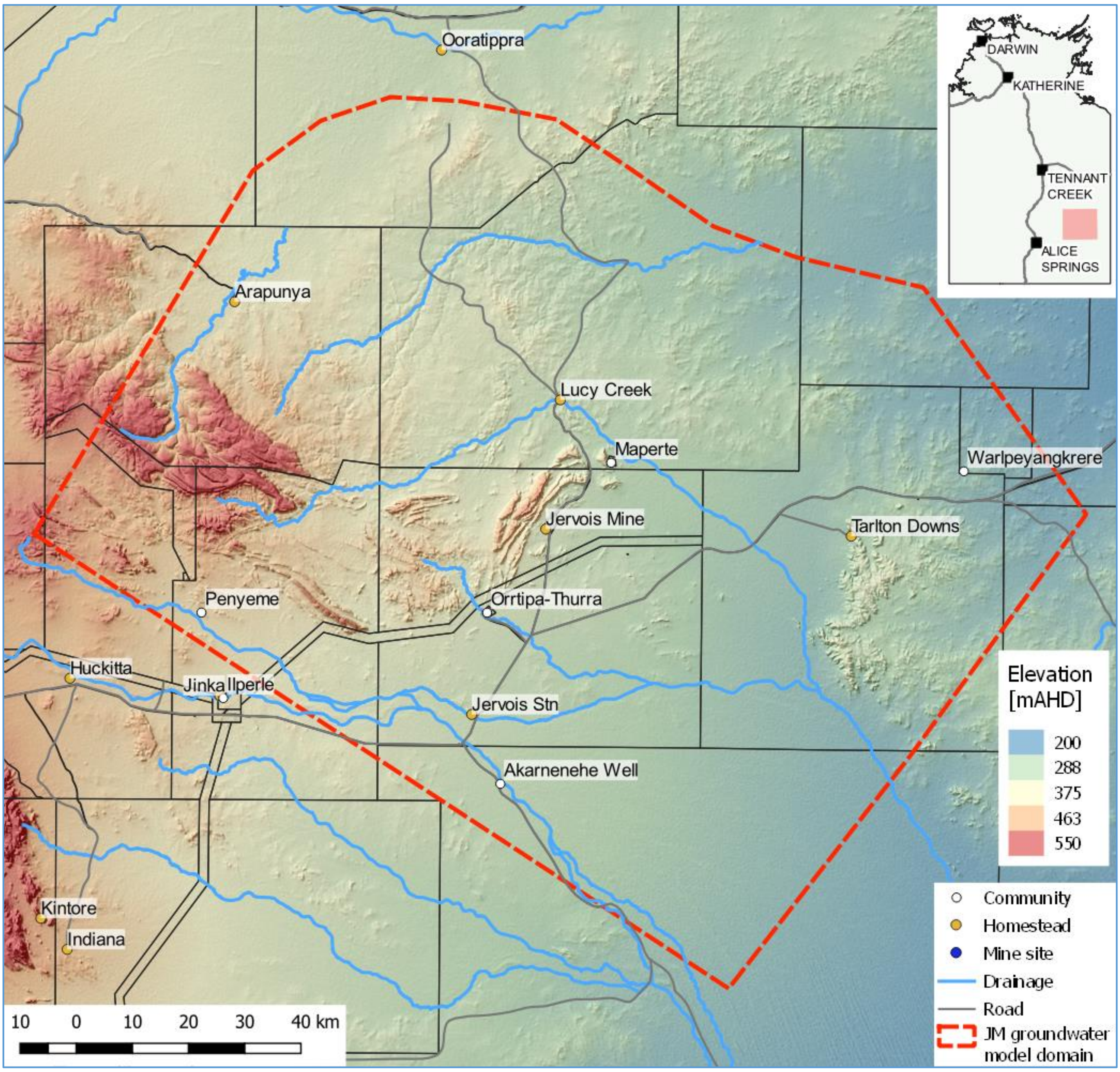


Figure 3-2 Topography of the study area with surface water drainage

3.3. Hydrology

The project area climate is arid with median rainfall of 150- 200mm. Most rain falls in the summer months, however, this can vary considerably from year to year. The project area is crossed by a number of non-perennial creeks/rivers such as Bonya Creek and Thring Creek, which both feed into the Plenty River to the southeast.

Surface water is non-perennial, and there are no known accurate records of surface water hydrology in the study area. Water levels in Unca Creek (G0070009) are available from DENR for the period 1972 – 2011.

Detailed hydrology of the study area is presented by WRM Water & Environment (2018).

3.4. Geological setting

3.4.1. Regional geology

The regional geology is presented in detail in CloudGMS (2018). In summary the mine site is located in the Bonya Metamorphics of the Arunta Block, and the mine water supply borefield about 25 km north is located in the carbonate sediments of the Georgina Basin.

The water supply borefield is located near Lucy Creek station, 25 km north of the JBMP, where the thin Cambrian sediments of the southern Georgina Basin onlap to the Paleoproterozoic basement rocks of the Arunta Block (Figure 3-3). The Georgina Basin is a large regional scale, intracratonic sedimentary basin of sandstones, shales and dolostones that extends across western Queensland and large areas of the eastern Northern Territory. The Georgina Basin sediments deepen and thicken to the north and west of Lucy Creek and dip to the north and north-east.

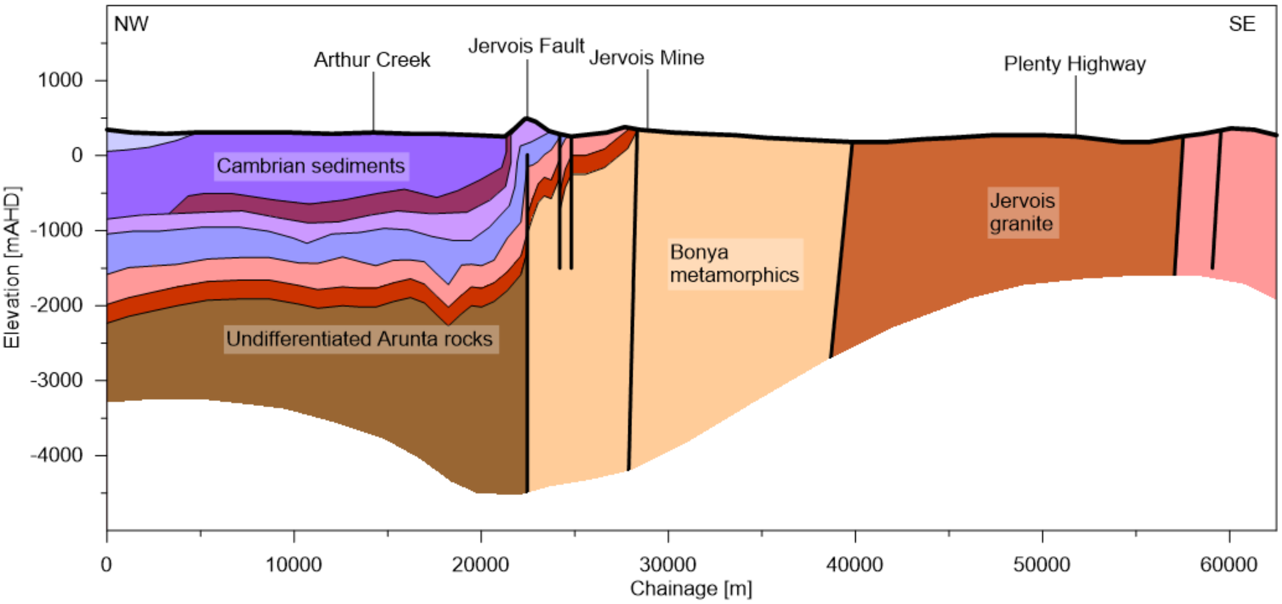


Figure 3-3 Geological cross-section through the study area showing the relationship between Cambrian sediments, and Fractured Rocks units comprising the Bonya Metamorphics and Arunta rocks (modified from Freeman, 1986) Jervois Mine offset along strike.

The south-west to north-east orientated Jervois Fault forms the major mapped geological fault in the vicinity of the JBMP site, where Cambrian sediments of the Georgina Basin have been thrust over the older Arunta Basement rocks to form the Jervois Range. Smaller scale structures have also been identified from resource drilling and are apparent in satellite images.

The dominant formation around the mine site is the Bonya Metamorphics, which are heavily deformed and folded, forming a near-vertical plunging syncline across the site. The surface expression of the structure forms the distinctive "J-Fold" which is a prominent topographic feature. The main mining targets align along the north-south trending "J-Fold" structure.

Minor Quaternary sedimentary deposits occur along drainage lines, as colluvium on the south-east margin of the Jervois range and as a thin veneer of aeolian soil overlying the Bonya Metamorphics that host the JBMP.

A more detailed description of the local geology of the mine site is presented below.

3.4.2. Local geology

The Jervois base metal deposits are hosted within the Bonya Metamorphics, the oldest exposed metasedimentary rocks in the Jervois area. This polymetamorphosed succession comprises predominantly clastic and chemical metasedimentary rocks. Fine-grained metapelitic schists dominate the succession and contain variable amounts of muscovite, biotite, poikiloblastic garnet, andalusite and cordierite; these are characterised by a distinct knotted texture. The schists represent a mudstone protolith and are interbedded with metasandstone, calc- silicate and marble rocks with poor strike continuity, hydrothermal iron and manganese-rich metasedimentary rocks, and minor tourmalinite. The geochronology of the metapelite in the Bonya Metamorphics sequence suggests a similar timing for mineralisation, sedimentation, high-thermal gradient metamorphism and bimodal magmatism. This is interpreted to represent sediment deposition in a high thermal gradient, extensional back-arc environment active at ca 1790–1780 Ma (Bennett, et al., n.d.).

The base metal mineralisation lode sequence at Jervois is stratabound to stratiform with sulfides generally forming bands parallel to metasedimentary host rocks along a strike length and contained within steeply dipping lenticular bodies (lodes) of calc-silicate, garnet-chlorite-magnetite rock and garnet-magnetite quartzite, within a thick succession of spotted andalusite-cordierite schist and quartz-sericite-magnetite schist.

The mineralized sequence has a strike length of some 12 km within the 'J'-shaped range and a stratigraphic thickness up to about 600 m (Figure 3-4). Within this sequence there is a broad zonation, best demonstrated on the eastern flank of the synform. From the west the mineralized zone contains calc-silicate units with scheelite-bearing skarns, below which a group of lead, lead-copper and scheelite lodes occur together with several marble beds. Stratigraphically below and to the east is a unit of quartz-magnetite-garnet schist containing the main copper lodes. Further east, there are at least three other zones containing copper lodes in quartz-magnetite-garnet rock and less commonly copper bearing skarns.

The Marshall-Reward and Bellbird deposits are copper-silver-rich and hosted by psammite and pelitic schist containing garnet, chlorite, biotite and magnetite. Reward South and Bellbird North are smaller, lead-zinc-rich deposits hosted by metacarbonate and calc-silicate rocks. Between Marshall-Reward and Bellbird there are several satellite prospects including Cox's Find, Rockface, Rockhole and Killeen.

The internal geometry of the Marshall-Reward (over 1 km long by up to 40 m wide, drilled to a depth of 800 m) and Reward South lodes is complex and imperfectly understood. Contacts are generally gradational and correlation of individual intercepts between drill holes is often difficult. The most extensively drilled Marshall-Reward deposit is a system of steeply dipping shoots within the relatively well-defined lode structure. The axis of the lode plunges north.

By comparison, the geometry of the main lode at the Bellbird deposit is relatively straightforward; copper mineralisation occurs in a steeply dipping tabular body.

Small pegmatite intrusions, quartz veins and amphibolite bodies (possibly mafic intrusions) are not common but locally disrupt the lodes. Core from several diamond drill holes in the Marshall-Reward deposit showed evidence of brecciation of the lode with remobilized and recrystallized sulphides infilling fractures. Two cross-cutting faults displace the mineralisation at the Marshall-Reward deposit.

Weathering has penetrated to depths of ~30 m at Marshall-Reward and Bellbird, but is less pronounced in unmineralised areas. Completely oxidised rock is rare and restricted to the first few metres from surface. There is a thick zone of transitional oxidation with sulfide content increasing gradationally with depth, although the depth to fresh rock is uneven and dependent on the amount of sulfide, shearing, foliation and faulting locally. The upper transitional zone has been leached with corresponding supergene copper enrichment in the lower transitional zone, where chalcopyrite alters to bornite, chalcocite and rare native copper.

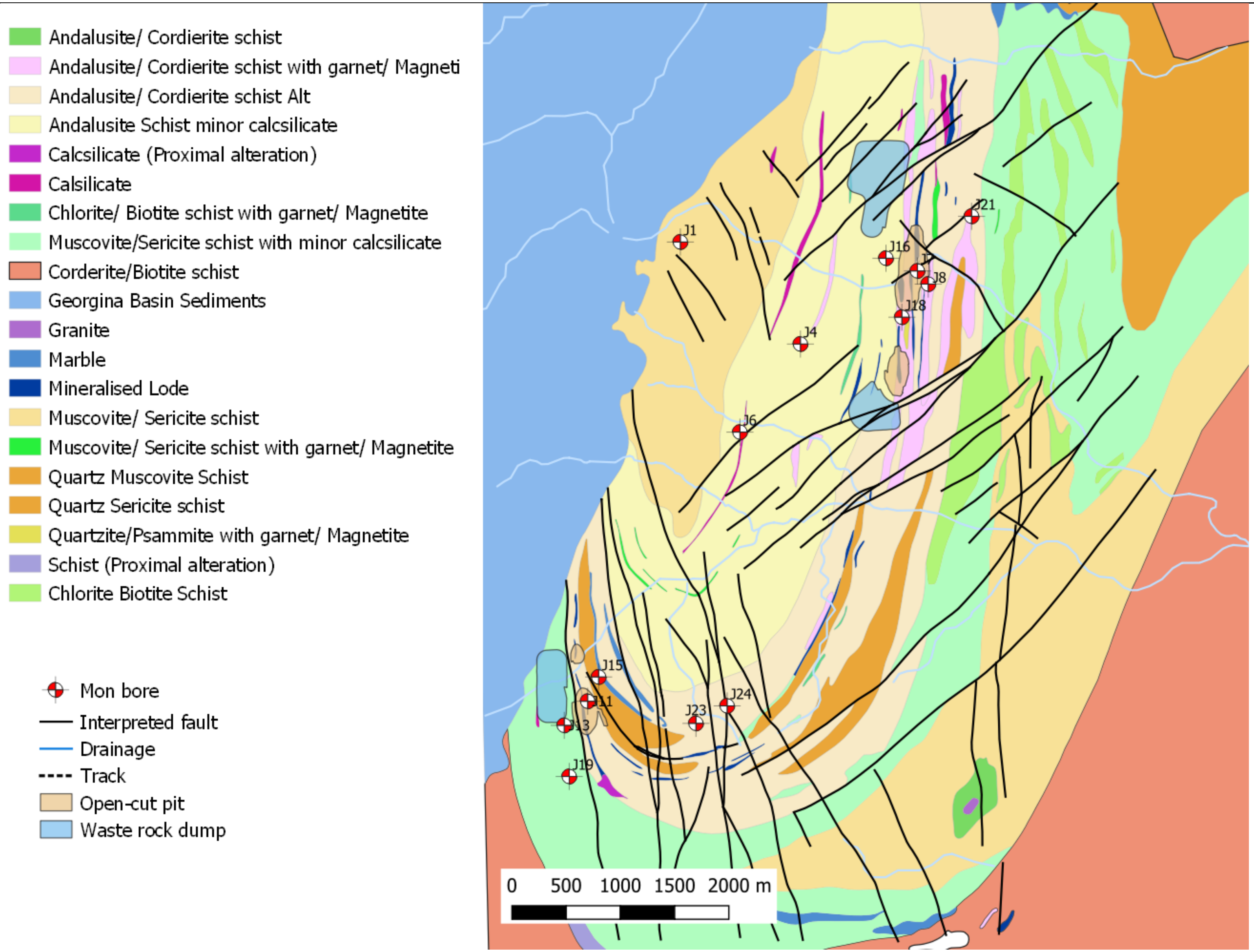


Figure 3-4 Local geological interpretation of the J-fold area showing monitoring sites, pits and waste rock dumps.

3.5. Hydrogeology

The hydrogeology within 40 km of the Jervois mine is described by Ride (2016, 1971) and CloudGMS (2018). The hydrogeology of the study area can be separated into two distinct groundwater systems:

- the Georgina Basin typified by karstic and fractured sedimentary rocks which host regionally extensive groundwater resources; and
- the Arunta Region typified by fractured and weathered metasediments with minor groundwater resources.

3.5.1. Hydrogeology of the fractured rocks

Numerous local minor aquifers occur within the granites, pegmatites and other basement formations of the Arunta Region. Groundwater yield and storage within these aquifers relies on fractures and jointing, they typically form poor to marginal aquifers that are only suitable for stock and minor domestic supply. Previous investigations in similar rocks beyond the mine site indicate yields ranging between 0.5 and 2.5 L/s.

The groundwater system in the mine area is within the fractured and weathered rocks of the Bonya Metamorphics. Metamorphic rocks such as schist and gneiss have low permeabilities and generally contain small amounts of groundwater which is commonly brackish to saline. Information on the hydrogeology of the fresh rocks at greater depths is limited.

A recent groundwater investigation (CloudGMS, 2018) recorded typical flows of about 0.01 L/s, with several sites recording no flow. One site, located on an interpreted fault, yielded 6 L/s and was pump tested. Higher yielding areas are related to localised zones of more intense local fracturing and jointing (CloudGMS, 2019).

3.5.2. Hydrogeology of the Georgina Basin

Groundwater resources capable of meeting the water demand for the process water supply (63 L/s) have been located within the southern Georgina Basin (refer to Figure 3-7) in the regionally extensive fractured and karstic rocks of the Arrinthrunga Formation and Arthur Creek Formation. The Georgina Basin Carbonate Aquifer is part of the regionally extensive Georgina Basin that underlies approximately one quarter of the Northern Territory and extends beneath the northwest of Queensland.

The Georgina Basin represents a large regional scale groundwater resource of ~1,320,000 GL, assuming a specific yield of 0.04, a saturated accessible thickness of 100m and an area of ~330,000 km^2.

Recent investigations have sited bores to the north of the Jervois mine site (CloudGMS 2018 and CloudGMS in prep). The bores have typically yielded ~10 L/s.

3.6. Drilling investigations

3.6.1. 2018 mine site drilling investigations

The mine site investigation drilling and pumping test program was completed by Tomlin Drilling over a three week period from late September to mid-October, 2018. The program involved the construction of 14 groundwater monitoring bores and two test production bores. Bore depths were typically less than 100 metres depth and baseline groundwater levels, water quality and estimates of hydraulic parameters determined and presented in CloudGMS (2019) Jervois Base Metals Project Mine Site

Groundwater Investigation v0.1. Summary drilling results from the mine site investigation are presented below in Table 3-1.

3.6.2. 2018 process water supply drilling investigations

Drilling for the process water supply investigation was also completed by Tomlin Drilling over a three week period from end July to mid August 2018. The Phase 1 investigation bores were drilled at nine sites, six sites in Area 1 and three sites in Area 2, including the construction of two test production bores, one in each of the two investigation areas and seven monitoring bores. Further drilling targets were identified to secure sufficient water supply for the Project.

The results of this investigation are presented in CloudGMS (2018) Jervois Base Metals Project Lucy Creek Water Supply Investigation v0.1. Summary drilling results from this investigation are presented below in Table 3-2.

3.6.3. 2019 process water supply drilling

Additional drilling to install process water supply production bores was completed in mid-June 2019 and the results from this drilling are consistent with the 2018 investigation drilling results. The final report documenting the results of this work are expected in early August 2019.

Table 3-1 Summary of drilling results from Jervois mine site investigation drilling

Site ID	Bore Type	Aquifer Type	Drilled Depth (mBGL)	Cased Depth (mBGL)	Airlift Yield (L/s)	Standing Water Level (mBGL)	Electrical Conductivity (µS/cm)	Comment
J1	Monitoring	Fresh schist	66	53	0.05	18.42	2110	Groundwater seepage intersected around pegmatite veins from 32-36 m and 41-42 m
J4	Monitoring	Fresh schist	54	54	<0.01	12.19	2040	Groundwater seepage in fresh schist at 40 m
J6	Monitoring	Fresh schist	72	72	-	14.66	-	Drilled into fresh schist, no free groundwater during drilling but foam injection required to clear hole from 63 m.
J7	Test Production	Fractured schist with quartz veins	150	70	5	15.86	1660	Investigation bore located in Reward pit, originally drilled to 150 m subsequently reamed to 90 m and constructed as a test production bore. Main groundwater influxes in discrete zones of fractured, iron-stained schist around quartz veins.
J8	Test Production	Fractured schist	48	48	3.6	16.74	2810	Investigation bore to the S-W of N-S trending Reward structure, drilled to investigate lateral extent of aquifer in J7. Struck zone of heavily fractured schist from 23 – 42 m. Constructed as test production bore.
J11	Investigation	Fresh schist	150	108	0.02	28.15	2950	Investigation bore in centre of Bellbird pit, intersected seepage in fresh schist from 132 m
J13	Monitoring	Fresh schist	54	54	0.01	30.34	2260	Groundwater seepage in fresh schist from 42 m
J15	Monitoring	Fresh schist	78	78	-	22.98	-	Sited to test aquifer at the location of a mineral hole abandoned due to water and hole stability. Drilling intersected schist with abundant pegmatite veins. No free water observed during drilling.
J16	Monitoring	Fresh schist	75	73.45	0.1	14.73	1850	Groundwater seepage in fresh schist from 48 m
J18	Monitoring	Fractured schist	60	60	0.75	22.05	1600	Groundwater intersected in discrete zones of fractured schist with pegmatite veins from 33 – 51 m
J19	Monitoring	Discrete fracture in schist	48.6	48.6	0.1	31.08	2570	Groundwater intersected in discrete fracture within fresh schist from 35 – 35.5 m, airlifted at 0.5 L/s during drilling.
J21	Monitoring	Fractured schist	54	54	0.6	25.1	3450	Groundwater intersected in band of fractured schist with quartz veining from 38 – 48 m
J22	Investigation	Fresh schist	84	84	-	Dry	-	Sited to test groundwater potential of schist at proposed Rockface mine. No free water observed

Site ID	Bore Type	Aquifer Type	Drilled Depth (mBGL)	Cased Depth (mBGL)	Airlift Yield (L/s)	Standing Water Level (mBGL)	Electrical Conductivity (µS/cm)	Comment
								during drilling, bore constructed as water level monitoring point but remained dry at end of program
J23	Monitoring	Fresh schist	72	72	-	27.27	-	Sited to test aquifer at the location of a mineral hole abandoned due to water. Drilling intersected fresh schist. No free water observed during drilling. Bore was not developed due to insufficient groundwater but was constructed as water level monitoring point
J24	Monitoring	Discrete fracture in schist	60	60	0.4	28.73	2330	Groundwater intersected in discrete fracture from 43 – 43.5 m set in otherwise hard, fresh schist.

Table 3-2 Summary of drilling results from Lucy Creek investigation drilling

Bore ID	Site ID	Area	Bore Type	Drilled Depth (mBGL)	Cased Depth (mBGL)	Airlift Yield (L/s)	Standing Water Level (mBGL)	Electrical Conductivity (µS/cm)	Comment
RN019782	LCP1	1	Test Production	60	58	14+	14.21	680	Bore tested at 14 L/s for 24 hours, intersected significant fractured aquifer in Arthurs Creek dolomite, located on same SW structure as LC3
RN019774	LC1	1	Monitoring	90	90	< 0.05	11.82	3300	Drilled into calcareous shale of the lower Arthurs Creek Formation, only groundwater seepage intersected
RN019776	LC3	1	Monitoring	78	28.5	8 - 10^ (4.5)	11.31	710	Airlifted 8 – 10 L/s from 78 m during drilling from Arthurs Creek Formation, only constructed to 28.5 m due to hole collapse. Located on same SW structure as LCP1.
RN019775	LC4	1	Monitoring	117	117	2.5	20.3	650	Intersected cavernous fracture at transition of upper/lower units of Arthurs Creek Formation but did result in notable increase in airlift yield
RN019793	LC5	1	Monitoring	101.5	101.5	7	14.46	720	Observation bore located 25 m north-west of test production bore LCP2
RN019781	LC6	1	Monitoring	53.4	53.4	0.8	21.27	1500	Intersected small flows in minor fractures in lower Arthurs Creek Dolomite/shale
RN019777	LC7	1	Abandoned	66	-	-	-	-	No water intersected, hole backfilled and abandoned
RN019794	LCP2	2	Test Production	69	65	5+	12.04	2800	Test production bore constructed in the Arrinthrunga Formation, pumped at 5 L/s for 24 hours
RN019778	LC9	2	Monitoring	168	168	3	9.58	3750	Shallow and deep aquifers encountered in Arrinthrunga Formation
RN019779	LC14	2	Monitoring	150	150	8		2760	Observation bore located 20 m west of test production bore LCP1
RN019780	LC15	2	Monitoring	150	148.3	4.5	12.34	1540	Lost circulation from 19 m, negligible groundwater intersected in Arrinthrunga from 30 – 150 m

3.7. Aquifer hydraulic properties

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

3.7.1. Fractured rock bulk transmissivity / hydraulic conductivity and storage coefficients

Berry & Matthews documented a transmissivity (T) of 40 m^2/d for the weathered and fractured rocks encountered above 30 mBGL in RN016189. Assuming a saturated thickness of 20 metres, this narrow localised zone could be expected to have a hydraulic conductivity of 2 m/d.

RN016189 provided an airlift of 1.5 L/s; all other bores in the investigation yielded <0.5 L/s. Assuming a linear relationship between airlift and hydraulic conductivity, the weathered and fractured Bonya Schist generally has an inferred hydraulic conductivity less than 0.1 m/d.

Slug tests and a recovery test were completed on monitoring bores installed in 2018 (CloudGMS, 2019). A summary of the results is presented below in Table 3-3.

Table 3-3 Hydraulic testing of monitoring bores installed around the mine site (source CloudGMS, 2019).

Site ID	Aquifer Type	Test Type	Bouwer-Rice (1976) – m/day		Hvorslev (1951) - m/day		Comments
			Falling	Rising	Falling	Rising	
J1	Fresh Schist	Slug test	0.03	0.04	0.03	0.06	
J4	Fresh Schist	Slug test	0.04	0.04	0.05	0.05	
J6	Fresh Schist	Slug test	0.01	0.03	0.01	0.04	
J10	Fresh Schist	Recovery test	-	0.0002	-	0.0002	Recovery following drilling – free water not observed during drilling
J13	Fresh Schist	Slug test	0.45	-	0.01	-	Sensor cable snagged as slug removed
J15	Fresh Schist	Slug test	0.05	0.11	0.07	0.14	
J16	Fresh Schist	Slug test	0.03	0.03	0.04	0.04	
J18	Fractured schist	Slug test	0.72	0.66	0.91	0.83	
J19	Fractured schist	Slug test	0.42	1.73	0.5	2.32	Sensor cable snagged with slug removal – rising head value unrepresentative
J21	Fractured schist	Slug test	0.55	0.56	0.70	0.70	
J22	Fresh Schist	NA	-	-	-	-	Dry bore
J23	Fresh Schist	Slug test	0.03	0.04	0.04	0.05	
J24	Fractured schist	Slug test	0.17	-	0.2	-	Sensor cable snagged as slug removed

No hydraulic information is available for fresh rocks at depths greater than 100 metres at this time at the Jervois mine site, although it is expected to be considerably lower as the fracture width and intensity are expected to decrease with depth, causing a decrease in hydraulic conductivity with depth.

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 or dewatering. However, no such information is currently available for the Bonya Schist Formation and values typical of weathered and fractured rocks have been adopted (~0.01).

3.7.2. Georgina Basin sediments hydraulic conductivity and storage coefficients

The mine process water supply is to the north of the Jervois mine site within the sediments of the Georgina Basin targeting the Arrinthrunga Formation and Arthur Creek Formation.

The values listed in Table 3-4 are summarised from the pumping test results conducted during the process water supply investigations (CloudGMS, 2018b). The values are consistent with the estimated hydraulic conductivity values in the Western Davenport region in similar lithologies indicate hydraulic conductivity values of between 0.8 to 2.2 m/d can be expected.

Table 3-4 Site specific transmissivity and hydraulic conductivity parameters derived from recent pump tests.

Site	Depth [mBGL]	SWL [mBGL]	T [m^2/d]	K [m/d]
RN019782	58	14.2	84	1.9
RN019794	65	12	114	2.15

Previous studies of the Cambrian aged carbonate aquifer systems in the NT indicate unconfined characteristics with a specific yield of about 0.01 to 0.04 (Jolly, 2002; Jolly et al., 2004; Knapton, 2006).

3.8. Hydrostratigraphic units

The geological formations within the study area have been combined into four hydrostratigraphic units (HSU) for inclusion in the groundwater model. A hydrostratigraphic unit can be described as being a grouping of geological sub-units with identified lateral and vertical distributions, that have the same or similar hydrogeological characteristics. The hydrostratigraphic units defined are presented below in Table 3-5.

Table 3-5 Hydrostratigraphic units

Age	Name	Lithology	Hydrogeology	HSU
Quaternary		Silty sand and gravels	Permeable, but mostly above water table.	-
Ordivician	Tomahawk Beds		Fractured and weathered with some intergranular porosity	1
Devonian	Dulcie Sandstone		Fractured and weathered with some intergranular porosity	2
Cambrian	Arrinthrunga Formation / Arthur Creek Formation		Fractured and karstic regional scale aquifers	3
Proterozoic	Bonya Metamorphics	Blue grey fresh Phyllite.	Fractured and weathered rocks with minor groundwater. Low permeability, locally, fractured aquifers, yields less than 2 L/s.	4
Proterozoic	‘J-fold’ Bonya Metamorphics	Blue grey fresh Phyllite.	Fractured and weathered rocks with minor groundwater. Low permeability, locally, fractured aquifers, yields less than 5 L/s.	5

3.9. Groundwater levels and groundwater movement

3.9.1. Regional groundwater levels and movement

Regional groundwater levels and flow directions presented in CloudGMS (2018) are reproduced below in Figure 3-5 for reference.

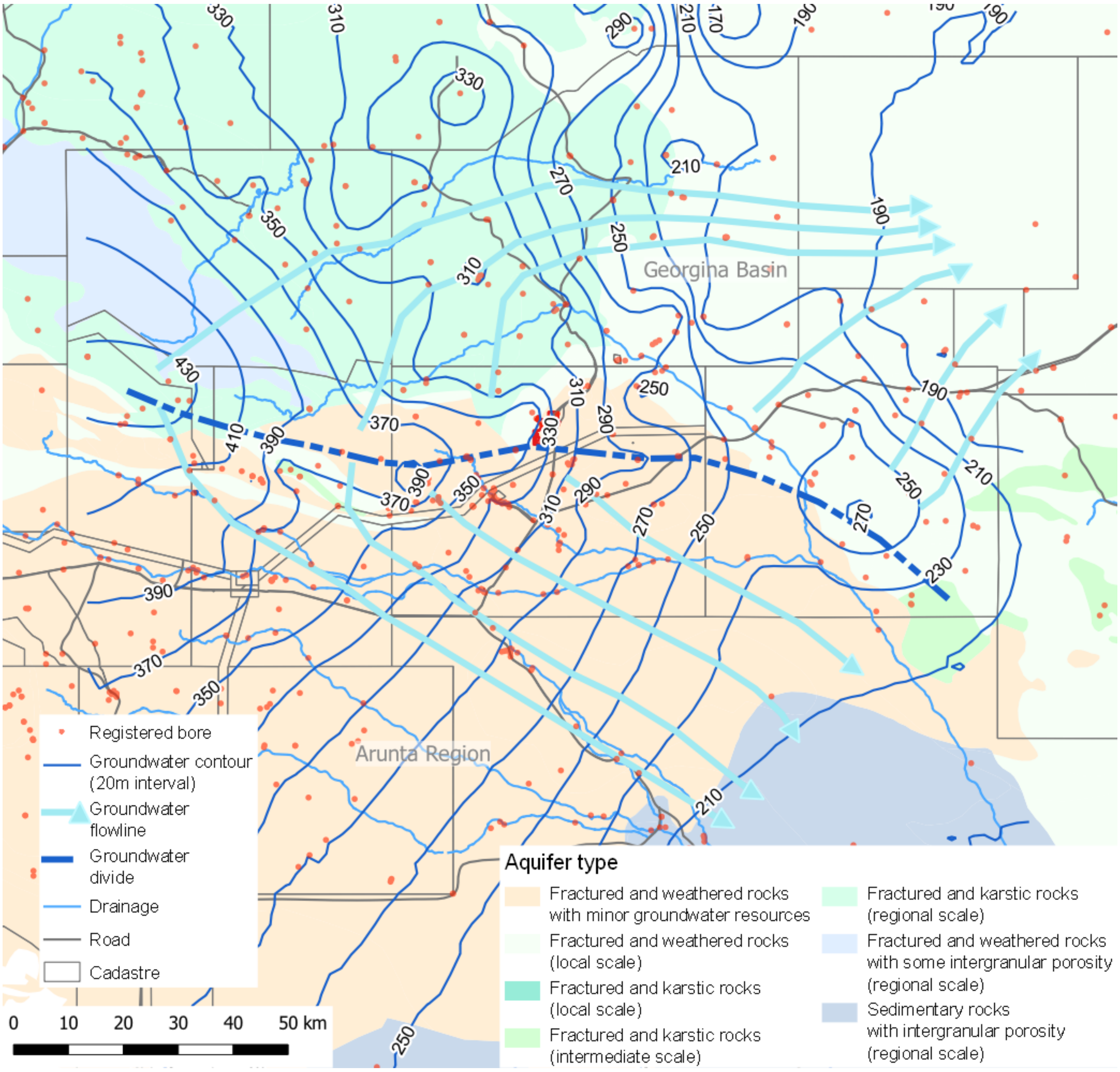


Figure 3-5 Groundwater potentiometric surface and inferred groundwater flow directions.

3.9.2. Process water supply groundwater levels and groundwater movement

Groundwater levels were obtained during the process water supply investigation in 2018 and are presented above in Table 3-2. Groundwater levels in the vicinity of the borefield are between 10 and 20 metres below ground level. The water table is relatively flat and the variation in depth to water table is related to the topography.

The local groundwater levels and flow direction are consistent with the regional groundwater levels and flow direction.

3.9.3. Jervois mine site groundwater levels and groundwater movement

Groundwater levels at the Jervois mine site were collected during the 2018 groundwater site investigation. The data are presented above in Table 3-2. Some of the bores are inclined and the observed water level has been corrected for the inclination.

Locally groundwater levels indicate flow from northwest to southeast, with elevated groundwater levels associated with leakage from the Jervois Dam.

Solar Bore (RN012917) pumps groundwater to a water storage tank via a 50 mm diameter poly pipeline installed by Jervois Station; as such the groundwater level at this site is impacted by pumping.

Windmill Bore (RN006910) is adjacent to Camp Bore (RN007598) and the groundwater level is expected to be influenced by the pumping for the camp water supply.

Table 3-6 Jervois mine site groundwater levels 2018

Bore ID	Incl	RL ToC [mAHD]	SWL [mBG]	Corr SWL [mBG]	RWL [mAHD]	Comment
J1	-90	362.65	18.82	18.82	343.83	
J4	-90	348.88	12.58	12.58	336.30	
J6	-90	348.21	15.03	15.03	333.18	
J7	-90	346.33	16.38	16.38	329.95	
J8	-90	347.81	17.22	17.22	330.59	
J10	-90	347.57	Not Static	-	-	
J11	-90	363.68	28.54	28.54	335.14	
J13	-90	365.26	31.00	31	334.26	
J15	-90	360.4	23.58	23.58	336.82	
J16	-90	348.6	15.14	15.14	333.46	
J18	-90	354.39	22.40	22.4	331.99	
J19	-90	362.46	31.48	31.48	330.98	
J21	-90	353.25	25.54	25.54	327.71	
J22	-90	370.72	DRY	-	-	
J23	-90	361.2	27.76	27.76	333.44	
J24	-90	362.76	29.45	29.45	333.31	
KJC125	-57	347.18	16.20	13.61	333.57	
KJC178	-62	359.51	27.08	23.99	335.52	
KJC189	-60	339.86	19.85	17.27	322.59	
KJCD261	-90	348.3	14.38	14.38	333.92	
KJCD283	-90	348.93	15.22	15.22	333.71	
CF_UI1	-65	356.7	35.01	31.73	324.97	Position accuracy DGPS?
CF_UI2	-65	355.1	33.16	30.06	325.04	Position accuracy DGPS?
OLD_SHAFT	-90	358.03	26.46	26.46	331.57	
RN010121	-90	347.3	14.18	14.18	333.12	
RN006910	-90	343.84	20.45	20.45	323.39	Windmill Bore
RN007598	-90	343.03	Not accessible	-	-	Camp Bore
RN010323	-90	345.21	14.52	14.52	330.69	Shaft Bore
RN012917	-90	338.03	17.04	17.04	320.99	Solar Bore

RL ToC = relative level for top of casing; SWL = standing water level; RWL = relative water level

3.10. Groundwater quality

Regional groundwater quality dataset was obtained from DENR NR Maps. (http://nrmaps.nt.gov.au/nrmaps.html accessed July 2018). The distribution of water quality as TDS across the study area is detailed previously (CloudGMS, 2018a) and summarised below.

3.10.1. Total dissolved solids (TDS) and chloride

To provide a spread of indicative water quality across the mine site the field EC data presented above in Table 3-1 was converted to TDS assuming a conversion of 0.57 (based on regression between EC and TDS of available groundwater samples below in Table 3-7). The estimated TDS indicates that water quality is in the range from 1000 to 2000 mg/L.

Similarly a regression between EC and Cl (Cl = 0.255 x EC – 191) was used to estimate chloride values across the mine site. The estimated values range 215 – 690 mg/L and averaging 400 mg/L.

Groundwater samples were collected and sent for analysis at the mine site for J7, J8 and Camp Bore (RN007598) and for the process water supply at LCP1 and LCP2. The results are presented below in Table 3-7.

Table 3-7 Jervois mine site and Lucy Creek borefield groundwater in situ (field) data and laboratory results

Analyte	Units	Limit of reporting	J7	J8	Camp Bore	LCP1	LCP2
FIELD DATA							
Electrical Conductivity	uS/cm	-	1810	3290	3760	688	2660
pH	pH unit	-	6.96	7.07		6.96	7.07
Temperature	° C	-	28.3	29.3		28.3	29.3
LABORATORY PHYSICAL PARAMETERS							
Electrical Conductivity	uS/cm	1	1810	3290	3760	657	2650
Total Dissolved Solids	mg/L	10	1020	2000	2080	394	1570
Total Hardness	mg/L	1	494	595	915	324	612
Total Alkalinity	mg/L	1	451	797	718	338	464
LABORATORY TOTAL METALS							
Aluminium	mg/L	0.01	<0.01	0.01	<0.01	<0.01	0.05
Arsenic	mg/L	0.001	<0.001	<0.001	<0.001	0.001	<0.001
Boron	mg/L	0.05	0.37	0.83	0.78	0.05	0.68
Barium	mg/L	0.001	0.016	<0.001	0.002	0.275	0.029
Beryllium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	mg/L	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cobalt	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	mg/L	0.001	0.003	0.003	<0.001	<0.001	<0.001
Iron	mg/L	0.05	0.41	0.21	<0.05	<0.05	0.18
Mercury	mg/L	0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001
Manganese	mg/L	0.001	0.316	0.026	0.002	<0.001	0.002
Nickel	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lead	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Selenium	mg/L	0.01	<0.01	<0.01	0.01	<0.01	<0.01
Vanadium	mg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Uranium	mg/L	0.001	0.013	0.021	0.025	0.004	0.006
Zinc	mg/L	0.005	0.009	<0.005	<0.005	<0.005	<0.005
LABORATORY DISSOLVED MAJOR ANIONS							
SO4 as Sulfate	mg/L	1	259	388	414	11	341
Chloride	mg/L	1	179	387	584	14	436
LABORATORY DISSOLVED MAJOR CATIONS							
Calcium	mg/L	1	76	80	129	77	80
Magnesium	mg/L	1	74	96	144	32	100
Sodium	mg/L	1	157	429	374	18	273
Potassium	mg/L	1	5	6	7	3	12

Mine site groundwater is generally fresh to brackish (500-3000 mg/L TDS). However, salinity is suitable in less than 40% of instances for potable use (<1000 mg/L), and other criteria render it generally non-potable without treatment, but most bores report water suitable for watering cattle (CloudGMS, 2018a).

3.10.2. Groundwater types

The groundwater samples collected during the 2018 groundwater investigations have been plotted against the data available from the DENR bore water quality database are presented in Figure 3-6 as a Piper plot.

Samples from areas around the Jervois mine, Lucy Creek homestead and the community of Orrtipa-Thurra are highlighted for comparison. Samples collected in 2018 are consistent with previous water samples obtained in the vicinity of the Jervois mine completed in the Proterozoic Basement rocks and exhibit Pastoral (stock) water quality with a mixed chemical composition dominated by Na-Mg-HCO_3-Cl. The water is generally not potable due to elevated Fluoride, Nitrate and Boron.

Groundwater from the 2018 bores completed in the Georgina Basin aquifers (identified by symbols designated Lucy Creek 2018) are consistent with previous sampling and exhibit marginal to non-potable water that is otherwise suitable for pastoral use. The water exhibits a chemical composition similar to the Proterozoic Basement Aquifer, however elevated in Ca, Mg and SO4, indicative of equilibration with carbonates; calcite ($CaCO_3$) dolomite ($CaMg[CO_3]_2$) and Gypsiferous rock ($CaSO_4$).

3.10.3. Beneficial uses

The salinity of the Georgina Basin Carbonate Aquifer can support potable use in most instances and is typically suitable for Pastoral (Stock) use.

Groundwater at the mine site in the Fractured Rock groundwater system is also generally too saline for potable use (TDS > 1000mg/L for more than half the bores) and it also has elevated Fluoride, Nitrate and Boron. However, it is suitable for Pastoral (Stock) and Industrial use (ie RN006910, RN010321, & RN012917) are only suitable for stock due to TDS > 2000 mg/L, elevated F, Fe and SO_4).

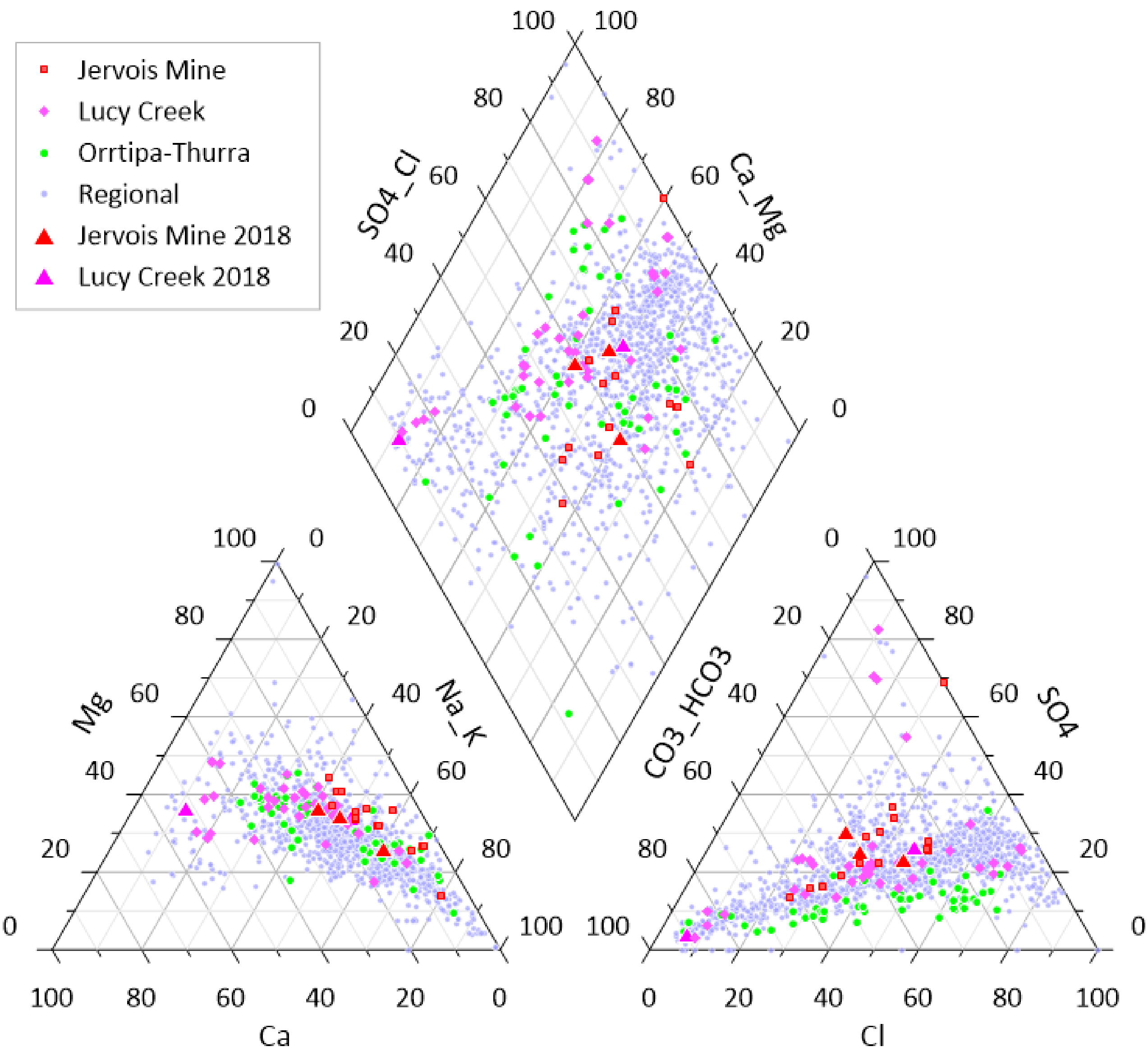


Figure 3-6 Groundwater chemistry (Piper Plot). Red triangles indicate 2018 mine site groundwater sampling, green triangle indicate 2018 groundwater sampling from the Georgina Basin and pale blue symbols are the regional DENR dataset.

3.11. Mining activities

The Life of Mine (LOM) is expected to be 10 years. The mining activities that will impact on groundwater resources in the study area include:

- Bellbird open-pit operational from year 4 to 6
- Bellbird underground operational from year 7 to 10
- Reward open-pit operational from year 1 to 5
- Reward underground operational from year 5 to 10
- Reward South open-pit operational from year 6 to 7
- Rockface operational from year 1 to 5
- Process water supply operational from year 1 to 10 (63 L/s)
- Waste rock dumps operational from year 1 to 8
- Tailings storage facility (TSF) operational from year 1 to 10

The TSF is likely to continue being a source of contaminants beyond the life of the mine for an indefinite time period.

The Bellbird pit, Reward pit and Reward South pit are expected to continue to impact the groundwater resources within the footprint of the mining tenement beyond the life of the mine forming local groundwater sinks.

The locations of the components listed above (except the process water dam) are presented below in Figure 3-7.

Based on the mining schedule provided, a series of pit shells and the development of the underground access and stopes were developed for input to the groundwater model. The pit shells and underground workings are applied to the model using seepage face boundary conditions (BCs) in yearly steps.

3.11.1. Process water supply

The process water supply comprises six bores abstracting up to 5.4 ML per day (63 L/s, 2 GL/year) for 10 years. Bores will be completed into the Georgina Basin Carbonate Aquifer in an area about 20 km to the north of the Project mine site. The locations of the bores are presented in Figure 3-7. Investigation drilling for these bores was undertaken in September 2018, and the results of this work informed the final design of the process water supply borefield installed in June 2019.

3.11.2. Waste rock dumps

Waste rock dumps are planned adjacent to the Bellbird, Reward and Reward South pits and have footprints of 17.4, 33.5 and 14.9 Ha respectively.

Geochemical characterisation results for metallurgical ore feed samples are presented by EGi (2018). The results show that the Project open cut and underground mine waste rock materials will include broad zones of mainly non-acid forming (NAF) material but also some potentially acid forming (PAF) materials within a halo around the sulphidic ore. This material has a low to moderate probability of generating acid mine drainage and can be associated with poor drainage water quality in terms of acidity, salinity and elevated metals.

Water extract testing indicates that the majority waste rock materials will not liberate significant acid, salinity or metals/metalloids. However, under acid conditions mobilisation can be expected of Al, Cd, Co, Cu, Fe, Mn, Ni, SO4 and Zn, and possibly Pb. In addition, PAF materials during the lag phase and some higher S (>1%S) NAF materials may generate salinity (SO_4) and elevated Cu, Mn and Zn with oxidation. The solubility of metals/metalloids will largely be determined by pH and therefore control of acid generation will effectively control metal leaching.

NAF materials accounted for 70% of the waste rock samples tested, but this proportion does not reflect the true proportion of materials to be mined, and the overall proportion of NAF is expected to be higher.

3.11.3. Tailings storage facility (TSF)

The geometry of the proposed TSF located west of the Reward mining area is shown in Figure 3-7. The area of tailings is around 65 ha. The proposed TSF will have two cells and be constructed partly from mine waste rock. The basin area will have a soil lining below the operating supernatant pond to limit seepage. Tailings will enter the facility sub-aerially via banks of spigots spaced regularly on all embankments to position the supernatant pond centrally round the decant tower. To promote de-watering, the active tailings beach will be regularly rotated.

The tailings solids were found to contain certain elements which are readily soluble in water. On the basis of a brief comparison with the water quality data from the Jervois Camp bore it is considered that an engineered low permeability liner will be required throughout the basin area in each cell. The tailings sample is a non-plastic sandy silt and was classified as ML. The P_{80} is approximately 120 µm and permeability is about 6e-06 m/s (0.52 m/d) (Knight Piésold, 2015).

The TSF will also have a basin underdrainage system installed that will further reduce seepage to the water table, increase the density of the tailings (reducing the permeability of the tailings) and improve the geotechnical stability of the facility. The underdrainage system comprises a network of finger, branch and collector drains. This will drain by gravity above the liner in the decant area to a collection sump at the lowest point in the TSF basin. Water in the sump will be pumped back into the supernatant pond. A tower abstraction decant system will remove supernatant from the TSF to be pumped back to the plant for re-use as process water.

Currently the performance of the underdrainage system is uncertain, however, it is expected that some tailing liquor may seep from storage in the TSF to the groundwater table. The design specifications of the TSF identifies a target leakage rate of 1kL/Ha/day (Knight Piésold, 2015). This will result in some increase in groundwater level and change to the chemical composition of groundwater.

The saturated footprint of the two TSF cells is estimated at 30 Ha and 33 Ha, assuming a target leakage rate of 1kL/Ha/day (0.1 mm/d) the total daily leakage is estimated at 63 kL/d or 23 ML/yr.

While the seepage will change the water quality, the EIS shows that seepage from the TSF into the underlying rock sequence is acceptable because it will not impact third party users or sensitive environmental receivers. Modelling of the regional groundwater regime predicts that the mound beneath the TSF will dissipate towards the Reward and Reward South pit voids and accumulate in the pit lakes.

Geochemical characterisation results for tailings are presented by EGi (2018). Results suggest that tailings from sulphide ore samples will have moderate S values of around 1% S, but are still likely to be PAF. Tailings showed enrichment in a similar suite of metals/metalloids as the waste rock and ore, including Ag, Bi, Be, Cd, Co, Cs, Cu, Fe, Mn, Pb, S Mo, Se, Tl, W and Zn. Some mobilisation of Cd, Co, Cu, SO4, Mn and Zn can be expected during the lag period. This material has a low to moderate probability of generating acid mine drainage and can be associated with poor drainage water quality in terms of acidity, salinity and elevated metals.

3.11.4. Process water dam

The process water dam will have a capacity of 180 ML and will have emergency spillway to the adjacent Unca Creek diversion channel. (WRM 2018)

The maximum operating level for the Process Water Dam is 347.1 mAHD (an operating storage volume of 94.5 ML).

The Process Water Dam is located between the Unca Creek diversion and the Reward Pit. To prevent floodwater from the Unca Creek diversion from entering the Process Water Dam, the spillway from the dam will enter the diversion near the eastern end of the upstream bund. The spillway level will be 348.50 mAHD, which is above the predicted 0.1% (1 in 1000) AEP peak flood level in the Unca Creek diversion.

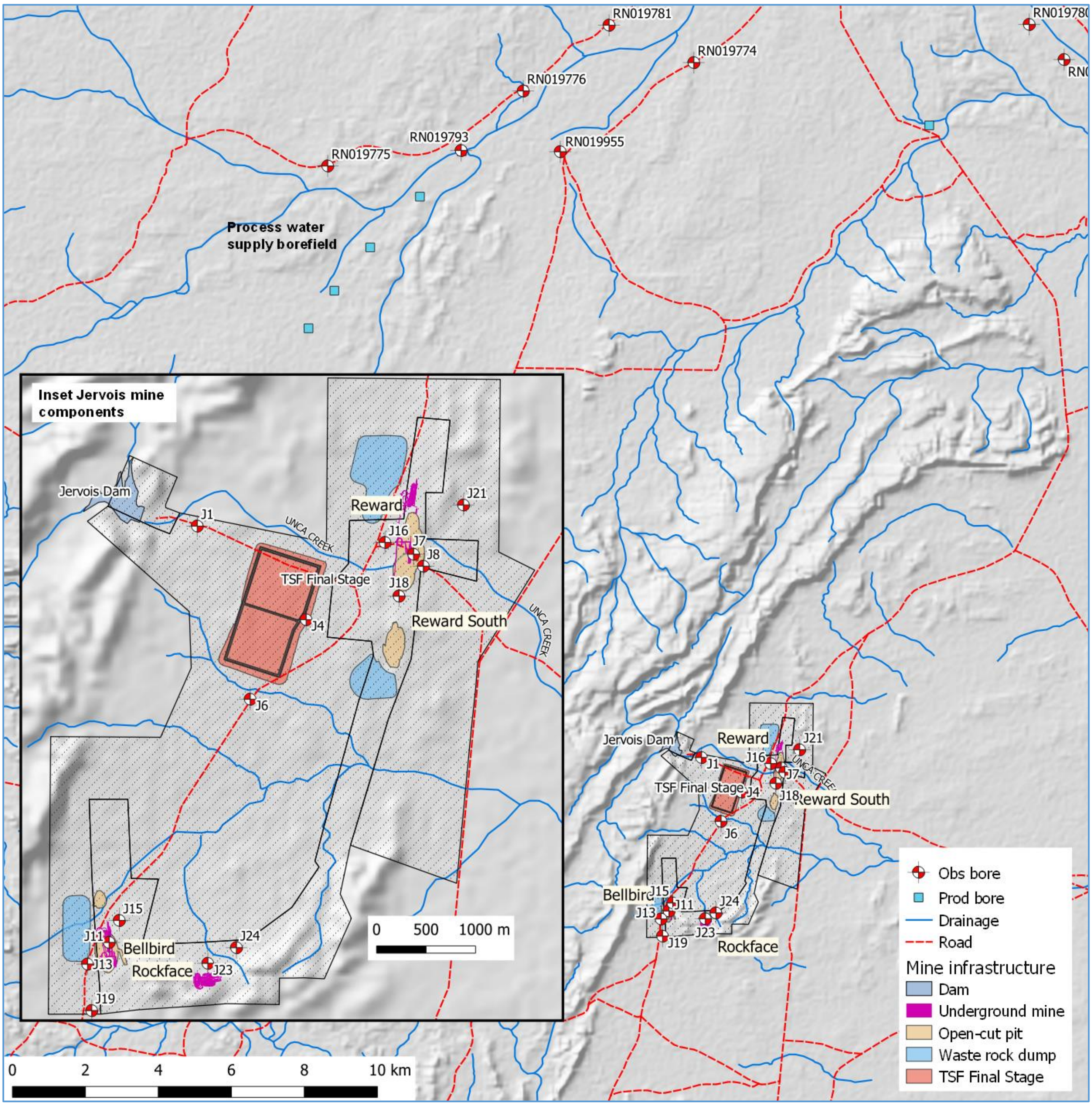


Figure 3-7 Location of mine features within the mine tenement including the pits, underground mines, TSF and the proposed process water supply to the northeast of the mine site.

3.11.5. Bellbird final pit shell and underground geometry

The Bellbird open pit shell extends to a depth of 100 metres below ground level and a final RL of 262 mAHD. The main pit is 410 metres long and 210 metres wide.

Underground workings reach a total depth of 420 metres below ground level at Bellbird.

The location of the Bellbird pit and underground workings are presented above in Figure 3-7 and the relationship between the open cut pit and the underground workings are presented below in Figure 3-10.

3.11.6. Reward final pit shell and underground geometry

The Reward open pit shell extends to a depth of 150 metres below ground level and a final RL of 215 mAHD. The main pit is 800 metres long and 250 metres wide.

The location of the Reward pit and underground workings are presented above in Figure 3-7 and the relationship between the open cut pit and the underground workings are presented below in Figure 3-10.

3.11.7. Reward South final pit shell geometry

The Reward South open pit shell extends to a depth of 100 metres below ground level and a final RL of 242 mAHD. The main pit is 450 metres long and 200 metres wide.

The location of the Reward South pit is presented above in Figure 3-7.

3.11.8. Rockface final underground depth

Underground workings reach a total depth of 700 metres below ground level at Rockface (Figure 3-11.

3.11.9. Pit void volumes

The pit areas and projected elevations at the end of mining were provided as dxf files. The elevation data has been converted into contours in mAHD and are presented below in Figure 3-8 The planar area (A) at ground surface of the Bellbird pit is 81,200 m^2, the planar area (A) at ground surface of the Reward pit is 165,000 m^2 and the planar area at ground surface of the Reward South pit is 65,500 m^2.

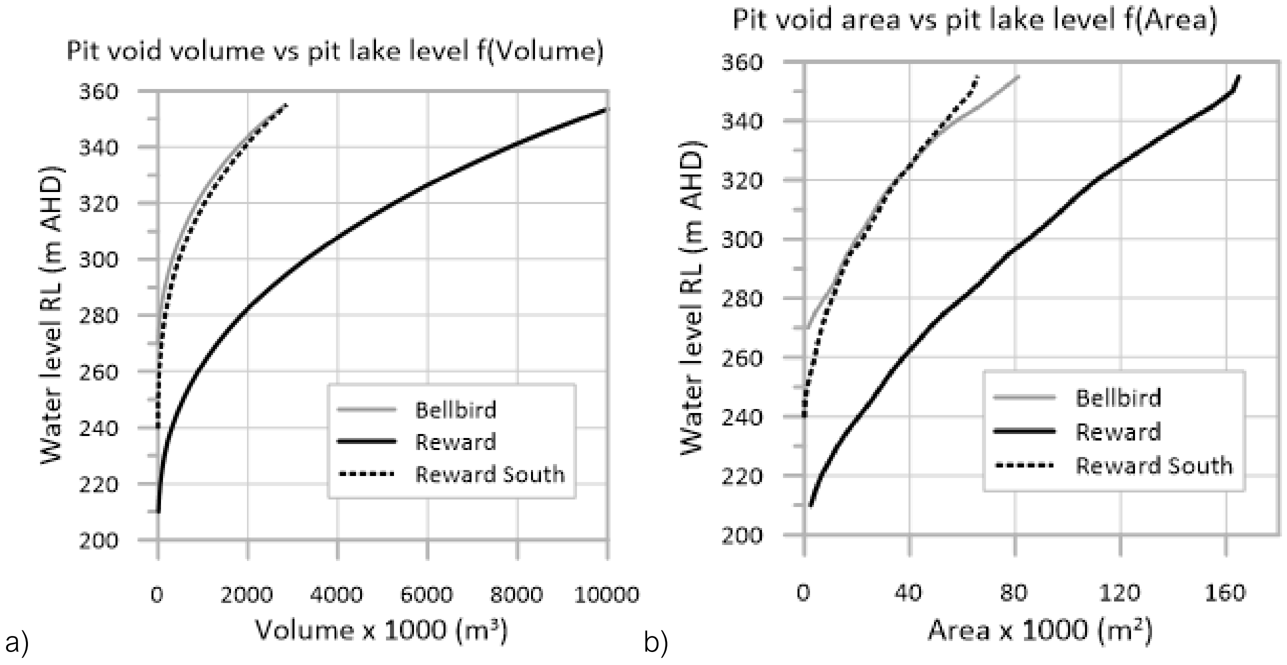


Figure 3-8 Jervois pit void a) volume vs pit-lake water level b) area vs pit-lake water level relationship.

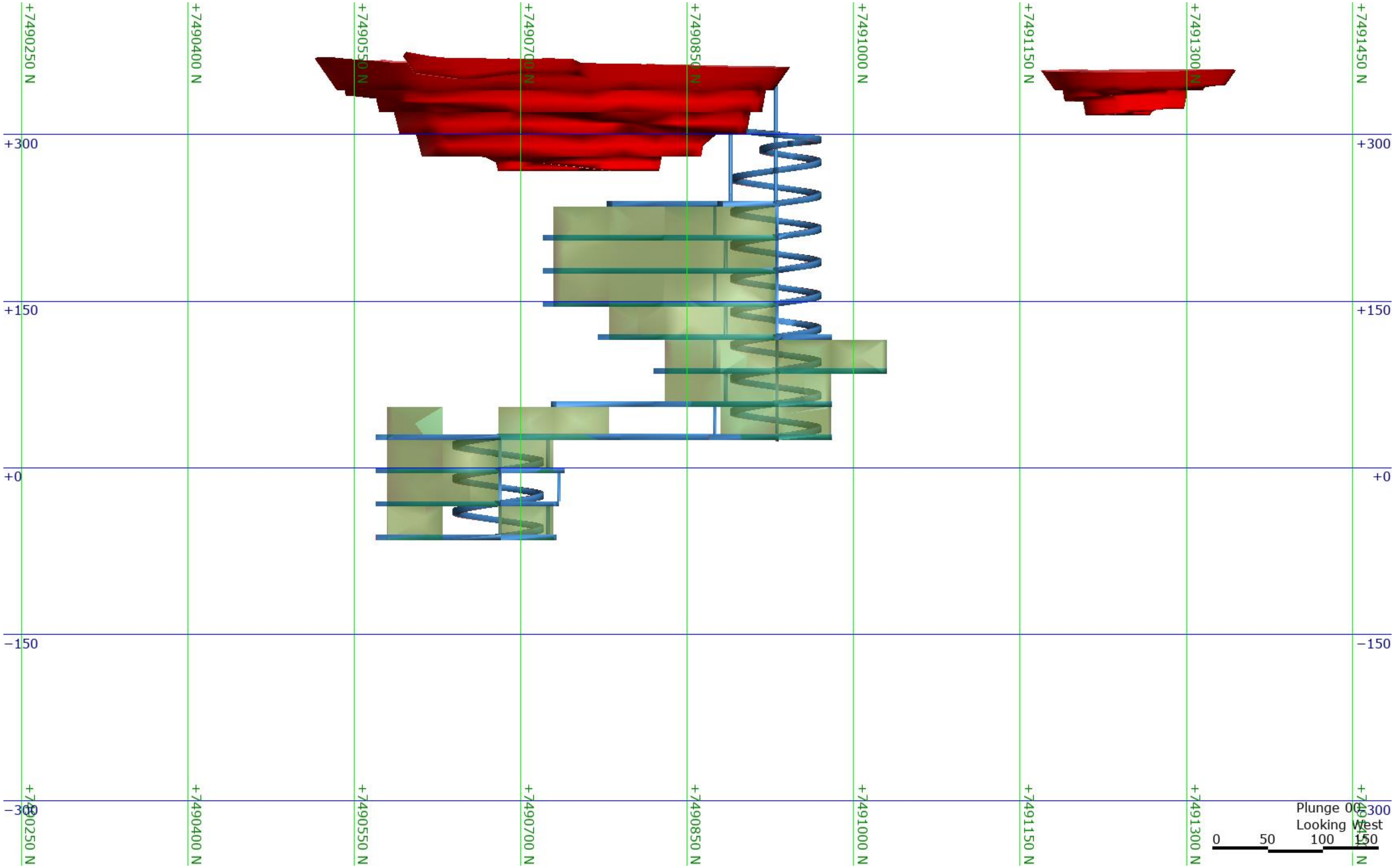


Figure 3-9 Looking west the Bellbird combined mine workings at the EOY 10 (source KGL).

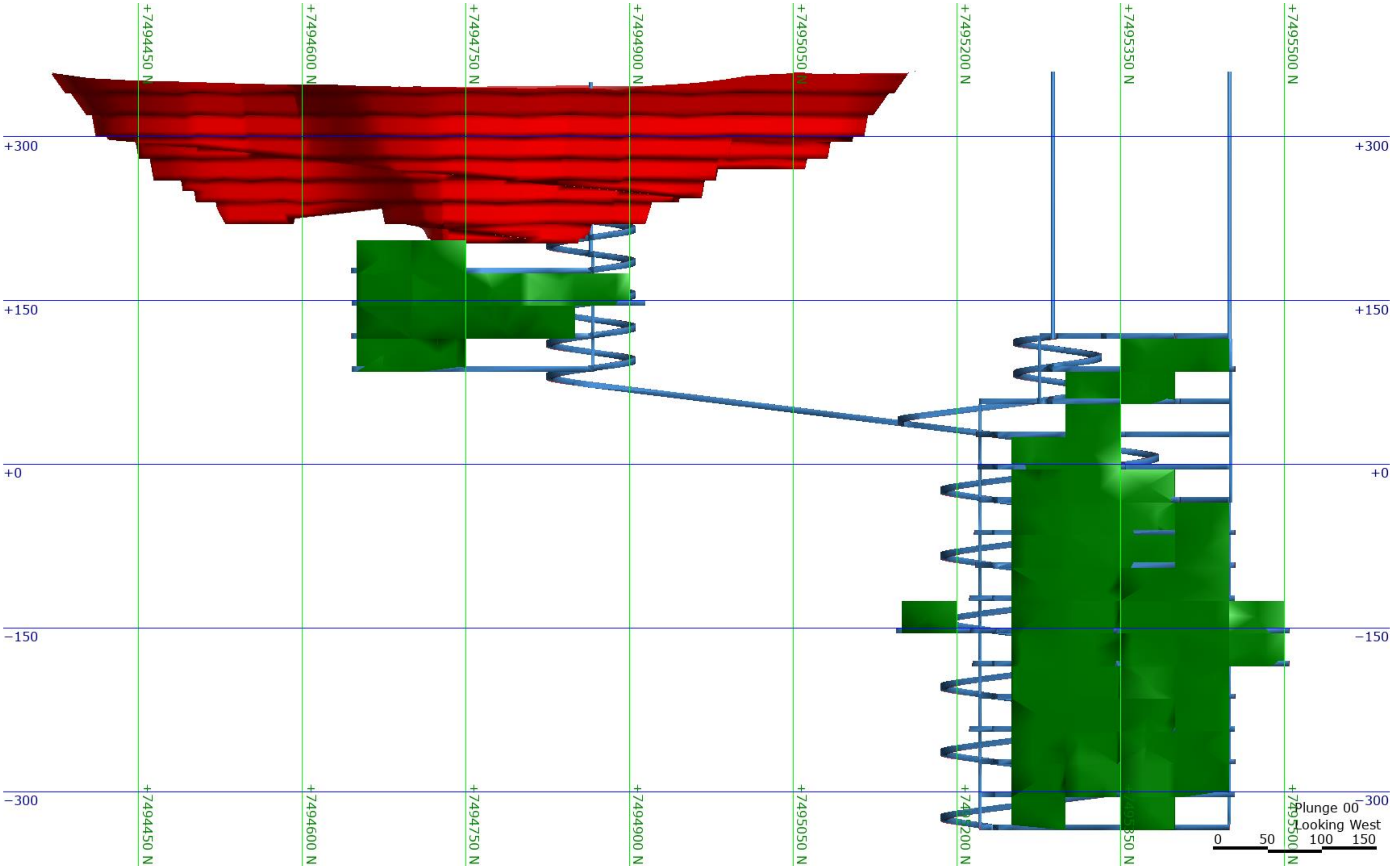


Figure 3-10 Looking west Reward combined mine workings at the EOY 10. (source KGL).

3.11.10. Rockface underground workings

The final underground workings extend from ground surface (380 mAHD) to a depth of 760 metres below ground level (-380 mAHD).

The location of the Rockface prospect are presented above in Figure 3-7 and the final underground workings at end of year 7 are presented below in Figure 3-11.

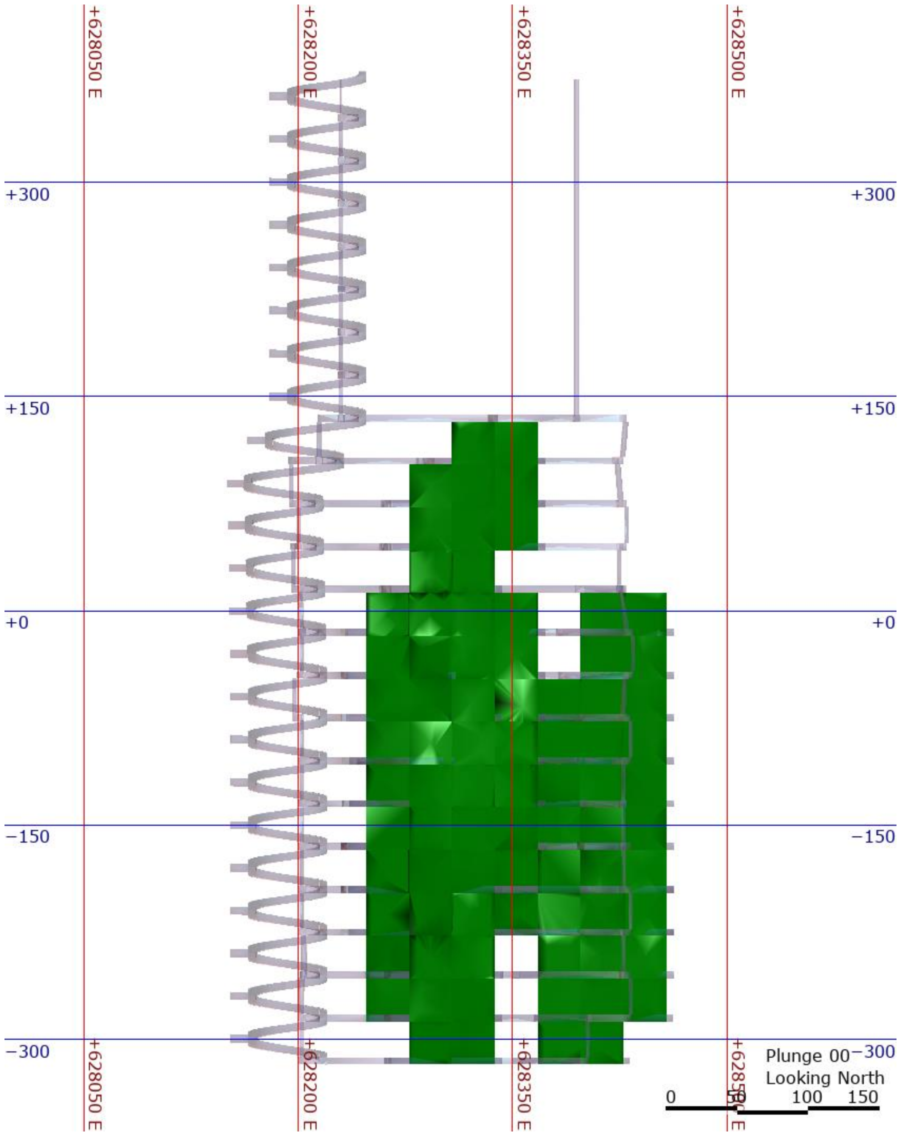


Figure 3-11 Rockface combined underground mine workings EOY 7 (source KGL).

3.11.11. Inflow water quality

The drives distal to the ore are expected to be excavated into non-acid forming (NAF) rocks and to have seepage water quality similar to the samples obtained from the mine site monitoring bores J7 & J8. The stopes and drives close to the ore are likely to be sulphidic and PAF, and underground seepage water from these zones is expected to be ultimately acidic, although cement backfill may offset this to some degree (EGi, 2018).

3.12. Existing groundwater users

Third party users include pastoral bores used for stock watering and station water supplies, and community water supplies. Pastoral bores, homestead bores and community water supply bores are presented below in Figure 3-12.

- Arapunya Station stock and domestic bores (52 km to the northwest of the process water supply);
- Jervois Station stock and domestic bores (30 km to the SW of the mine site);
- Lucy Creek Station stock and domestic bores (process water supply borefield is 10 km from the station domestic bore and 1.5 km from the closest pastoral bore);
- Maperte outstation water supply 17 km to the northeast of the mine site; and
- Orrtipa-Thurra (Bonya) Community water supply 18 km to the southwest of the mine site.

Lucy Creek Station, Arapunya Station and the northern portion of Jervois Station use bores completed in the Georgina Basin Carbonate aquifer for stock and domestic purposes.

Lucy Creek Station utilises groundwater from the Georgina Basin Carbonate aquifer (RN013689) and is located 10 km from the process water supply borefield. The Maperte outstation bore is located in the Georgina Basin Carbonate aquifer and are about 18 km to the southeast of the process water supply. Orrtipa-Thurra (Bonya) Community water supply and Jervois Station utilise groundwater from the Fractured Rock aquifer and is located more than 30 km and 50 km from the planned process water supply borefield respectively.

The closest stock bores to the process water supply bores are RN011101, RN011102 and RN013274 on Lucy Creek Station, which are about 1.5 km from the closest production bore.

Arapunya Station homestead is about 52 km to the northwest of the process water supply borefield and utilises groundwater sourced from RN011915 and RN014227. A summary of the bores used to assess the effects of the mining activities on groundwater is presented in Table 3-8.

Table 3-8 Summary bore statistics for existing users.

Site ID	Location	Completion Depth (mBGL)	Screen Interval (mBGL)	SWL (mBGL)	Available Drawdown (m)
RN011915	Arapunya	61	55 – 61	27	28
RN014227	Arapunya	57	39 – 57	31	8
RN011101	Lucy Creek (Stock)	88.5	Unknown	15	<72
RN011102	Lucy Creek (Stock)	28	Unknown	21	<7
RN013274	Lucy Creek (Stock)	49	43 – 49	14	29
RN013381	Lucy Creek (Stock)	34	25 – 31	9	16
RN013689	Lucy Creek (Hstd)	15	Unknown	4	<11
RN018943	Lucy Creek (Stock)	33	28 – 33	6	22
RN016283	Maperte	49	31 – 37	25	6
RN018072	Orritipa-Thurra	37	29 – 33	14	15

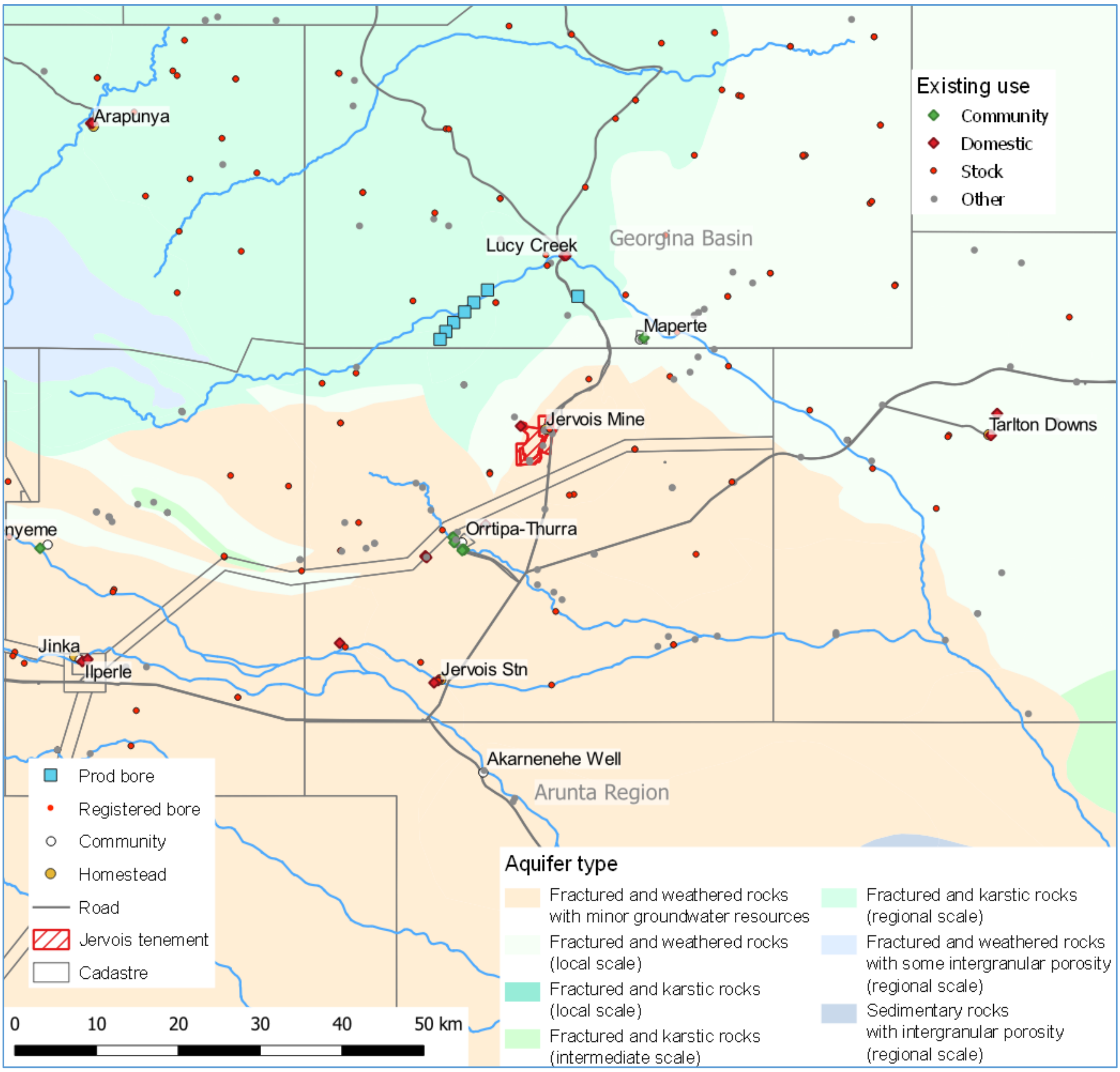


Figure 3-12 Distribution of existing users in the study area.

3.13. Groundwater dependent vegetation

The understanding of, and information available for, groundwater dependent ecosystems (GDEs) in central Australia is developing slowly.

In arid and semi-arid zones, groundwater is especially important to groundwater dependent vegetation, particularly in prolonged dry periods when evaporation exceeds precipitation.

Plants exhibit an incremental response to drawdown (from any cause): as groundwater reaches a depth at which roots cannot access it, plants become increasingly dependent on soil moisture.

Eucalyptus camaldulensis (river red gum) and some Corymbia species are known to be dependent on groundwater in at least a facultative manner. E. camaldulensis is dependent on shallow ground water, up to 10 m below ground level, while Corymbia species tend to be deeper rooted, from 8-20 m. It should be noted that E. camaldulensis has been shown to be sustained by shallow groundwater perched above the regional groundwater system associated with river gravels overlying less permeable strata (Villeneuve, et al., 2015), this is likely to be the case in the mine site given the hard, tight nature of the rocks underlying the drainage features.

Mature Corymbia opaca (Bloodwood) trees that have survived long lasting droughts may be better at extracting soil water against higher pressure deficits. The species is locally common within 20 km of the proposed pipeline and borefield (Low, 2019). However, it should be noted that in the Ti-Tree basin area,

In addition to Eucalyptus camaldulensis and Corymbia opaca, Corymbia apperrinja (Ghost Gum), and Vigna lanceolate (Bean Trees) were observed throughout the pipeline area. These two species are deep rooted, and would be considered facultative GDE species. However, there is little information on these species with regard to their ground-water dependencies in central Australia. Eucalyptus camaldulensis and Corymbia opaca were abundant along riparian areas, particularly Arthur Creek. Vigna lanceolate was observed in the southern section of the pipeline area.

There are no identified groundwater dependant ecosystems (GDEs) in the study area and the depth to groundwater often exceeding 15m generally precludes ecosystem use. However, as discussed further below, due to the depth to groundwater it is possible that the riparian vegetation along Arthur Creek near Lucy Creek Homestead are accessing groundwater from time to time.

In the absence of any site specific targets, the impacts on GDEs have been assessed using the following criteria adopted by the NT Dept of Environment and Natural Resources (DENR, 2018) to assess impact to GDEs due to groundwater abstraction:

- Modelled extraction does not cause the maximum depth to water table to exceed 15 metres below ground level in areas where groundwater is less than 15 metres;
- Modelled extraction does not result in the maximum depth to water table declining by more than 50% below the levels that would be expected under a natural baseline scenario (no pumping scenario); and
- Modelled extraction does not result in a rate of groundwater drawdown that exceeds 0.2 metres/year.

Note the study area is not covered by the Commonwealth Atlas for potential GDEs (BOM, 2017) and does not contain any wetlands of National Significance.

3.13.1. Process water supply

Groundwater level decline associated with the abstraction from production bores is considered a possible threat to GDEs. At greater distances from bores, in areas of lower drawdown, floristic changes have been shown to be more gradual and more dependent on rainfall.

The depth to groundwater in proximity to the process water supply borefield is greater than 10 metres and several sites intersected groundwater levels greater than the 15 metres that is considered too deep to support GDEs (LWA, 2009). Table 3-2 above presented the depth to water measured at bores installed in 2018 within the footprint of the process water supply area. Table 3-8 above presents the depth to water measured at existing bores outside the footprint of the process water supply area.

The closest sites that record water levels within 15 m of the ground surface are to the west of Lucy Creek station homestead. RN011495, RN012993, RN013381, RN013689 and RN18943 are located about 10km east of the process water supply borefield. The bore reports indicate a standing water level of 6 – 9 m below ground surface. In this area the ground surface elevation is relatively low (<320 mAHD) and coincides with the location of the Lucy Creek Fault Zone which is interpreted to impede groundwater flow to the east, resulting in a shallow water table.

Riparian vegetation along the may be accessing the regional groundwater, however, it is more likely that this vegetation is reliant on the water stored in the alluvial sediments associated with the larger creeks and hence the very limited extent beyond these river channels. Riparian vegetation health is therefore more dependent on maintaining the surface water flow regimes in the creeks.

3.13.2. Mine site

Generally groundwater levels in the mine site are greater than 20 metres below ground level (refer to Table 3-1). Two sites (RN010321 & RN010323) when drilled in 1972 reported groundwater levels less than 5 m below ground level and are interpreted to be associated with alluvium associated with Unca Creek. Both of these bores are completed to less than 15 metres suggesting that this feature may be perched (overlying the much less permeable rocks) and possibly disconnected from the regional groundwater system.

It is likely that these bores are installed in alluvial sediments overlying the much less permeable basement rocks that receive and temporarily store periodic surface run-off that recharges a local shallow/perched system that is has limited connection to the regional water table. The long-term health of the trees is therefore related to the maintenance of the surface water flow regime in the creeks.

3.14. Stygofauna

3.14.1. Jervois Project

The Jervois Mine groundwater impact assessment (CloudGMS, 2018a) identified through a desktop study that the habitat suitability for stygofauna in the mine site was poor and that the fractured and karstic nature of the process water supply aquifer had a much higher habitat suitability. Following this assessment a sampling campaign was conducted of the monitoring and test production bores drilled in the 2018 process water supply investigation (CloudGMS, 2018b).

A total of ten bores were surveyed for stygofauna in May 2019 by frc environmental. The sampled bores were all within the process water supply borefield area, to the west of Lucy Creek and about 20 km north of the proposed mine site.

Presence and composition of stygofauna

Overall, the stygofauna community of the borefield area was assessed as having low environmental value based on:

- the limited occurrence of a single stygoxene taxon; and
- on the basis of total dissolved solids, the water quality of groundwater is only potentially suitable for stygofauna.

3.15. Data uncertainty

Sources of uncertainty can be simply differentiated as either intrinsic or epistemic. Sources of uncertainty identified in this study are presented below in Table 3-9.

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

Table 3-9 Intrinsic and epistemic uncertainties associated with the groundwater modelling.

Uncertainty from	Intrinsic component	Epistemic component
Topograhic 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	Commensurability errors of simulated equivalent outputs with respect to observed values arising from inappropriate handling of scale effects.
Parameter correlation	Adopted parameters may compensate for parameter correlation (e.g. aquifer response depends on ratios of parameters such as aquifer diffusivity (T/S), or recharge and transmissivity (R/T)).	Adopted parameters may be inadvertently biased to compensate for conceptual issues.

4 Conceptual model

4.1. 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 to identify 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.

4.2. Groundwater system extents

Two groundwater systems are present within the study area:

- Fractured metasediment rock groundwater system hosting the Jervois Mine ore bodies; and
- Fractured and karstic (cavernous) limestone aquifers targeted by the associated mine process water supply groundwater extraction bores.

The groundwater model covers both these environments and the extents are presented below in Figure 5-1. The model domain has adequate lateral extents such that the impacts on the groundwater system due to mining activities (relating to dewatering associated with mine excavation and groundwater abstraction for the process water supply) do not reach the model boundaries (about 50-60 km separation).

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

- The southern boundary coincides with the regional groundwater flow line associated with the fractured rocks, and is assumed to be a no-flow boundary.
- The northern boundary coincides with the regional groundwater flow line associated with the carbonate aquifer, and is assumed to be a no-flow boundary.
- The north eastern boundary represents regional groundwater outflow from the carbonate rocks and has been assigned the groundwater contour value using transfer boundary conditions.
- The south eastern boundary represents regional groundwater outflow from the fractured rocks and has been assigned the groundwater contour value using transfer boundary conditions.
- The model layering has been selected primarily to adequately resolve the inclusion of the underground mine workings.

4.3. Hydraulic characteristics

4.3.1. Bonya Metamorphics

Previous groundwater occurences in the Bonya Metamorphics Complex were identified in fractures at about 25 metres below ground surface (M.I.M Exploration, 2001). The Bonya Schist is typical of metamorphic rocks and has a poor record of successful groundwater exploration (Berry & Matthews, 1992). Metamorphic rocks such as schist and gneiss have low permeabilities and generally contain small amounts of groundwater which is commonly brackish to saline.

Hydraulic testing during the 2018 mine site investigation confirmed that the permeability is relatively low with hydraulic testing indicating hydraulic conductivity values of less than 0.1 m/d and slug tests averaging about 0.04 m/d (Table 3-3).

The ‘J-fold’ metasediments in the area of the mine site exhibit localised increased permeability along interpreted faults cross-cutting the vertically dipping formations. The two pumping tests conducted indicate hydraulic conductivities of these features could be between 2 and 4 m/d.

Anisotropy is expected, associated with the obvious strike and near vertical dip of the units in the ‘J-fold’ and it has been assumed that there is increased permeability along strike and vertically down dip.

The storage characteristics are unknown, however, the specific yield is expected to be low at about 0.01, which is typical of fractured rocks. Specific storage was previously set at the default value set by FEFLOW of 1e-04 m^{-1}, in this study the specific storage has been reduced to a more representative value of 5e-06 m^{-1} for the metamorphosed fractured rock aquifer system.

4.3.2. Cambrian Carbonate Sediments

Recent pumping tests indicate a hydraulic conductivity of about 2 m/d (Table 3-4), which is consistent with the values identified previously.

These values are consistent with a summary from 15 bores from the Western Davenport area constructed in similar Cambrian carbonate sediments as those identified in the study area (Knapton 2016). The transmissivity (T) values for the Cambrian aged sediments are less than 400 m^2/d with an average of ~190 m^2/d and median of 109 m^2/d, indicating an average hydraulic conductivity of 1 m/d based on aquifer saturated thickness. Separating the Cambrian aged sediments based on aquifer formation, the average T for the Chabalowe Formation is 212 m^2/d and the Arrinthrunga Formation is 150 m^2/d, with the corresponding hydraulic conductivity values 2.2 m/d and 0.8 m/d respectively.

Specific storage was previously set at the default value set by FEFLOW of 1e-04 m^{-1}, in this study the specific storage has been reduced to an upper value of 1.3e-05 m^{-1} for the unaltered sediments of the Carbonate aquifer system (Rau, et al., 2018).

4.4. Groundwater flow dynamics

There is limited groundwater elevation data in the study area, although the water table through the area will generally mirror the topography; flowing generally from northwest to southeast and locally from areas of higher topography to areas of lower topography such as drainage features and discharging as evapotranspiration or possibly as small seepages adjacent to the rivers and lowlands.

4.5. 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).

Recharge in this environment is generally via direct infiltration to outcropping or thinly covered aquifers such as the fractured rock aquifers outcropping in the Jervois Range to the south of the Southern Georgina Basin, and the Watt, Spring, and Tomohawk Ranges further south. Focussed recharge occurs after heavy rainfall events where ephemeral streams flow from the ranges onto the plains, for instance at the Oorotippra Creek, Tomohawk Creek, Arthur Creek Flood-Out to the north of the project site. The potentiometric surface which exhibits a gradient from the ranges toward the Georgina Basin indicates that these ranges are recharge areas in this setting. Likewise the low salinity stock bores along the creeks and rivers indicate riverbed recharge.

Recharge rates are difficult to measure, however estimates in this environment have been generated based on water balance methods (Rooke, 2009) and Chemical Tracers (Harrington, 2002). The water balance approach applied to the WDWCD by Rooke estimated recharge at 5 to 12 mm per year averaged over the entire region. Harrington's 2002 study of chemical tracers and stable isotopes in groundwater within the Ti-Tree Basin indicated that significant recharge occurs mainly after heavy rainfall exceeding 150-200 mm per month, and that recharge beneath stream flood-outs averages 2mm per year, whilst recharge to the surrounding landscape averages around 0.2mm per year.

Recharge estimation for the Jervois project area applied the chloride mass balance method (Ericksenn and Khunakasem, 1969) to this project setting. Chloride in rainfall was defined as 0.7 mg/L (CSIRO, 2012; Keywood, et al., 1997) whilst the median chloride in groundwater at the mine site is about 400 mg/L (section 3.10.1). For an annual rainfall of 227 mm/year, this equates to an average groundwater recharge of approximately 0.4 mm/year.

4.6. 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
- Groundwater outflow at depth to east in the Georgina Basin and to the southeast in the fractured and weathered rocks in the Arunta Region;

Groundwater from the Georgina Basin Carbonate Aquifer does not discharge to surface within the study area. The water table ranges from 10 to 80m below ground surface and there are no springs, soaks, wetlands or salt lakes associated with the aquifer in this region. Groundwater flows from the margin of the Southern Georgina Basin, eastward into the broader regional Georgina Basin for eventual discharge many hundreds of kilometres from the study site.

Groundwater discharge to surface features within the Fractured Rock groundwater system will be very low as the Bonya Metamorphics has a low hydraulic conductivity and the groundwater level is typically well below ground surface.

The discharge from the groundwater systems is expected to be primarily as throughflow to the southeast for the Fractured Rock region and to the east for the Carbonate Rock of the Georgina Basin. An estimate of throughflow based on the groundwater gradient and representative hydraulic conductivity values are presented below in Table 4-1.

Table 4-1 Throughflow estimates for the Fractured Rock and Carbonate Rock groundwater systems in the study area.

Aquifer type	Hyd Cond [m/d]	h [m]	l [m]	Gradient [-]	Width [m]	Depth [m]	Throughflow [m^3/d]	Throughflow [ML/yr]
Fractured rock	0.001	20	10,000	0.002	50,000	800	80	29
Cambrian limestone	1	40	40,000	0.001	60,000	800	48,000	17,520

4.6.1. Pit-lake water budget

At the completion of mining it is assumed that the pits will infill over a period of years forming pit-lakes. The annual components of the pit water balances are:

Bellbird

- rainfall incident on the pit area (61,200 m^2) at 230 mm/yr = 14,080 m^3/yr
- groundwater flow into the pit (170 m^3/d) and 62,050 m^3/yr
- evaporation from the surface of the pit-lake assuming the pit is full (61,200 m^2) at 2340 mm/yr = -143,200 m^3/yr

Reward

- rainfall incident on the pit area (174,000 m^2) at 230 mm/yr = 40,020 m^3/yr
- groundwater flow into the pit (520 m^3/d) and 189,800 m^3/yr
- evaporation from the surface of the pit-lake assuming the pit is full (174,000 m^2) at 2340 mm/yr = -407,160 m^3/yr

Reward South

- rainfall incident on the pit area (65,500 m^2) at 230 mm/yr = 15,065 m^3/yr
- groundwater flow into the pit (170 m^3/d) and 62,050 m^3/yr
- evaporation from the surface of the pit-lake assuming the pit is full (65,500 m^2) at 2340 mm/yr = -153,270 m^3/yr

Evaporation exceeds Inflows by a factor of about 2 times and it is expected that the pit-lakes will recover relatively slowly (decades) to a level below pre-mining levels and act as a groundwater sink. The salinity will increase slowly due to evapo-concentration, with the development of hypersaline water in the pit-lake. The pit-lakes will behave as hydrogeological sinks and the movement of the hypersaline water from the pit is likely to be negligible (McCullough, et al., 2012).

4.7. Summary hydrogeological conceptualisation

The conceptual model of groundwater flow is a fractured rock aquifer with a thin weathered zone. In general, flow in the aquifer is away from topographic highs (recharge areas) toward groundwater discharge areas. For the most part, topographic highs and streams in the area act as recharge areas with limited or no surface groundwater discharge. Thus, groundwater flow in the Georgina Basin sediments is generally toward the east and the potentiometric surface generally follows topography where groundwater can discharge from the area as throughflow. Thus, water originating in the vicinity of the mine and its infrastructure would be expected to migrate offsite, likely as throughflow, to the southeast.

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 / dewatering activities will influence the local flow direction. Post closure the resulting pit-lakes are likely to be local sinks.

The primary fractured rock unit through which groundwater flow occurs in the project area is the Bonya Metamorphics. Investigation drilling has identified that faults cross-cutting the ‘J-fold’ units of the Bonya Schist can locally increase permeability along these features.

The pits and underground workings are located in these low permeability metasediments, hence, based on analytical estimates of pit inflows, there is expected to be limited groundwater recharge or discharge through the walls of the mine excavations.

Table 4-2 Summary of key features of the hydrogeological conceptualisation

Aspect Feature(s)	
Hydrostratigraphy	Groundwater is present in two groundwater systems: the fractured and weathered Fractured Rock system dominated by the Bonya Metamorphics; and the fractured and karstic Carbonate Aquifer of the Georgina Basin.
Flow dynamics	Groundwater in the Fractured Rock groundwater system is generally from northwest to southeast from areas of higher topography to areas of lower topography. Groundwater in the Carbonate Aquifer groundwater system is generally from west to east from areas of higher topography to areas of lower topography.
Recharge processes	Recharge primarily occurs as diffuse recharge with localised recharge along the surface water drainage features.
	Total recharge fluxes are difficult to estimate in this environment, however, surface discharge of groundwater is not observed and it is expected that recharge will be balanced with the throughflow estimates.
Discharge processes	Generally groundwater levels are 20-30 metres below ground level in the mine site and 10-20 metres in the vicinity of the process water supply borefield and it is expected that limited diffuse discharge occurs via streambed seepage or via evapotranspiration from shallow groundwater. Groundwater discharges primarily as throughflow to the east in the Georgina Basin and to the southeast in the fractured and weathered rocks in the Arunta Region.
	Total discharge fluxes as throughflow to the southeast and east were estimated at 20 GL/year.
Beneficial uses	The groundwater hosted by the Carbonate Aquifer is generally suitable for potable uses. The groundwater hosted by the Fractured Rock is generally suitable for stock watering / industrial uses. The monitoring bores installed at the mine site show water quality is suitable for stock due to TSD > 1000 mg/L, elevated F and Fe.

5 Model design & construction

5.1. Model design strategy

The model has been designed to meet the following criteria:

- Designed to run as quickly as possible to undertake uncertainty analysis;
- Refined mesh in the areas representing the pits and underground workings; and
- Refined mesh in the areas that may be impacted by the mine pit such as the river features.

5.2. Model platform

The FEFLOW (Finite Element subsurface FLOW and transport system v 7.109) modelling code was 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.

5.2.1. 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 that is used in MODFLOW, another widely used model. 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:

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

where K_{xx}, K_{yy} and K_{zz} and are the hydraulic conductivity along the x, y and z axes of the model, which are assumed to be parallel to the principal axes of the hydraulic conductivity tensor, h is the hydraulic head, *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.

5.3. Model domain and grid

5.3.1. Model domain

The 3D finite element model domain is centred on the Project mine site and covers an area of 17,278 km^2. The mesh has been refined along the geological contacts and drainage lines, the pit /

underground workings footprint and the process water supply bores. The model domain is discretised into a total of 397,455 elements consisting a mesh of 26,497 elements per layer with 15 layers.

The final FEFLOW mesh extents are summarised in Table 5-1 and the model domain is presented below in Figure 5-1.

Table 5-1 Jervois project numerical flow model domain specifications.

X min	535286
X max	726619
Y min	7412874
Y max	7593054
Model area	17,278 km^2
Map projection	GDA94 / MGA zone 53

5.3.2. Vertical discretisation / model layers

A total of 15 model layers (16 slices) were used in the JBMP groundwater model to represent the two groundwater flow systems. The slice elevations were selected based primarily on the development of the underground mine workings. The elevations of the 16 slices bounding each of the 15 layers are presented below in Table 5-2.

Table 5-2 FEFLOW layer structure.

Slice Number	Elevation (mAHD)
1	Topography
2	210
3	170
4	140
5	110
6	80
7	30
8	-30
9	-60
10	-120
11	-180
12	-210
13	-270
14	-330
15	-390
16	-450

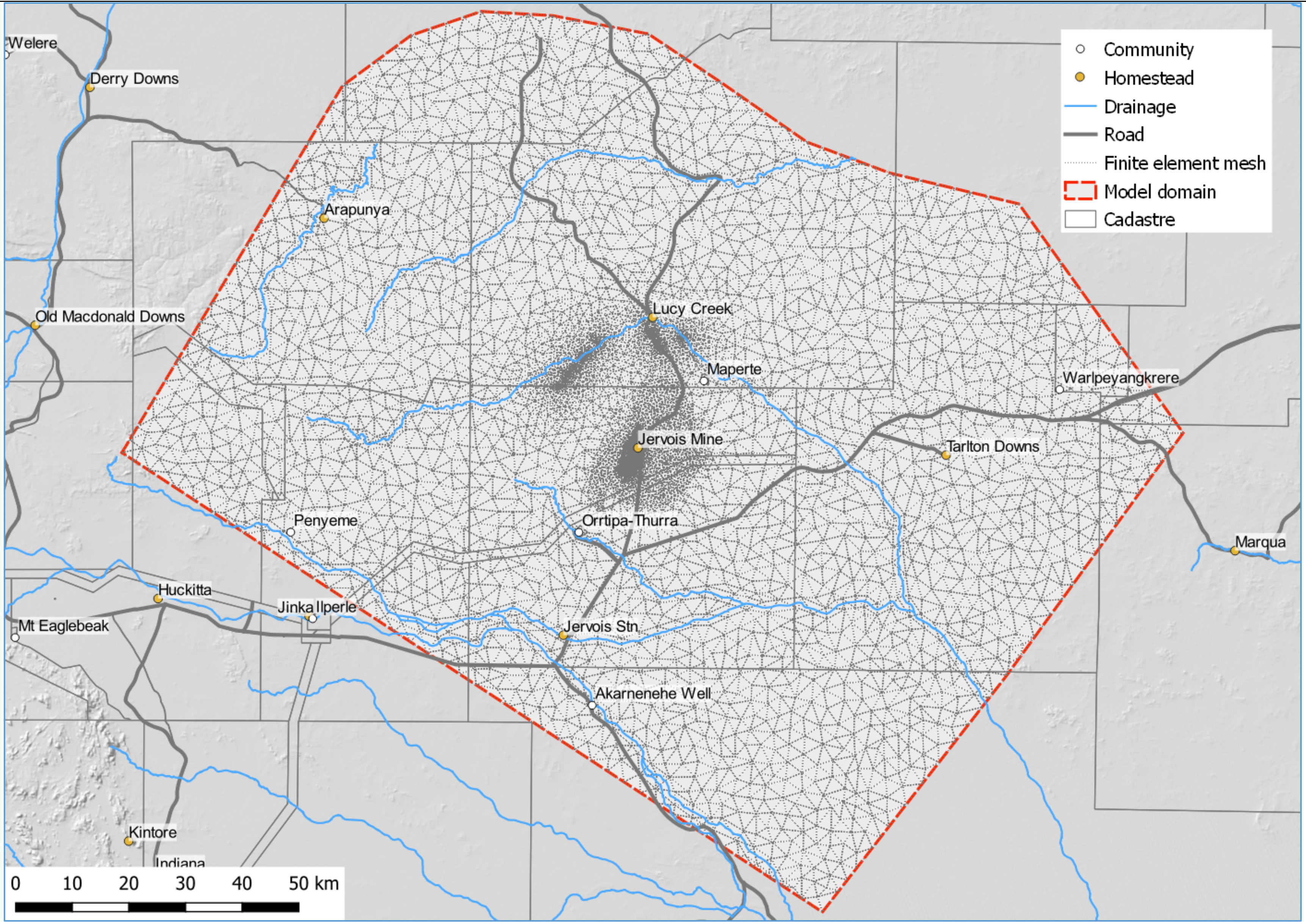


Figure 5-1 Jervois mine model domain and finite element mesh

5.3.3. Nodal boundary conditions

The boundary conditions (BCs) 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 at the specified node.
- Transfer BCs are also referred to as ‘third-type’ or ‘Cauchy’ boundary conditions, and are specified by an external head value and a conductance value. The external head value is used to represent a known value of hydraulic head at a location outside of the model domain, and the conductance value, calculated from the distance to the external head and assumed hydraulic conductivity of intervening strata represents the degree of hydraulic connection between the external head and the model boundary.
- 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 5-2.

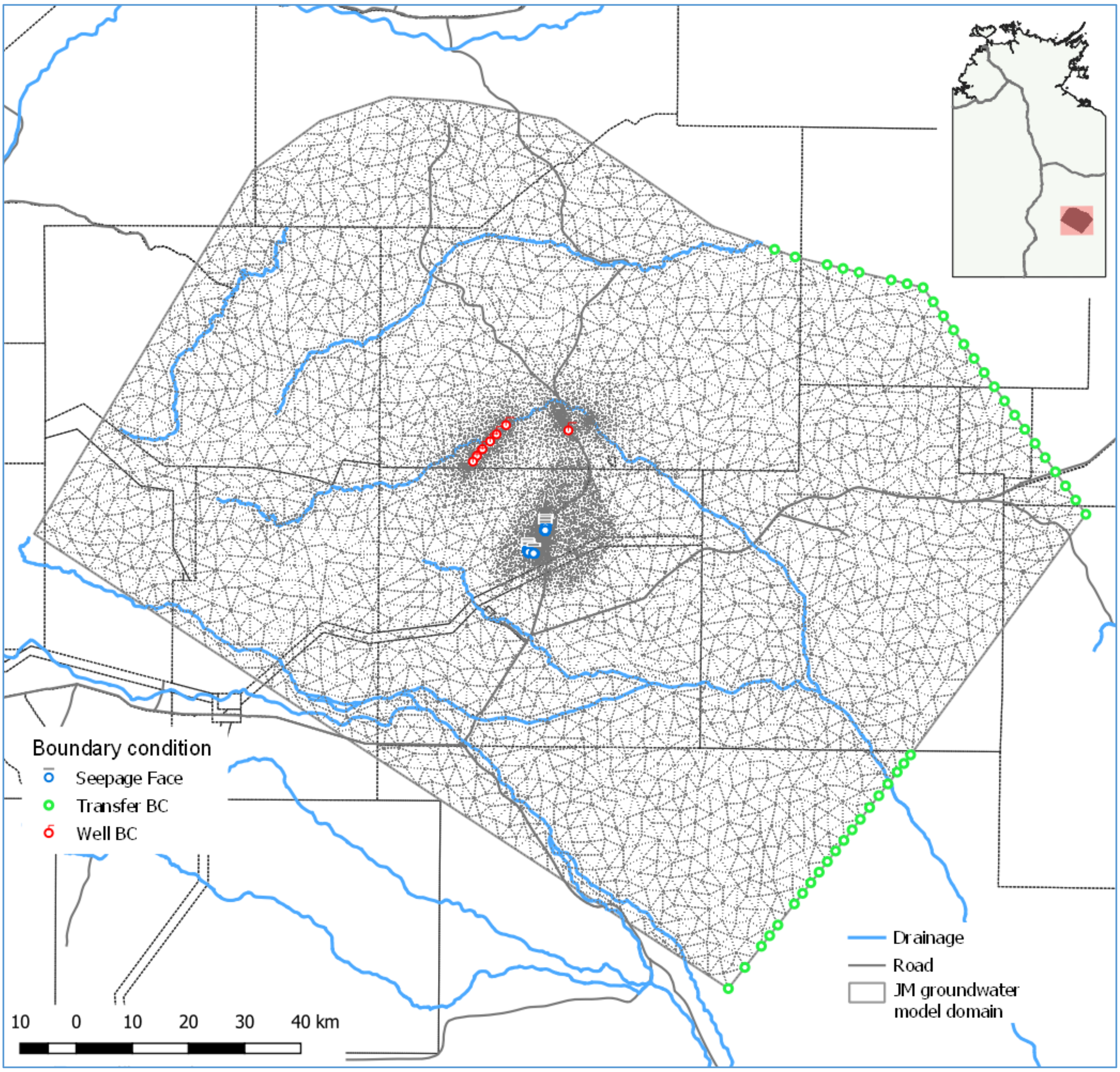


Figure 5-2 Distribution of boundary condition types in the model domain.

5.3.4. Areal flux distributions (recharge and evapotranspiration)

The recharge is applied to the model as a Parameter Expression areal flux distribution.

The Parameter Expression is a user-defined expression linking the In / outflow on top / bottom parameter recharge values to the recharge zones, which are attributed to the different soil types in the area, as detailed in section 4.5.

The depths to water table and sparse vegetation distributions mean that evapotranspiration has not been identified as a key process in conceptual terms (see section 4.6 for more detail).

Discharge of groundwater to the ground surface (if it occurs) is represented by seepage face boundary conditions. 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. Seepage face boundary conditions are used to represent inflows to open pit and underground mines and declines.

5.3.5. 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. The seepage face boundary conditions report inflow to the pit 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 3.11.

5.3.6. Representation of the underground workings during mining

The access declines will be constructed through basement rocks. In the modelling, dewatering and depressurisation of the access decline is represented using seepage face boundary conditions at which the maximum value of hydraulic head is constrained to specified elevations. The seepage face boundary conditions are activated sequentially in time and corresponding to the planned progression of the access decline over the LOM. At seepage faces the groundwater pressure cannot rise above zero (atmospheric pressure) but can fall below zero if pore-drainage and desaturation of rock at the seepage face occurs. Thus, a seepage face can discharge groundwater if the pressure at the seepage face would otherwise be greater than atmospheric pressure, but no inflow can occur at seepage faces if the pressure falls below zero. The inflow to the decline is also a predicted output of the modelling, and the predictions of inflow are obtained from the model-calculated fluxes at the seepage face boundaries.

Within the metamorphic basement rock, the geometry of the mining stopes are approximated by vertical tabular features. Dewatering and depressurisation of the stope is simulated using seepage face boundary conditions that are activated sequentially in time, corresponding to the planned progression of the mine excavations over the LOM.

Predicted inflow to the mine excavations are an output of the modelling that is obtained from the model-calculated fluxes at the seepage face boundaries. In reality, dewatering and depressurisation of the stopes may occur either from the use of in-mine pumps or installation of production wells within the stope area above ground.

After mining has ceased, recovery of groundwater pressure in the underground void occurs by re-filling from the bottom upwards. This process is simulated by deactivating the seepage face boundary conditions allowing recovery inflow from the metasediment sequence to drain to the base of the underground workings.

5.3.7. Representation of the process water supply

The Project process water supply borefield is expected to extract up to 2000 ML/yr (63 L/s) and is located about 20 km north of the mine site. The Project process water supply is represented in the model by 6 multilayer wells each pumped at 10.6 L/s (915 kL/d) for the 10 year LOM period.

Multilayer FEFLOW wells are screened across the upper layer of the CLA unit and are active from the commencement of mining operations. The multilayer wells dynamically proportion the total extracted volume between the assigned layers during a simulation, with the proportion of water extracted from each aquifer being dependent on the relative transmissivities of the aquifers and the changing groundwater pressures in the aquifers at the extraction locations during each time step of the model simulation.

5.3.8. Post closure pit-lake representation

The development of the pit-lakes post-closure of the mine 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(Volume).

If the water level in the lake is higher than the surface level at a node, a 3rd kind (‘head-dependent flow’) boundary condition is set at this node with a value identical to the lake water level (in mAHD). 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 (href - hgw) to the actual water depth at the node (href – dtm). This is useful if the groundwater level drops below the bottom of the lake, which is the case at the end of mining.

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 taken into account during the simulation (the area of the lake is determined at the beginning of each time step).

The evaporation from the lake was set to 5 mm/d which is equivalent to 0.6 times the average daily pan evaporation of 8.5 mm/d (3120 mm/yr /365). The reduced evaporation is used to account for the different conditions encountered in the pit compared to the open water body conditions used to estimate pan evaporation.

The level of the lake is calculated using an empirical function f(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* + (*InflowGW* + *InflowExtMM*)*dT.

The IfmDTM elevations for Bellbird, Reward and Reward South pits were presented previously in Figure 3-9 and Figure 3-10 respectively.

5.4. Steady state model design & construction

Steady-state simulations are used to model equilibrium conditions representing the “average” hydrological balance, or conditions where aquifer storage changes are not significant. A system is said to be in a steady state when the flow processes are (at least to a good approximation) constant with time. The inflows to and the outflows from the system are equal and as a result, there is no change in storage within the aquifer. This also means that the heads and watertable elevation do not change with time. Steady-state models, therefore, do not use storage properties.

A steady state model was developed to provide:

1) an estimate of the hydraulic conductivity distribution;
2) an understanding of the areas of recharge; and
3) an initial head distribution for the transient groundwater model.

5.4.1. Objective function

The steady state groundwater model was calibrated against the estimated observed groundwater levels presented in section 3.9.

5.4.2. Infiltration (recharge zones)

The infiltration zones were informed by the drainage and the 1:250K surface geology.

As discussed in the hydrogeological conceptualisation, surface water drainage features are expected to play an important role in recharge to the groundwater system, however, it was felt that given the poor understanding of how overland flow moves across the landscape, the steady state distribution of infiltration has been confined to the location of the drainage features. Recharge zones local to the 'J-fold' were also delineated and used during the calibration process. The zones were identified based on rock type and topography. For example, zone 15 represents areas with high slope, which is expected to limit infiltration due to high rates of runoff. The distribution of the infiltration zones is presented below in Figure 5-3.

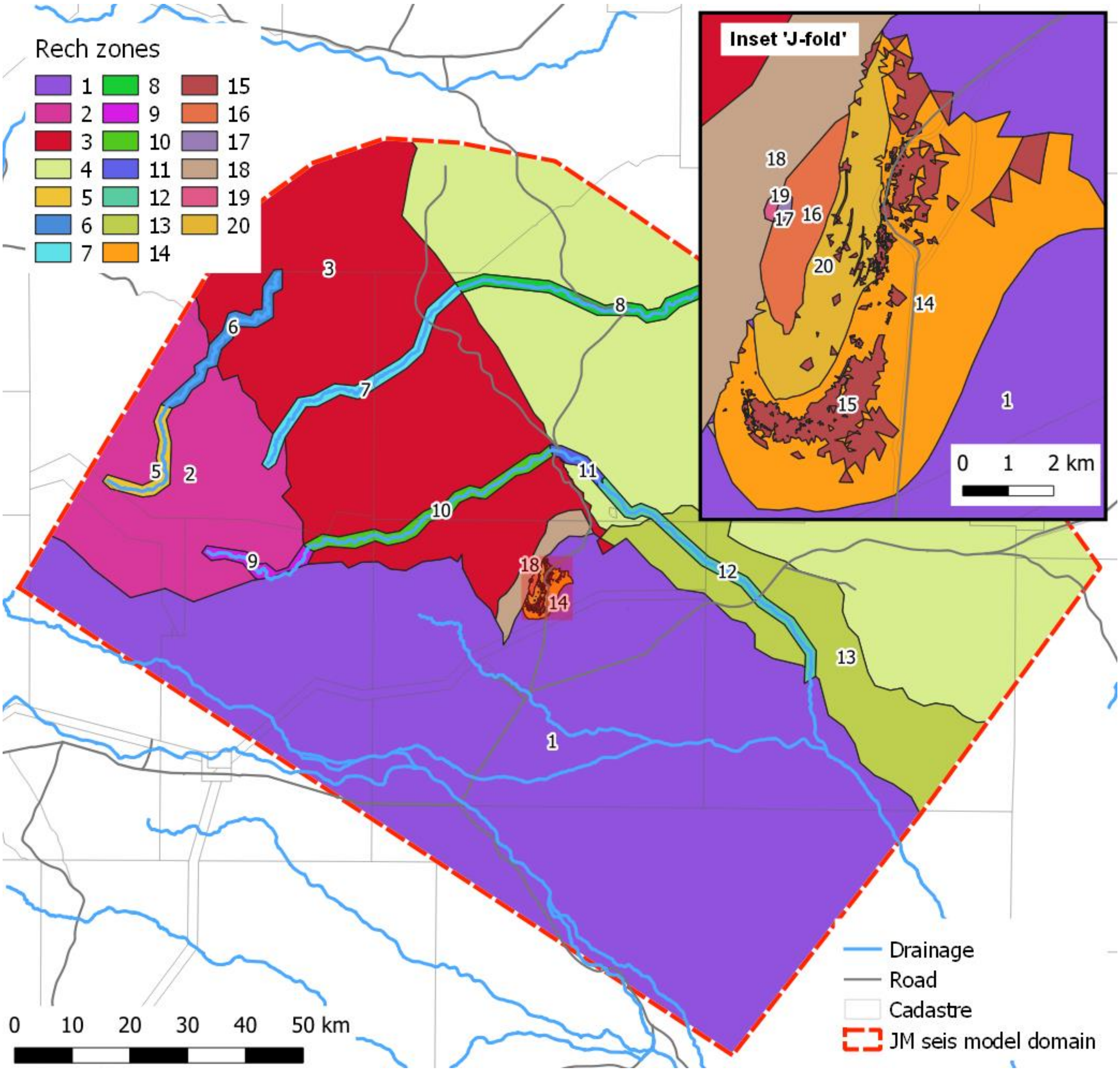


Figure 5-3 Infiltration zones used to delineate recharge to the groundwater system.

5.4.3. Hydraulic conductivity distributions

The FEFLOW model has been configured so that each layer extends over the entire model domain, this is reflected in the spatial distribution of hydraulic conductivity for each layer. The model domain was broadly zoned based on the regional geological formations. The local geological domains of the 'J-fold' were used to delineate the hydraulic parameters in the area around the mine site. A total of 24 zones were defined and their distribution is presented below in Figure 5-4. The zones associated with the 'J-fold' (zones 9 to 24) were considered in the calibration process.

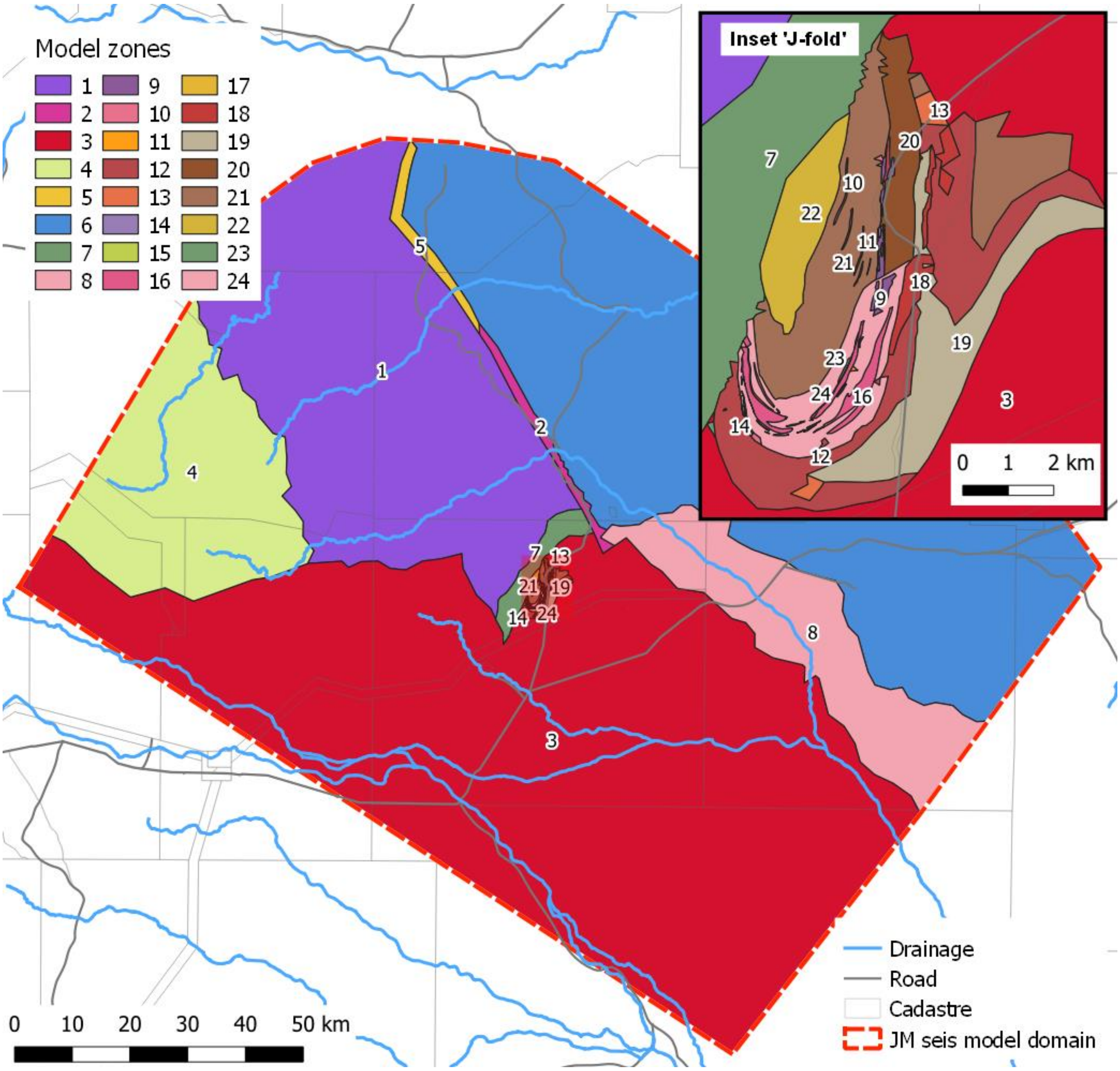


Figure 5-4 Model parameter zones.

5.5. Transient model design & construction

5.5.1. Simulation period and time stepping

The LOM model was run for a 10 year period (0 – 3650d) and the post-closure model was run for an additional 190 years. The FEFLOW simulation time, equation solver and numerical settings are presented in Table 5-3.

Table 5-3 FEFLOW simulation specification settings

Model code	FEFLOW
Software version	7.1.9 (x64)
Mesh	
Element geometry	Triangle prism
Free surface	Richards unsaturated (fixed mesh)
Head limits for unconfined conditions	
Top of model domain	Unconstrained head
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

5.5.2. 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.

5.5.3. Transient model initial heads

Initial heads for the transient model were obtained from the steady state groundwater model.

6 Parameter estimation

6.1. 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 that achieve an acceptable match to field-measured values within a pre-established range of error. Calibration establishes that the model can be accepted as a sound representation of the essential elements of the physical system of interest and a useful predictive tool.

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 (horizontal and vertical hydraulic conductivity, 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 using optimisation codes such as PEST (Doherty, 2016).

Regardless of the technique employed, all parameter 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 somehow limit the possible choices for the values of the estimated parameters.

6.2. Optimisation code

The purpose of PEST, which is an acronym for Parameter ESTimation, is to assist in data interpretation, model calibration and predictive analysis (Doherty, 2016). The PEST code is an open-source, public domain software, which, along with extensive documentation, can be downloaded from http://www.pesthomepage.org.

In this study, automatic parameter estimation was undertaken in parallel on multiple computers using the BeoPEST variant of the model-independent parameter estimation software suite PEST.

6.3. Objective function

The objective function or phi (Φ) is a measure of the difference ('residual') between the observed values and the modelled values (or the 'goodness of fit'). The PEST suite of programs uses the weighted sum of squared residuals (WRSS) as the target objective function. A smaller objective function indicates a 'better' fit of the model values to the observed values. The objective function in groundwater models typically comprises many different types of target data, for example, hydraulic heads or gauged flows, however, in this study only heads are available.

The objective function in this study comprised a total of 42 groundwater level measurements within the model domain. Generally, each of the groundwater values were assigned a weight of 1, however, some measurements were considered erroneous and were assigned a weight of 0.

6.3.1. 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 weighted sum of squared residuals (WSSR)
- root mean squared error (RMS)
- scaled root mean squared error (SRMS).

The weighted sum of squared residuals (WSSR) is the default measure utilised by the PEST suite of programs as the target objective function to assess 'goodness of fit'.

$$WSSR = \sum_{i=1}^{n} \left(W_i * \left(y_i - f(x_i)\right)\right)^2$$

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 root mean squared error (RMS) is a standard statistical measure:

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

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 a key calibration criterion recommended in the groundwater modelling guidelines (Barnett et al. 2012). The 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.

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

where

W_i are weights between 0 and 1; and
H is the range of measured heads across the model domain.

6.4. Parameter estimation results

6.4.1. Recharge

The final calibrated recharge values for each of the recharge zones in Figure 5-3 are presented below in Table 6-1.

Table 6-1 Final calibrated recharge values.

Zone	Infilt.rate (mm/d)	Infilt rate (mm/yr)
1	1.00E-05	3.65E-03
2	1.26E-03	4.60E-01
3	4.07E-04	1.49E-01
4	1.00E-04	3.65E-02
5	5.77E-02	2.11E+01
6	1.00E-04	3.65E-02
7	1.00E-04	3.65E-02
8	1.00E-04	3.65E-02
9	7.33E-02	2.68E+01
10	2.90E-01	1.06E+02
11	9.03E-02	3.30E+01
12	9.65E-02	3.52E+01
13	1.00E-05	3.65E-03
14	1.71E-04	6.25E-02
15	3.00E-03	1.10E+00
16	3.00E-03	1.10E+00
17	4.69E-02	1.71E+01
18	4.60E-04	1.68E-01
19	9.64E-03	3.52E+00
20	3.18E-03	1.16E+00

6.4.2. Hydraulic conductivity and specific yield

The hydraulic conductivity and specific yield parameter fields were defined for individual model zones representing the hydrostratigraphic units as per the conceptualisation (section 3.8). The final hydraulic conductivity values across strike and parallel to strike and vertically down dip are presented below in Table 6-2. As discussed in section 4.3.1, anisotropy is associated with the obvious strike and near vertical dip of the units in the ‘J-fold’, which is reflected in the higher values parallel to strike in zones 9-24 (i.e. increased permeability along strike and vertically down dip).

Table 6-2 Final calibrated model parameters.

Zone	HSU	Hyd. cond. Across strike	Hyd. cond. Parallel to strike	Specific yield
1	3	1.00E+00	1.00E+00	0.04
2	3	1.00E-01	1.00E-01	0.04
3	4	1.00E-03	1.00E-03	0.01
4	2	5.00E-02	5.00E-02	0.04
5	3	1.00E-01	1.00E-01	0.04
6	1	8.00E-01	8.00E-01	0.04
7	3	7.38E-03	7.38E-03	0.04
8	3	7.81E-02	7.81E-02	0.04
9	5	1.00E-03	1.00E-02	0.01
10	5	1.00E-03	1.00E-02	0.01
11	5	1.00E-03	1.00E-02	0.01
12	5	1.85E-03	1.85E-02	0.01
13	5	1.06E-03	1.06E-02	0.01
14	5	9.97E-04	9.97E-03	0.01
15	5	1.00E-03	1.00E-02	0.01
16	5	1.16E-03	1.16E-02	0.01
17	5	1.00E-03	1.00E-02	0.01
18	5	1.07E-03	1.07E-02	0.01
19	5	1.80E-03	1.80E-02	0.01
20	5	2.27E-03	2.27E-02	0.01
21	5	2.96E-04	2.96E-03	0.01
22	5	1.00E-04	1.00E-03	0.01
23	5	1.00E-03	1.00E-02	0.01
24	5	1.34E-03	1.34E-02	0.01

The distribution of hydraulic conductivity values perpendicular to strike is presented below in Figure 6-1.

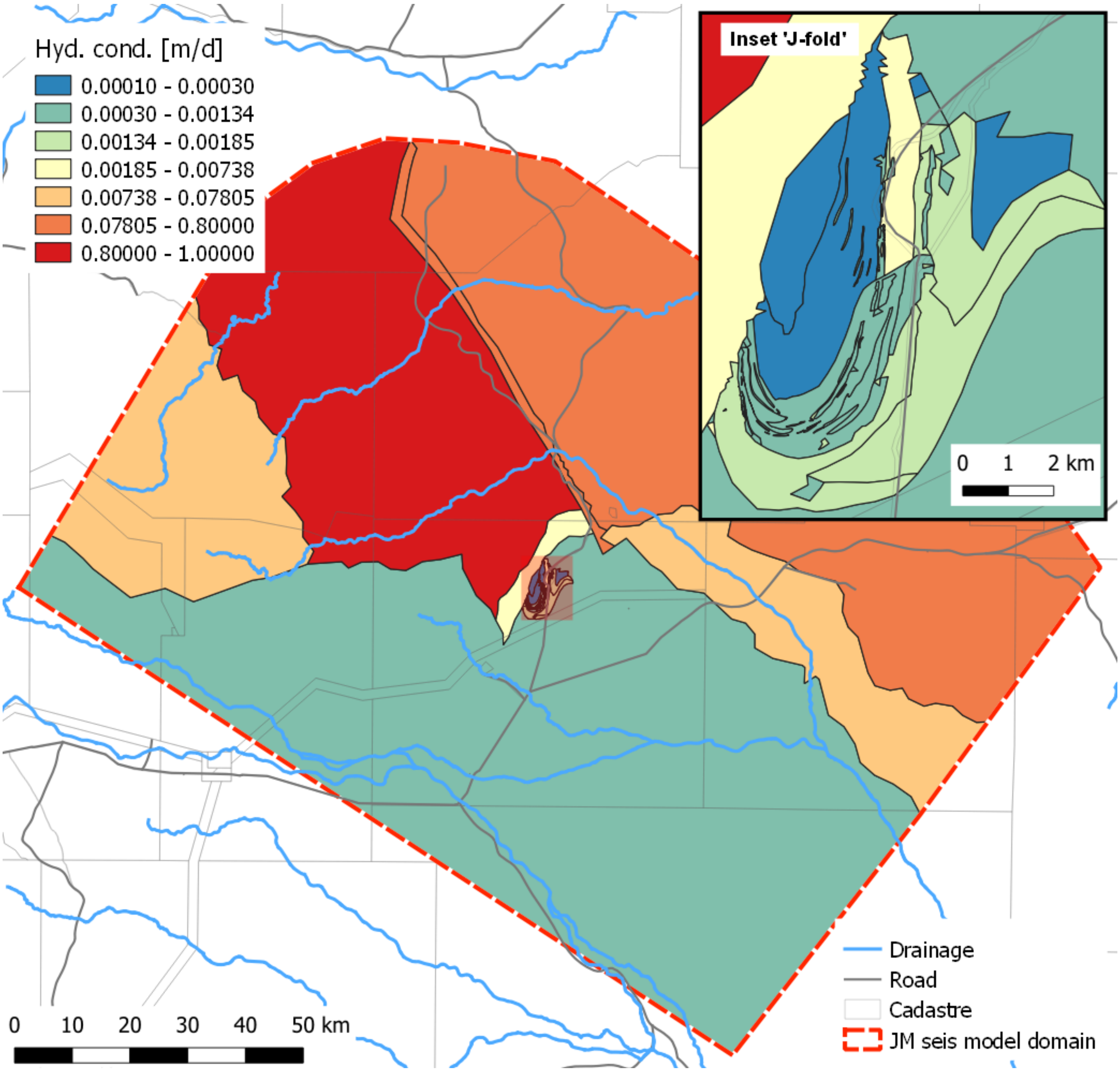


Figure 6-1 Final hydraulic conductivity distribution in the orientation perpendicular to strike.

6.5. 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 in statistical terms. 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 6-3. The performance of the JBMP groundwater model is discussed in the following sections.

Table 6-3 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.

6.5.1. Model convergence

Section 5.5.2 documents that the dimensionless error criterion in FEFLOW is used for the automatic time-stepping process.

On completion of the steady state model run, the model log was queried to ensure the model converged to a value less than the error criterion of 1e-03 (consistent with the guidelines).

6.5.2. Steady state model water balance

The steady state water balance for the entire model domain is presented below in Figure 6-2. The imbalance is -7.6e-04 m^3/d which is about 0.001% of the total inflows / outflows, less than the target criteria of <0.5%, and demonstrating the numerical accuracy of the model.

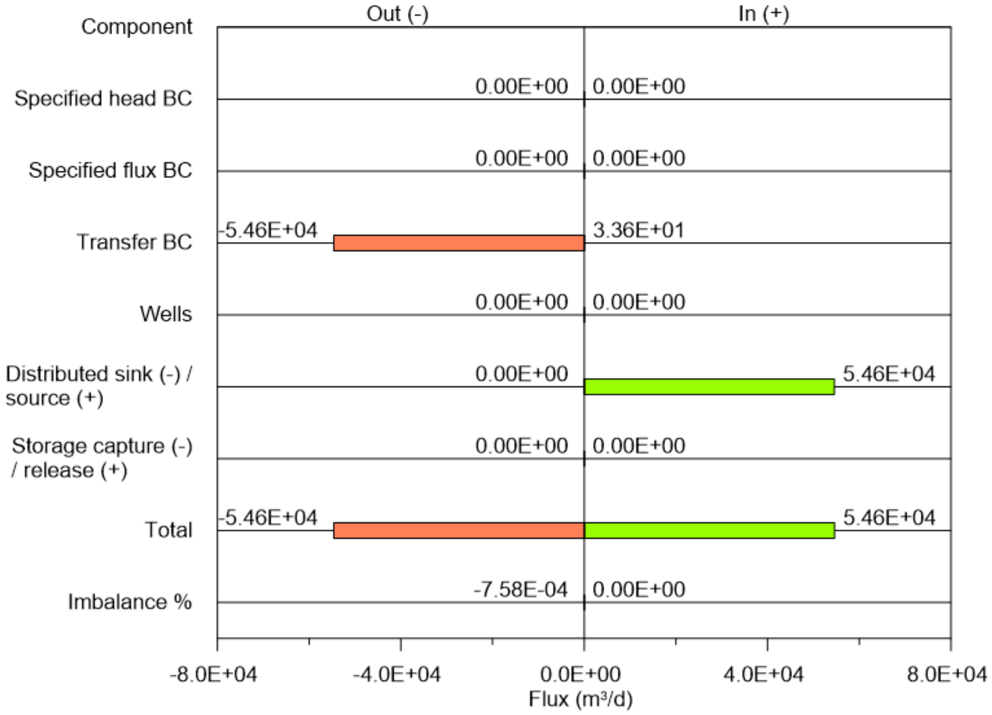


Figure 6-2 Steady state model water balance.

The steady state groundwater balance for the calibrated model over the entire model domain is presented below in Table 6-4. The average throughflow out of the area of 20 GL/yr is equivalent to 54,600 kL/d, which is consistent with the water balance estimate presented in section 4.6

Table 6-4 Steady state model water balance.

Component	Out (-) [m³/d]	In (+) [m³/d]	Out [ML/yr]	In [ML/yr]
Dirchlet	0	0	0	0
Neumann	0	0	0	0
Cauchy	-54,623	34	-19,900	0
Wells	0	0	0	0
Distributed Sink(-) / Source(+)	0	54,589	0	19,900
Storage Capture(-) / Release(+)	0	0	0	0
Imbalance	-0.4		0	

6.5.3. Qualitative performance

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

The modelled water inflows / outflows budget is also consistent with the conceptual model.

The contours of heads and flow patterns are reasonable (Figure 6-3), and similar to those anticipated, based on observed measurements. Generally, the absolute modelled groundwater levels are in reasonably good agreement with the observed values.

The modelled and measured heads are also presented as a scatter plot below in Figure 6-4. 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.

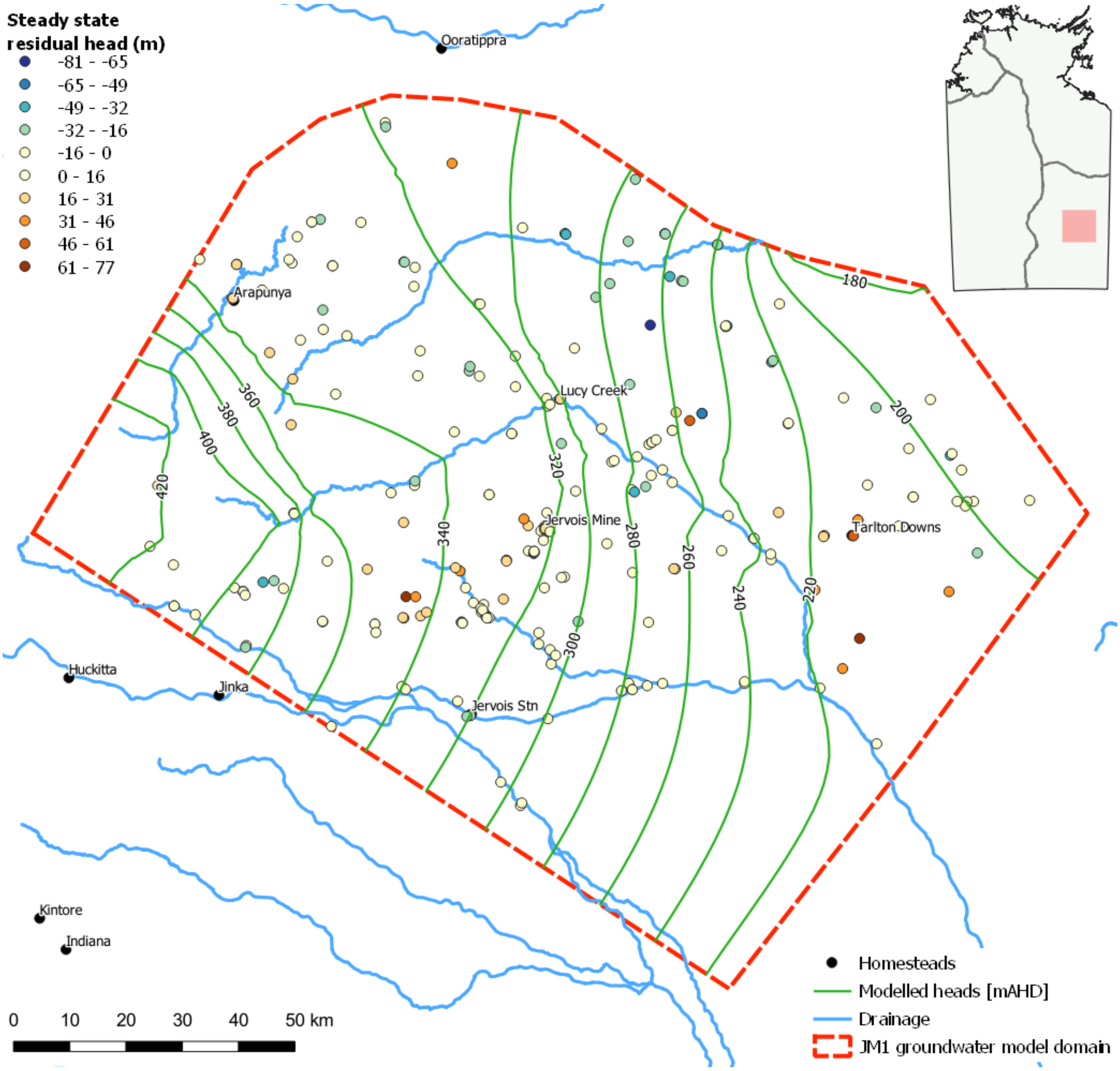


Figure 6-3 Modelled steady state groundwater heads with residuals (measured minus modelled) at observation bore locations.

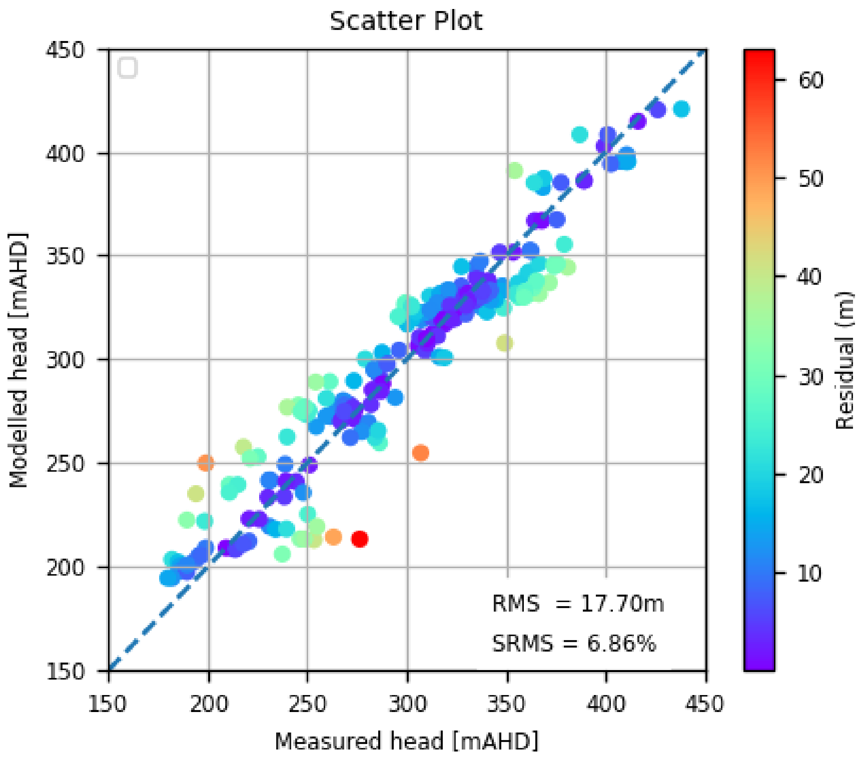


Figure 6-4 Scatter plot of modelled vs measured heads. The point colour indicates the magnitude of the residuals (ie the absolute difference between measured and modelled heads).

6.5.4. Model domain quantitative performance

At the conclusion of the parameter estimation process the final standard error (RMS) was 20 metres. The maximum head range of the observed heads across the model domain is 258 metres, therefore, the scaled root mean squared (SRMS) is 6.7% (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 3.2, can have considerable error particularly along drainage.

Statistical descriptions of the goodness of fit between the observed and modelled groundwater levels are presented in Table 6-5.

Table 6-5 Analysis of residuals using final estimated parameters.

Metric	all obs.
Number of residuals with non-zero weight	249
Mean value of non-zero weighted residuals	0.09m
Maximum weighted residual	63.1m
Minimum weighted residual	-50.8m
Standard variance of weighted residuals	313.3m
Standard error of weighted residuals (RMS)	17.7m
Scaled standard error (SRMS)	6.86%

6.5.5. Mine-site specific quantitative performance

At the conclusion of the parameter estimation process the final standard error (RMS) for the observation bores in the mine site was 4 metres. The maximum head range of the observed heads across the model domain is 22 metres, therefore, the scaled root mean squared (SRMS) is 18% (above the target SRMS of 5%). The SRMS value is considered acceptable given that some of the groundwater levels are probably affected by pumping influences (Solar Bore and Mill Bore) and dependent on the SRTM ground elevations (cf_ui1 and cf_ui2), which as indicated in section 3.2, can have considerable error particularly along drainage. Comparison of the observed and simulated groundwater levels with statistical descriptions of the goodness of fit are presented below in Table 6-6.

Table 6-6 Observed vs simulated heads (mAHD) in the mine site.

Site	Obs [mAHD]	Sim [mAHD]	Residual [m]
j1	343.80	343.75	0.05
j4	336.30	334.68	1.62
j6	333.20	335.04	-1.84
j7	330.00	329.89	0.11
j8	330.60	329.79	0.81
j11	335.10	329.96	5.14
j13	334.30	329.57	4.73
j15	336.80	330.20	6.60
j16	333.50	331.45	2.05
j18	332.00	330.26	1.74
j19	331.00	329.32	1.68
j21	327.70	329.34	-1.64
j23	333.40	330.41	2.99
j24	333.30	330.53	2.78
kjc125	333.60	330.71	2.89
kjc178	335.50	330.25	5.25
kjc189	322.70	330.57	-7.87
kjcd261	333.90	332.59	1.31
kjcd283	333.70	332.28	1.42
cf_ui1	325.00	330.67	-5.67
cf_ui2	325.10	330.69	-5.59
old_shaft	331.60	330.03	1.57
rn006910	323.40	329.41	-6.01
rn010121	333.10	331.14	1.96
shaft_bore	330.70	329.99	0.71
solar_bore	321.00	330.40	-9.40
Min	**321.00**	**329.32**	**-9.40**
Max	**343.80**	**343.75**	**6.60**
Ave	**331.55**	**331.27**	**0.28**
RMS			**4.04**

6.6. 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 groundwater model steady state calibration, 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 1% change in the parameter value and are presented graphically below in Figure 6-5. The sensitivities indicate that the groundwater levels are most sensitive to the assumed recharge rates in zones 1 – 4. The next most sensitive parameters are the recharge zones 7, 8 and 10 and the hydraulic conductivity in zone k6.

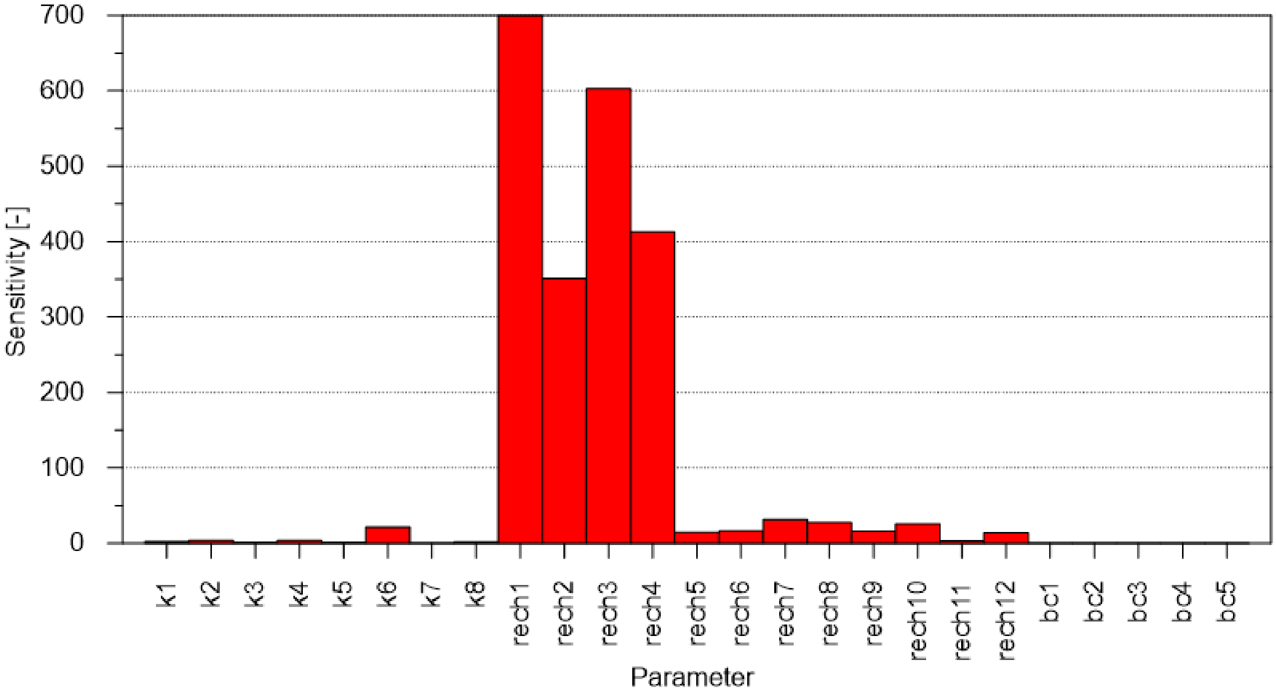


Figure 6-5 Sensitivities (relative change in objective function) determined by adjusting parameter values by 1%. (k1 - k8 = hydraulic conductivities; rech1 – rech12 = recharge scaling factor; bc1 – bc5 = boundary condition elevation)

7 Forecast scenarios

This section investigates the impacts of pit and underground mine development over the life of the mine and post closure.

The scenarios considered span a total time period of 1000 years and are summarised below:

- Life of mine (duration 10 years)
- Post closure (duration 990 years).

7.1. Life of mine (LOM) forecast results

The LOM forecast scenario was designed to investigate the effect of the mine development on groundwater flow dynamics in the area. The LOM models have been queried to generate outputs for selected metrics such as annual inflow volumes to open pit and underground mines, final drawdown contours, time series groundwater level changes at selected groundwater dependent vegetation (GDV) monitoring sites and waterholes identified in the study area. The results are presented for the suite of model realisations that have been considered using random parameter sets constrained by the current understanding of hydraulic parameters in the area. The following assumptions were made for the predictive model runs:

- All model parameters were taken from the calibrated model;
- Pit shell and decline / stope elevations were applied to the model as per section 3.11;
- Passive groundwater dewatering via seepage face boundary conditions, with no groundwater dewatering from production bores;
- Groundwater extraction for the entire LOM from the 6 process water supply bores at 10.6 L/s;
- TSF implemented with leakage at design rate of 0.1 mm/d;
- The model was run for a forecast period of 10 years;
- Initial conditions were taken from the final heads of the calibrated steady state model;
- Steady state recharge and evapotranspiration used for the forecast model.

7.1.1. Mine site groundwater levels

The locations of observation bores installed in 2018 (refer to Table 3-1) and used to monitor the local impacts of mining activities on the groundwater levels are presented below in Figure 7-1. The observation bores form the baseline monitoring network and additional monitoring sites may be installed as required.

The groundwater levels at the observation bores over the 10 year life of mine (LOM) are presented below for the TSF in Figure 7-2, Bellbird Pit in Figure 7-3, Reward Pit in Figure 7-4 and Rockface in Figure 7-5.

The observation bores adjacent to the TSF demonstrate some mounding. The groundwater levels decline towards the end of mining as the drawdown from the dewatering of the Reward Pit and underground workings extends beneath the TSF.

Groundwater levels at all other monitoring sites show continuing downward trends except at Rockface, which shows recovery of groundwater levels at the end of year 5 when mining at Rockface ceases.

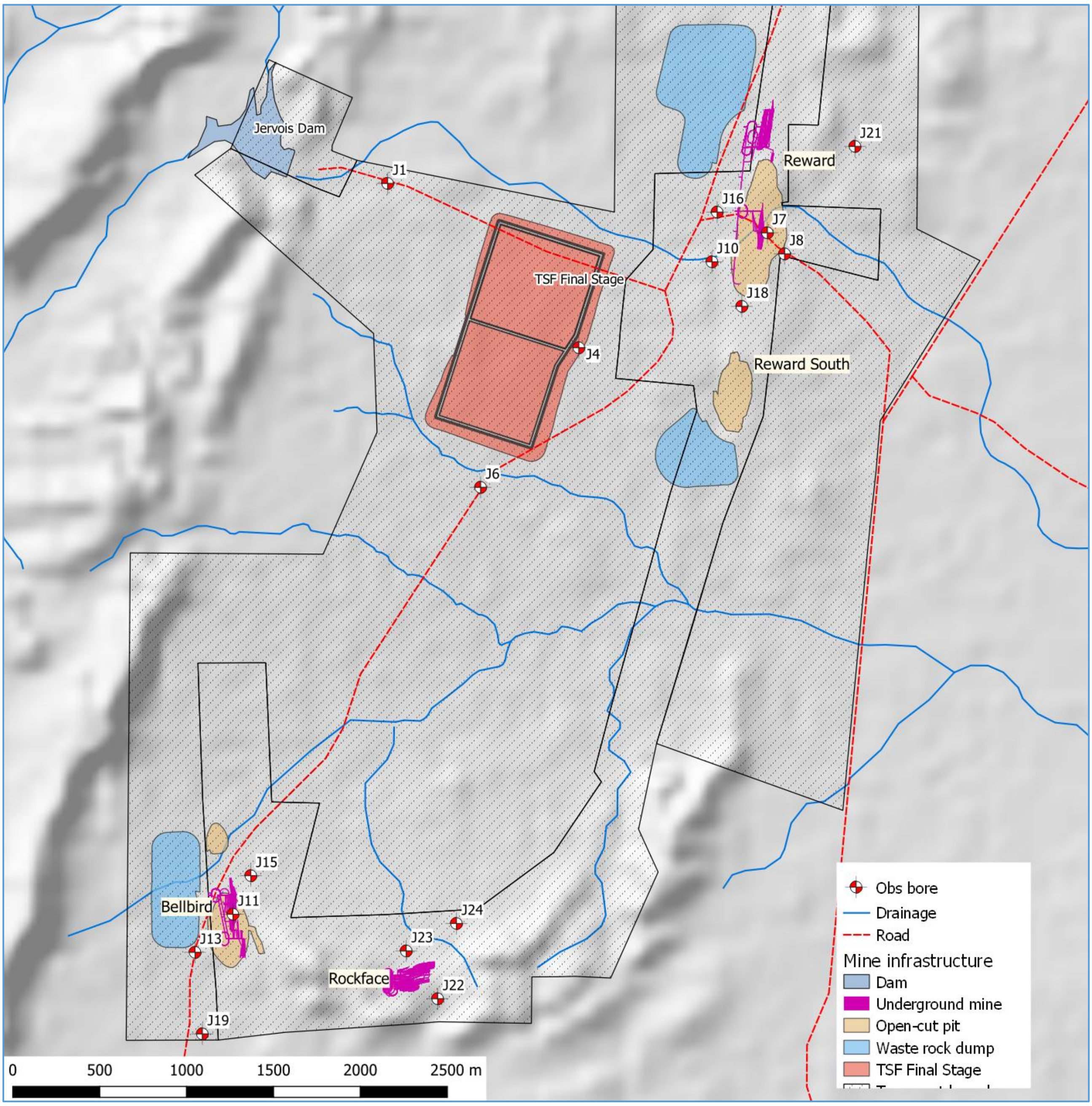
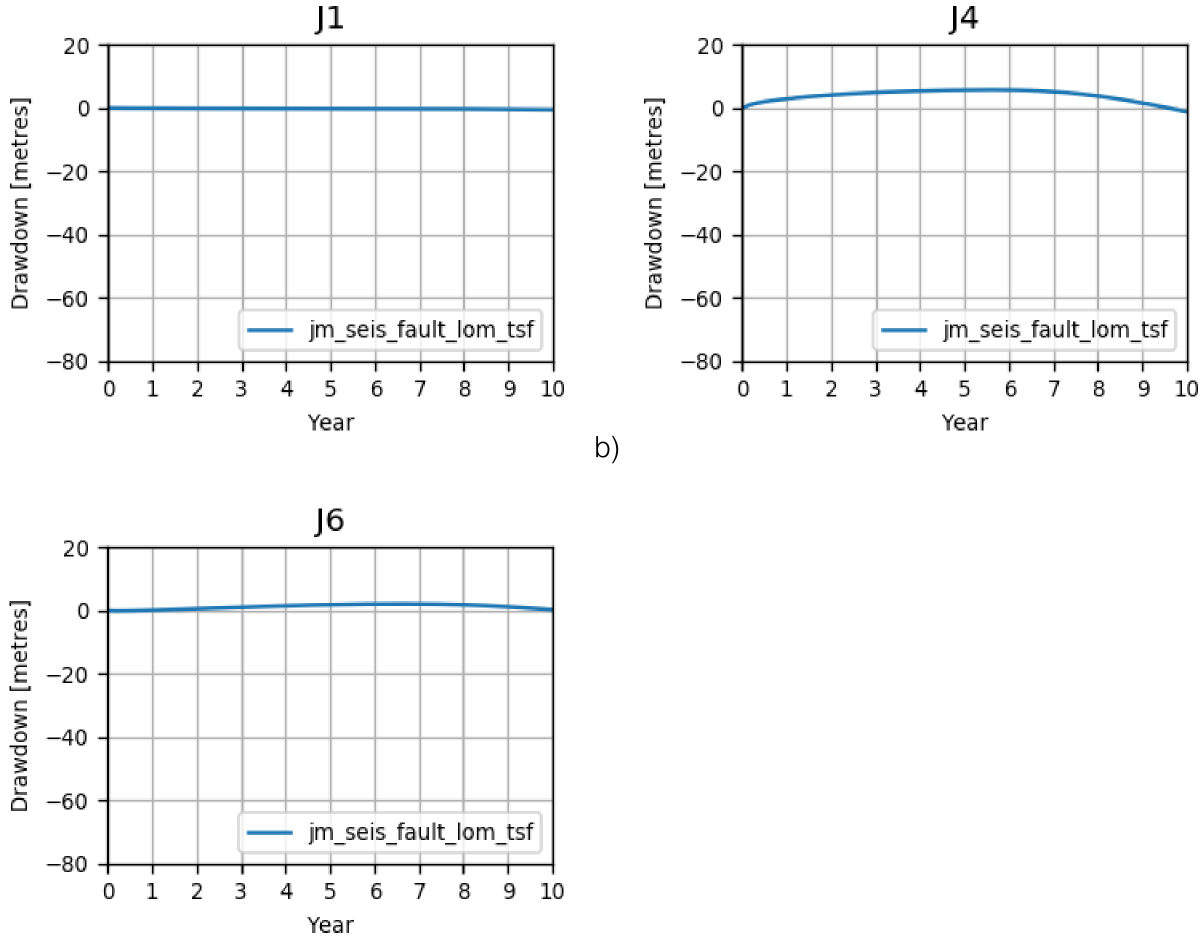


Figure 7-1 Locations of observation bores around the Jervois mine site.

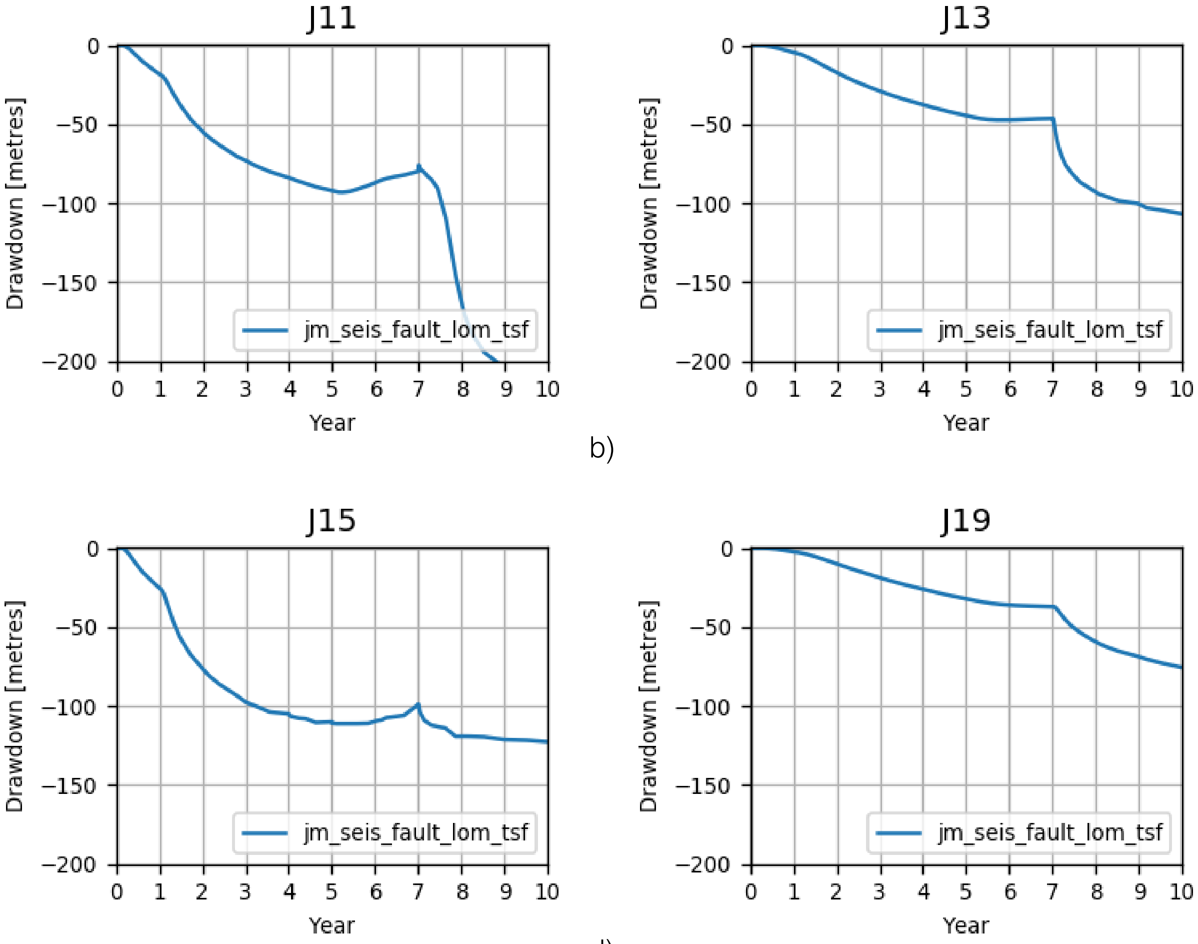


a)

b)

c)

Figure 7-2 Groundwater levels around the TSF.



a)

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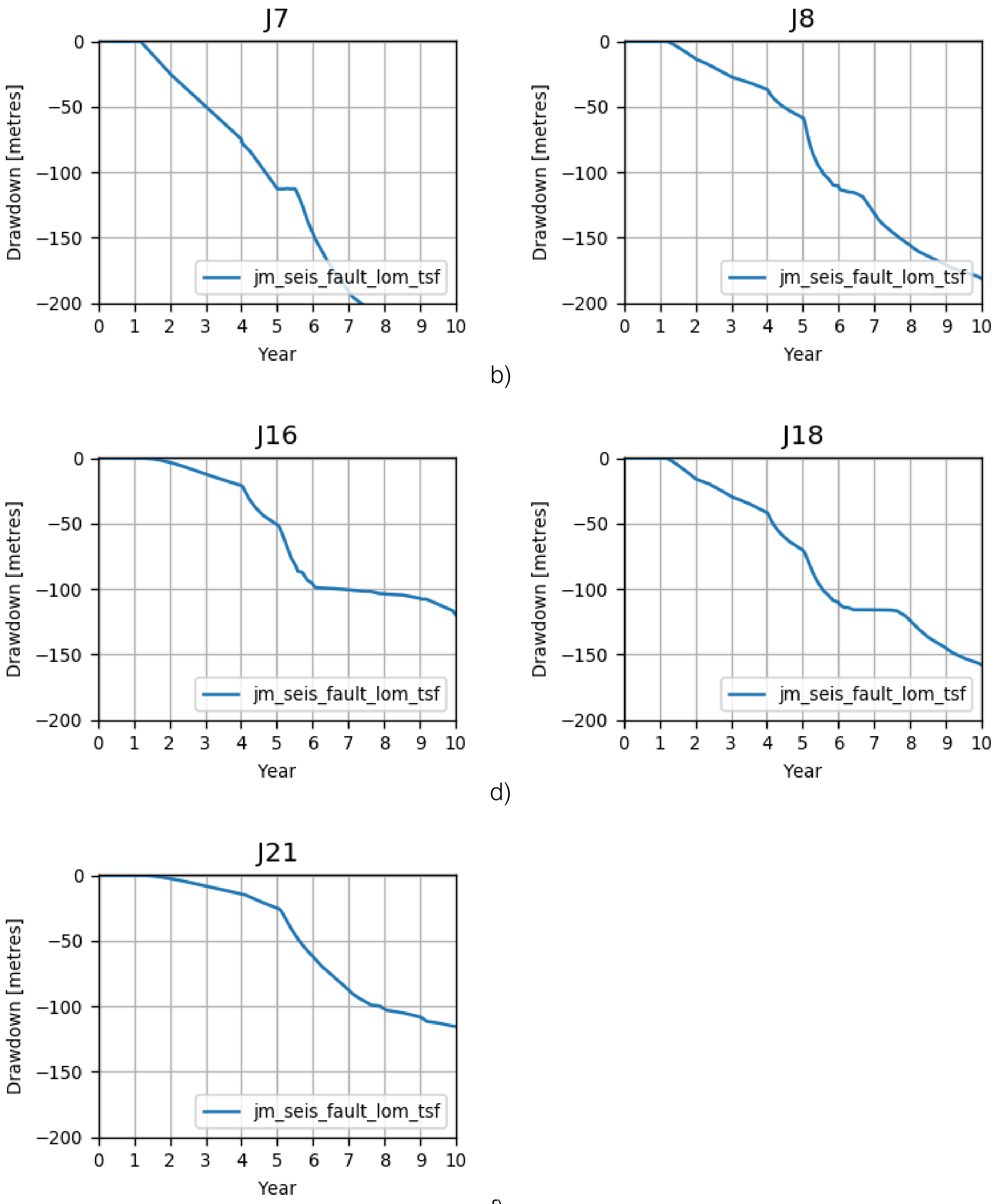
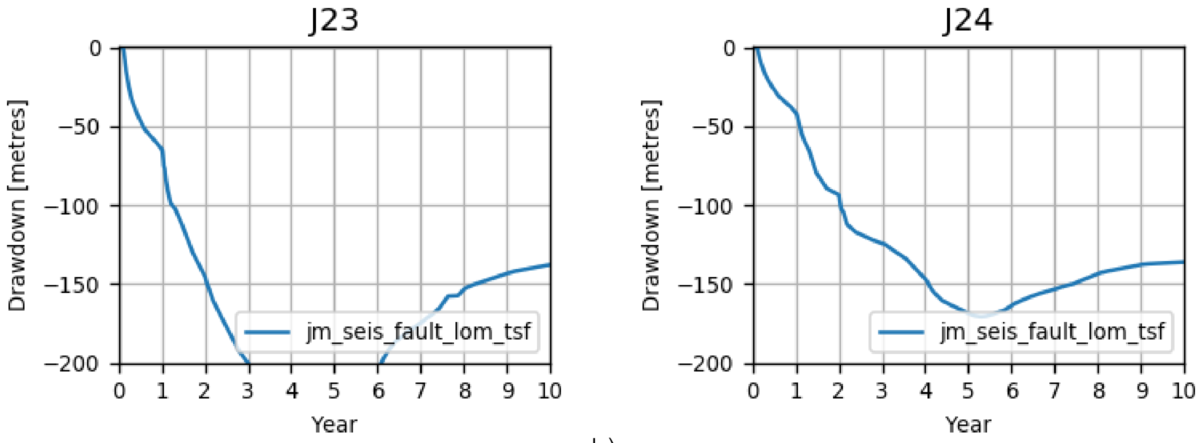
Figure 7-3 Groundwater levels at proposed monitoring sites near the Bellbird pit and underground mine.



a) b) c) d) e) f)

Figure 7-4 Groundwater levels around the Reward pit and underground mine.



a) b)

Figure 7-5 Groundwater levels around the Rockface underground mine.

7.1.2. Process water supply groundwater drawdown impacts

Groundwater drawdown contours after 10 years of pumping at the process water supply borefield are presented below in Figure 7-6. A more detailed map of the borefield drawdown is presented in Figure 7-7.

The drawdown at the domestic bores close to the Lucy Creek homestead, represented by RN013689, can expect to be impacted by drawdowns of about 1 metre at the end of LOM.

The drawdown at the stock bores close to the Lucy Creek homestead (RN013381 and RN018943) can be expected to be impacted by drawdowns of about 1 metre at the end of LOM.

The drawdown contours indicate that the two closest stock bores to the borefield (RN011101 and RN011102 & RN13274) can be expected to be impacted by drawdowns of about 1 – 2 metres at the end of LOM.

Groundwater levels at the production bores decline by about 9 metres. Drawdown hydrographs for the monitoring bores located within the footprint of the borefield are presented below in Figure 7-8 and Figure 7-9 and indicate a drawdown of about 6 – 7 metres can be expected over the 10 year LOM period at about 10 – 20 metres from the production bores.

Using the following criteria to assess the impact to GDEs (assumed to be the riparian vegetation adjacent to the river channels):

The modelled extraction does not cause the maximum depth to water table to exceed 15 metres below ground level assuming an initial depth of about 10 – 11 metres below ground level and a drawdown of 3 – 4 metres at a distance greater than 150 metres away from the production bores which is less distance than the distance to the riparian zone associated with Arthur Creek.

The abstraction at the borefield does not result in the maximum depth to water table declining by more than 5 metres (50%) below the initial depth of 10 – 11 metres.

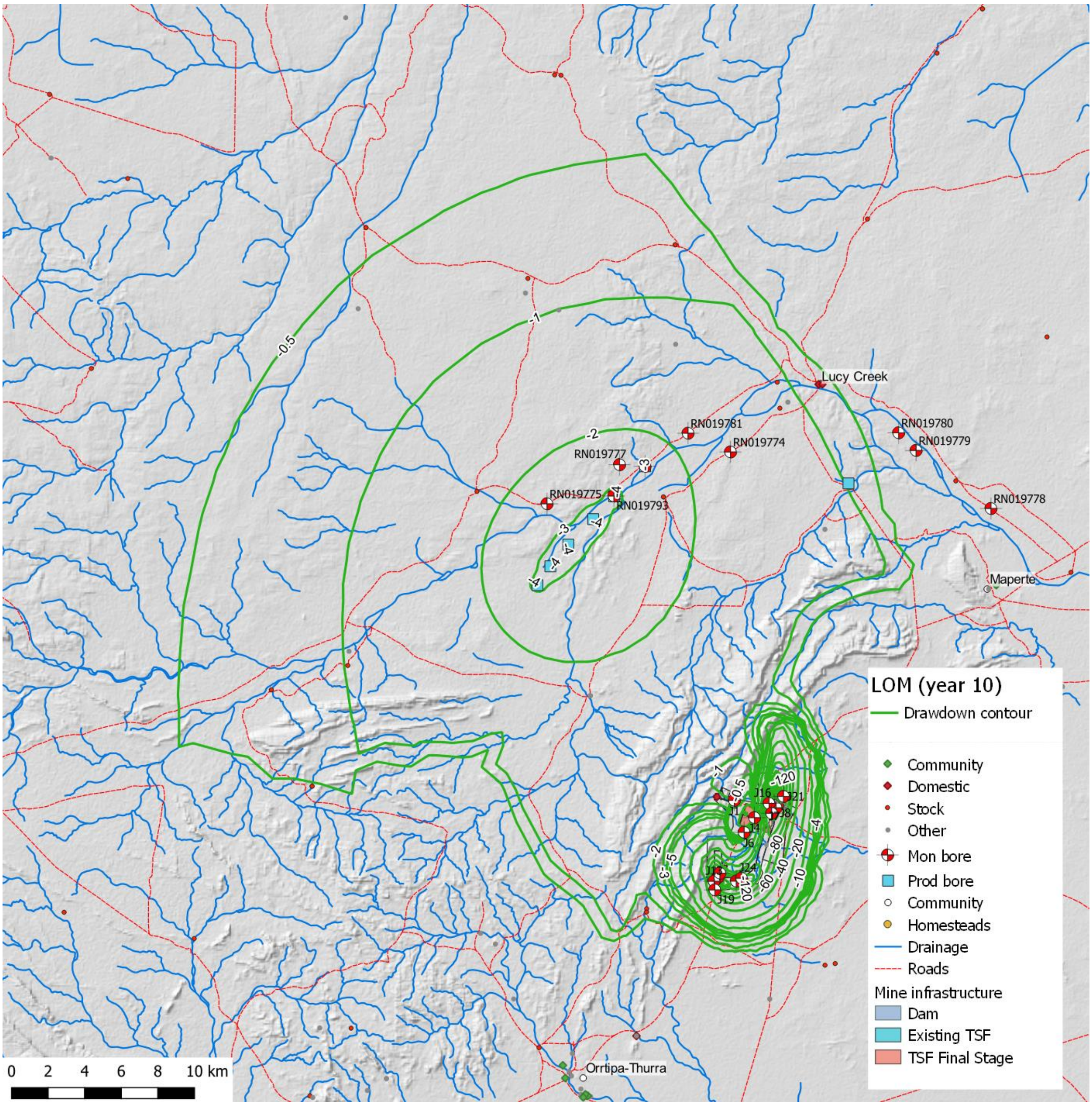


Figure 7-6 Drawdown after 10 years of groundwater abstraction from the process water supply borefield.

The rate of drawdown in an area close to the bores (radius of ~50 metres) is about 0.5 m/year which is greater than the DENR criteria of 0.2 m/yr, however, these areas do not correspond to areas of riparian vegetation (based on comparing drawdown contours to satellite imagery). The area encompassed by the 2 metre drawdown contour includes significant areas of riparian vegetation where groundwater level rates of decline of between 0.2 – 0.4 metres/yr are predicted.

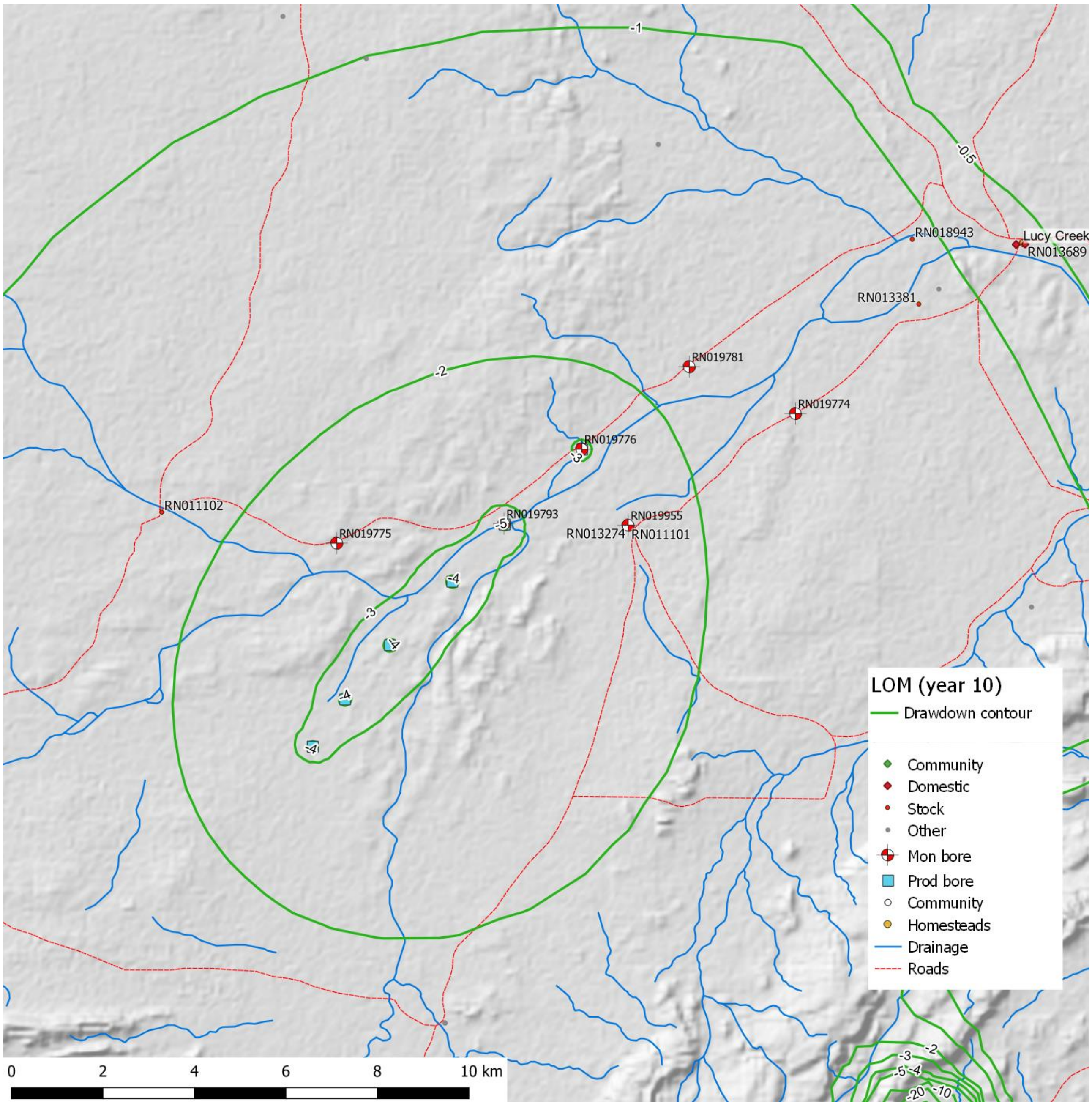
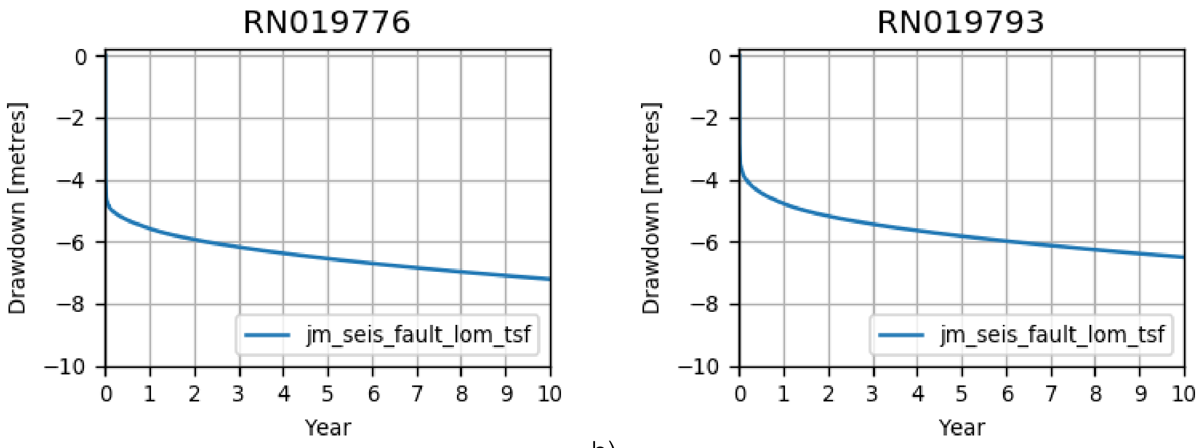
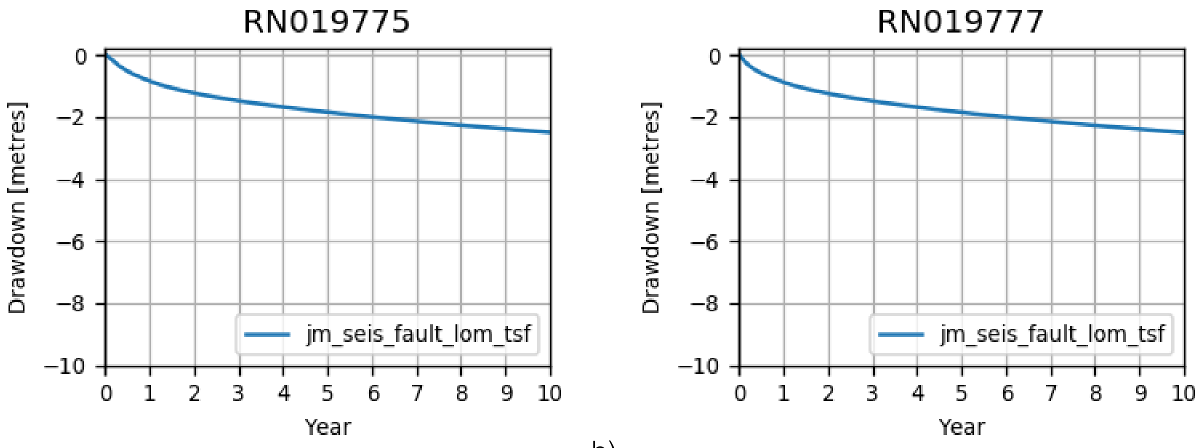


Figure 7-7 Detailed map of existing users, monitoring bores and drawdown after 10 years of groundwater abstraction from the process water supply borefield.



a) b)

Figure 7-8 Groundwater level response at the process water supply LC observation bores to the north of the mine site a) RN019776 and b) RN019793.



a) b)

Figure 7-9 Groundwater level response at the process water supply Lucy Creek observation bores to the north of the mine site a) RN019775 and b) RN019777.

7.1.3. Existing users

Maperte

Maperte outstation water supply is sourced from the production bore RN016283. The response at this bore is presented below in Figure 7-10. The response shows a subtle declining trend of much less than 1 metre over the 10 year LOM period.

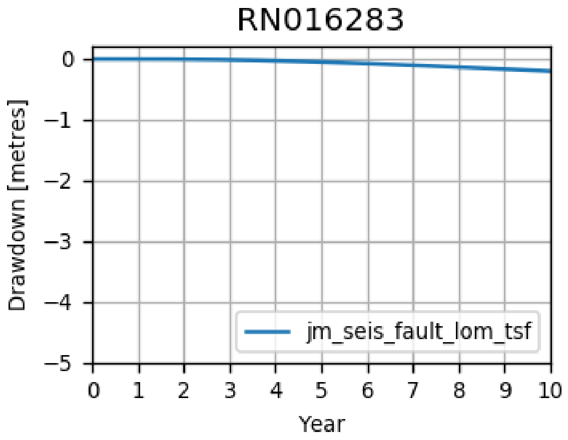


Figure 7-10 Groundwater level response at existing observation bores to the northeast of the mine site near Maperte RN016283.

Orrtipa Thurra

The closest water supply borefield is at Orrtipa Thurra, about 18 km to the southwest of the Jervois Mine site. Groundwater levels at the borefield are reported in the model at RN018072. The response at RN018072 over the 10 year LOM period are presented below in Figure 7-11 a). Groundwater levels between the community borefield and the Jervois Mine site are reported at RN018978. The response at RN018078 over the 10 year LOM period are presented below in Figure 7-11 b).

The impact of mine dewatering is not apparent on the Orrtipa Thurra bore hydrograph and a slight downward trend is evident at RN018078 after 5 years of mining.

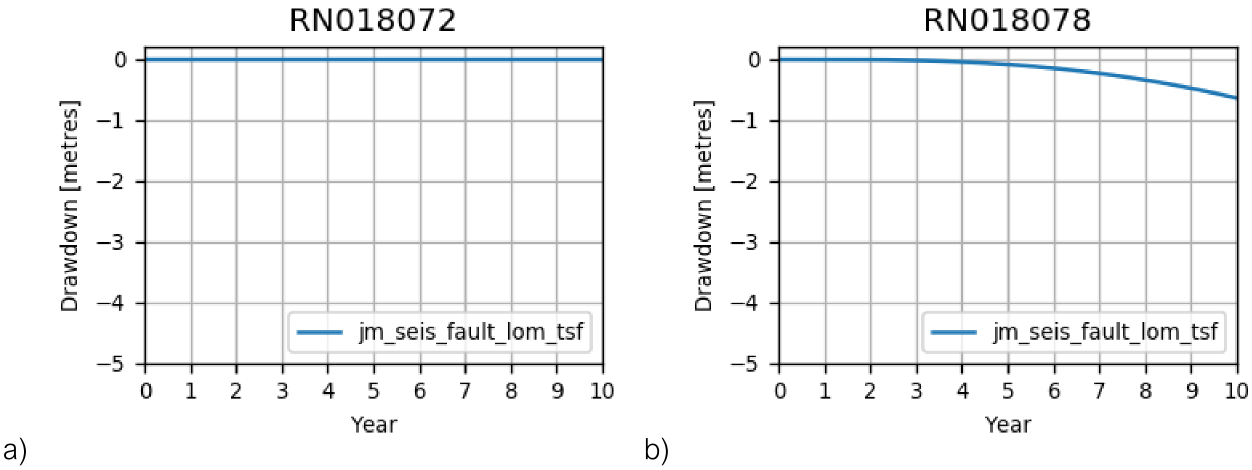
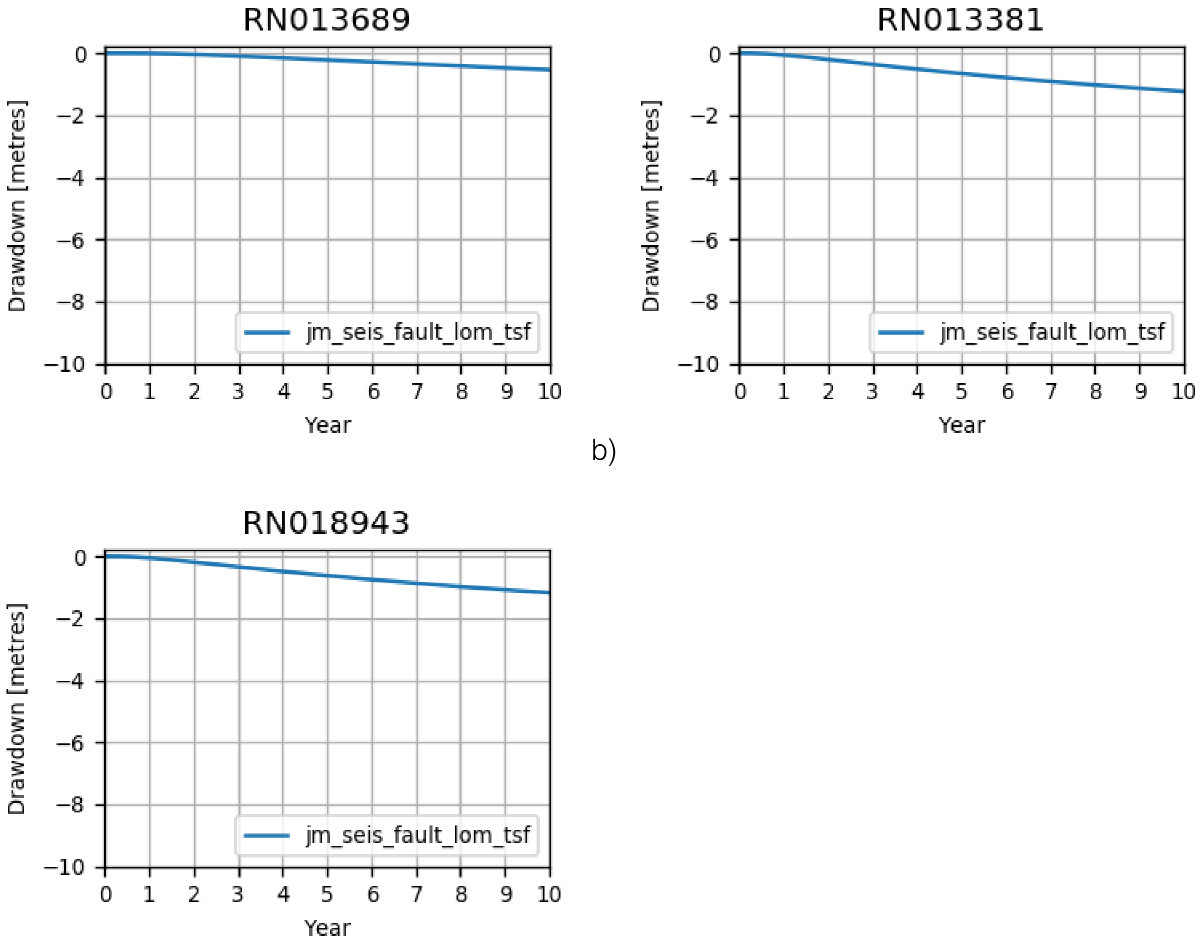


Figure 7-11 Groundwater level response at existing observation bores to the southeast of the mine site near Orrtipa Thurra a) RN018072 and b) RN018078.

Lucy Creek Station

Two stock bores RN013381 and RN018943 adjacent to the Lucy Creek Station homestead and the domestic water supply bore (RN011495) have been used to report impacts on the water supply (Figure 7-12). The sites show subtle declining trends of 1 – 2 metres over the LOM period.



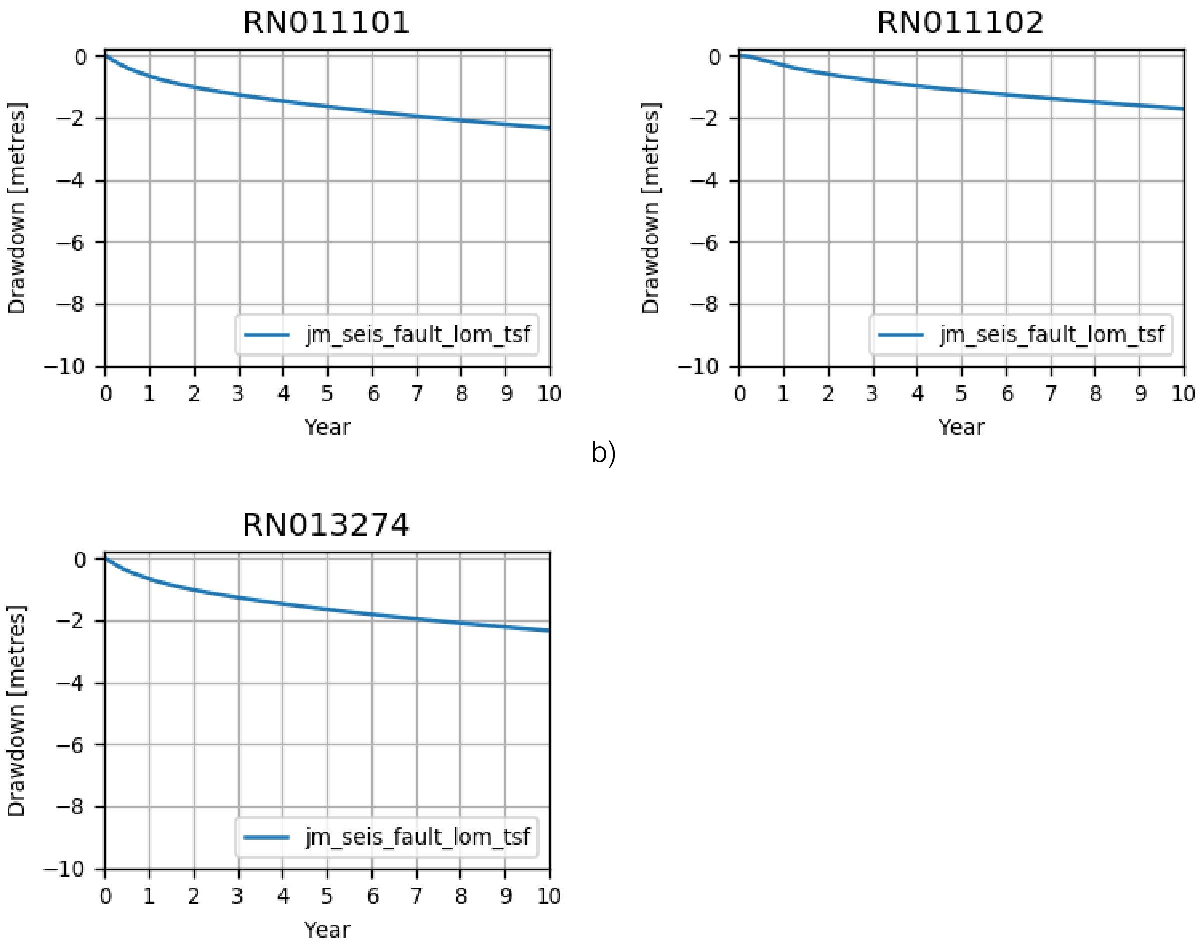
a) b)

c)

Figure 7-12 Groundwater level response at existing bores to the north of the mine site near Lucy Creek Station a) RN013689, b) RN013381 and c) RN018943.

Three stock bores RN011101, RN011102 and RN013274 adjacent to the process water supply have been used to report impacts on the water supply (

Figure 7-13). Both show a subtle declining trend of about 2 metres over the LOM period.



a)

b)

c)

Figure 7-13 Groundwater level response at existing observation bores to the north of the mine site near Lucy Creek Station a) RN011101 b) RN011102 and c) RN0137274.

7.1.4. Mine site groundwater drawdown contours

The LOM forecasted drawdown impacts are presented below in Figure 7-14. The 0.5 metre drawdown at the end of mining extends about 3 km beyond the mining lease to the south of Rockface underground mine and the north of Reward The drawdown extends only about 2 km to the east of the mining lease boundary, reflecting the higher north-south anisotropy. The maximum drawdown at various points around the mining lease boundaries ranges between about 40 and 100 metres, with mounding of around 5 metres at the boundary near the TSF.

The final contours in the vicinity of the mine tenement are different to those presented in the EIS assessment. This difference is due to the following factors:

- Higher hydraulic conductivity values introduced through the anisotropy discussed in section 4.3.1. The increased hydraulic conductivity promotes drawdown propagation.
- Higher bulk hydraulic conductivity values introduced through the inclusion of fault features cross-cutting the 'J-fold' formations.
- Reduced values of specific storage which decreases the available storage resulting in increased volume of rock dewatered and increased extent of drawdown.

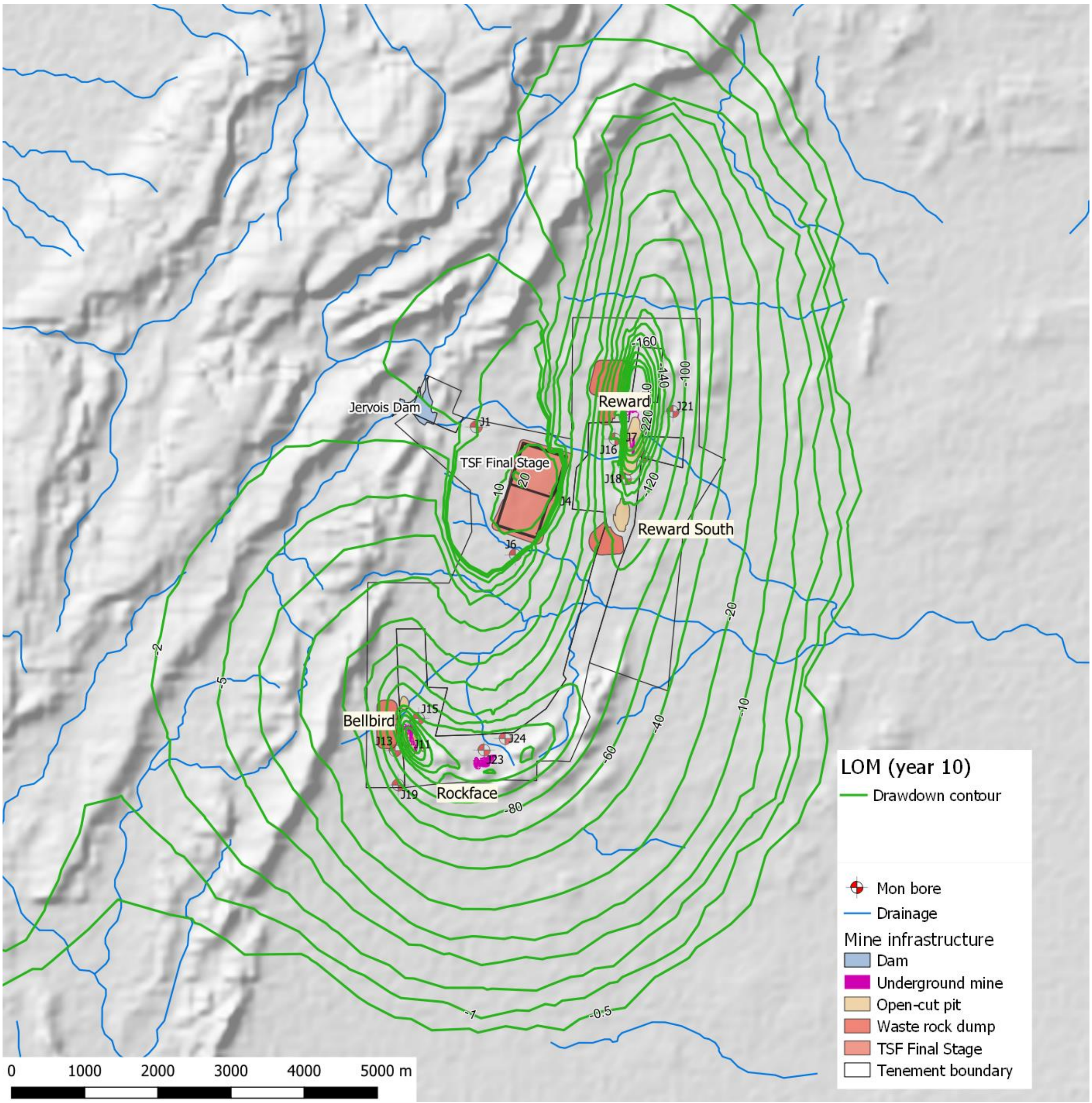


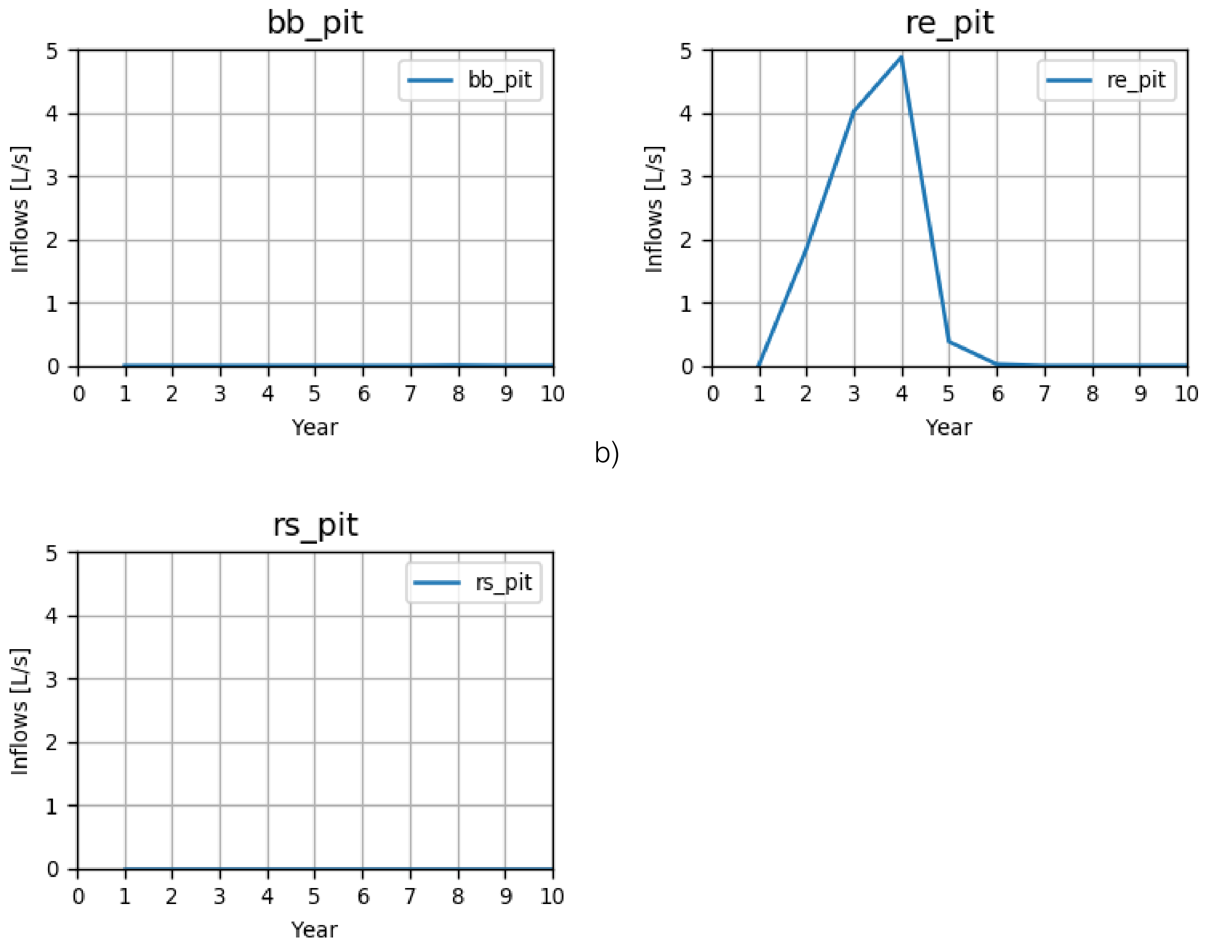
Figure 7-14 LOM final drawdown contours after 10 years of mining.

7.1.5. Forecast LOM pit inflows

Predicted inflows to the pits during the life of mine are presented below in tabular form in Table 7-2. Inflows increase from commencement of mining and reach a peak during year 4 at about 0.42 ML/d (4.9 L/s). The lack of inflows to the Bellbird and Reward South pits is due to the dewatering impacts of the underground mines along strike from these features. Inflows to the pits as L/s are also presented graphically below in Figure 7-15 a), b) & c) for Bellbird, Reward and Reward South respectively.

Table 7-1 Annual estimated inflows to the pits.

Year	Bellbird oc	Reward oc	Reward South oc	Bellbird oc	Reward oc	Reward South oc
		[L/s]			ML/d	
1	0.0	0.0	0.0	0.00	0.00	0.00
2	0.0	1.8	0.0	0.00	0.16	0.00
3	0.0	4.0	0.0	0.00	0.35	0.00
4	0.0	4.9	0.0	0.00	0.42	0.00
5	0.0	0.4	0.0	0.00	0.03	0.00
6	0.0	0.0	0.0	0.00	0.00	0.00
7	0.0	0.0	0.0	0.00	0.00	0.00
8	0.0	0.0	0.0	0.00	0.00	0.00
9	0.0	0.0	0.0	0.00	0.00	0.00
10	0.0	0.0	0.0	0.00	0.00	0.00



a)

b)

c)

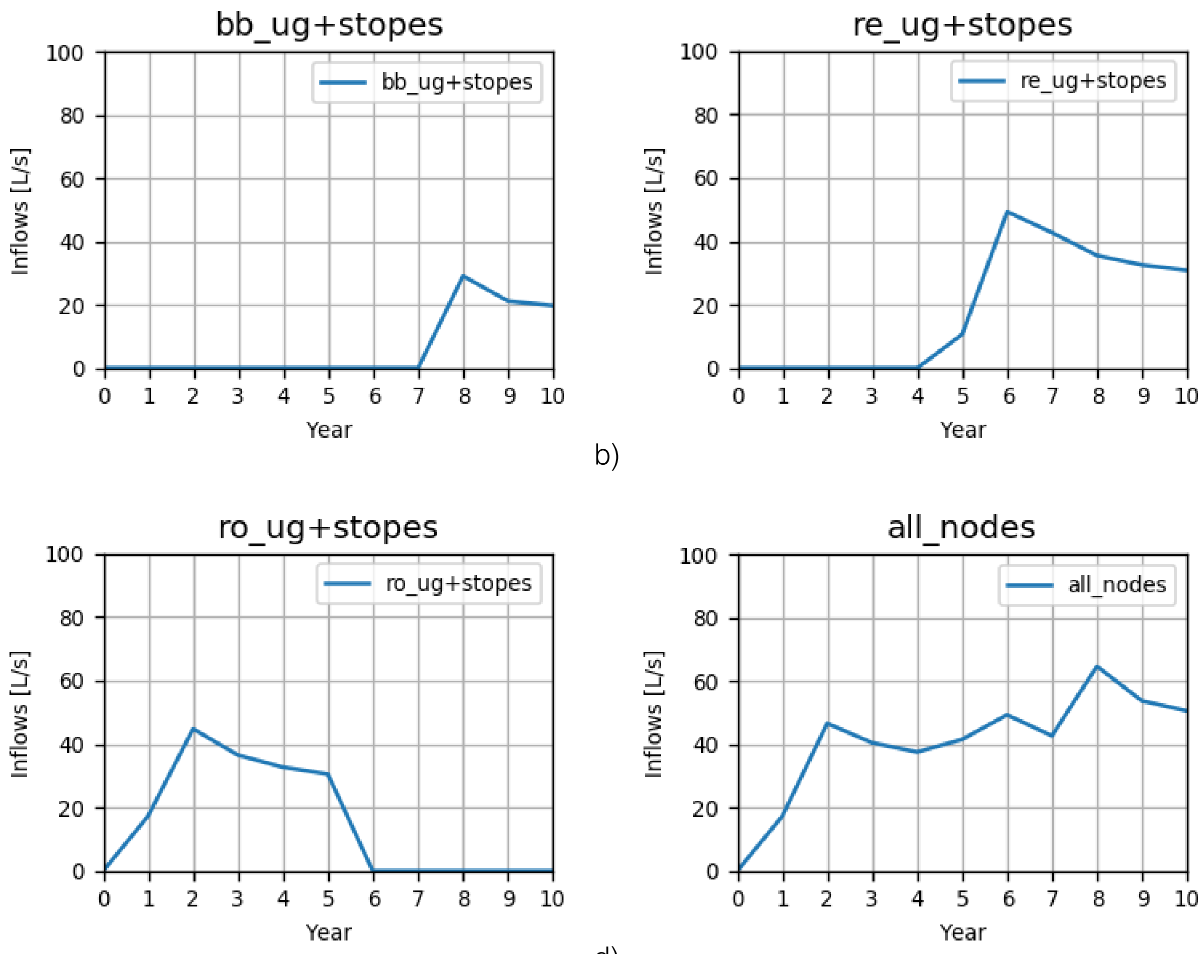
Figure 7-15 Predicted pit inflows (L/s) during life of mine to a) Bellbird pit, b) Reward pit and c) Reward South pit.

7.1.6. LOM Underground working inflows

Predicted inflows to the pits and underground mines during the life of mine are presented below in tabular form in Table 7-2. Inflows increase from commencement of mining and reach a peak during year 8 at about 5.6 ML/d (65 L/s). Inflows to the pits as L/s are also presented graphically below in Figure 7-16a), b), c) and d) for Bellbird, Reward, Rockface and combined inflows respectively.

Table 7-2 Forecast annual life of underground mine working inflows.

Year	All ug	Bellbird ug	Reward ug	Rockface ug	All ug	Bellbird ug	Reward ug	Rockface ug
	[L/s]	[L/s]	[L/s]	[L/s]	[ML/d]	[ML/d]	[ML/d]	[ML/d]
1	17.3	0.0	0.0	17.3	1.49	0.00	0.00	1.49
2	44.8	0.0	0.0	44.8	3.87	0.00	0.00	3.87
3	36.5	0.0	0.0	36.5	3.15	0.00	0.00	3.15
4	32.7	0.0	0.0	32.7	2.82	0.00	0.00	2.82
5	41.2	0.0	10.7	30.5	3.56	0.00	0.92	2.64
6	49.3	0.0	49.3	0.0	4.26	0.00	4.26	0.00
7	42.7	0.0	42.7	0.0	3.69	0.00	3.69	0.00
8	64.6	29.1	35.5	0.0	5.58	2.52	3.07	0.00
9	53.7	21.2	32.5	0.0	4.64	1.83	2.81	0.00
10	50.6	19.8	30.9	0.0	4.37	1.71	2.67	0.00



a)

b)

c)

d)

Figure 7-16 Predicted underground inflows (L/s) during life of mine to a) Bellbird underground, b) Reward underground, c) Rockface underground and d) Combined underground inflows.

7.2. Post closure forecast

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 timestep of the LOM scenario;
- The post closure model runs for an additional 990 years (i.e. 1000 year total simulation since mining commenced) with the final timestep ending at 730,000d;
- Removing the seepage face boundary conditions representing the pit and underground workings;
- Activation of the IfmLake module (section 5.3.8) to simulate the filling of the pit void.
    - The evaporation used in the IfmLake module was set to 5 mm/d which is equivalent to 0.6 times the average daily pan evaporation of 8.5 mm/d (3120 mm/yr /365).

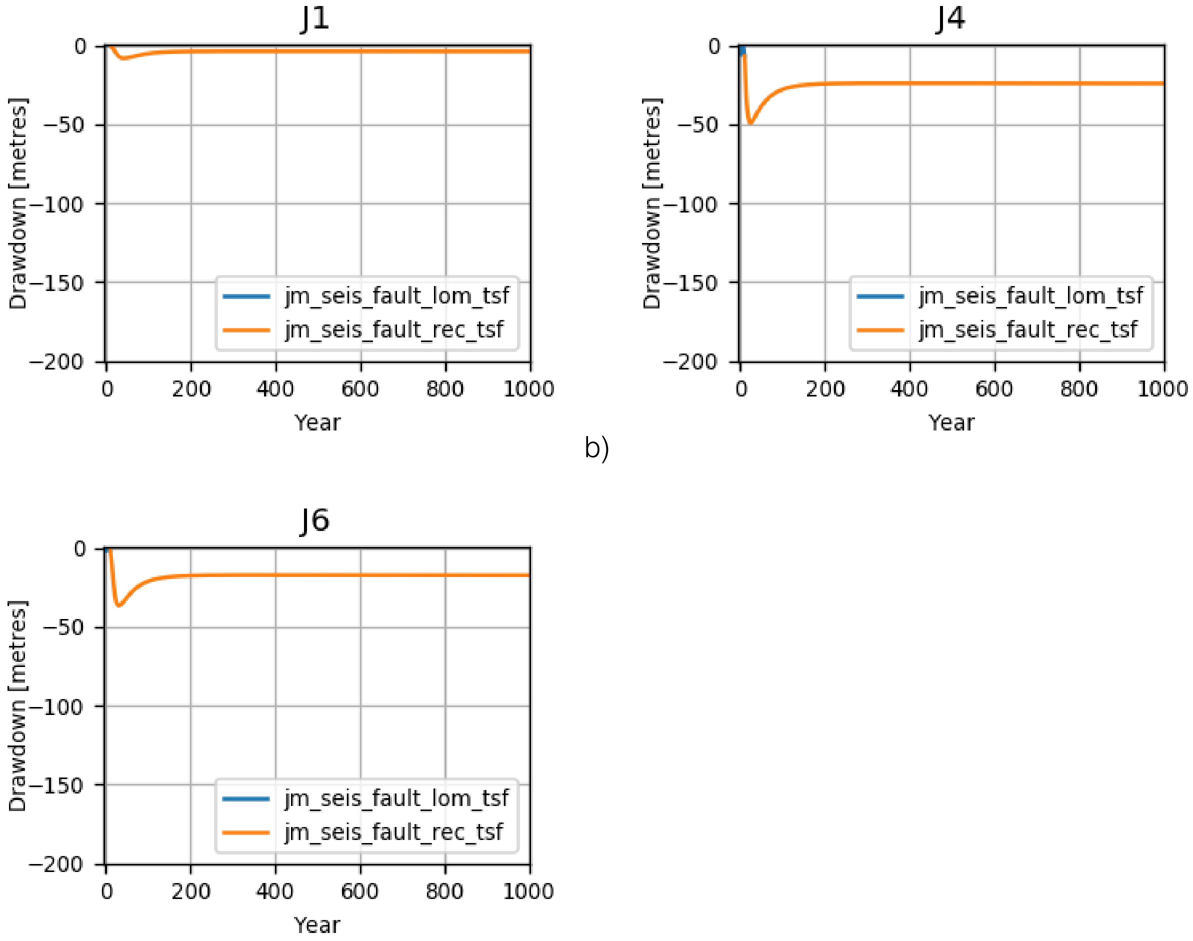
The post closure period of 990 years extends well beyond the 150 years that the model requires to reach a state of approximate dynamic equilibrium identified by the levelling out of the groundwater levels and inflows to the pit. Increasing the duration of the post closure period beyond 150 years does not alter the pit-lake levels, however, it does show that the drawdown effects continue to propagate very slowly away from the pit-lakes until induced recharge / leakage accounts for the deficit due to the evaporation of groundwater flowing into the pit-lakes.

7.2.1. Post closure mine-site groundwater levels

The groundwater levels at the proposed groundwater monitoring sites are provided below. Each plot provides the natural groundwater level response (blue), the life of mine response and the post closure response (green). The following observations can be made:

The groundwater levels at the proposed observation bores for:

- the TSF are presented below in Figure 7-17;
- the Bellbird pit and underground mine in Figure 7-18;
- the Reward pit and underground mine in Figure 7-19;
- the Rockface underground mine in Figure 7-20.



a)

b)

c)

Figure 7-17 Groundwater levels around the TSF.

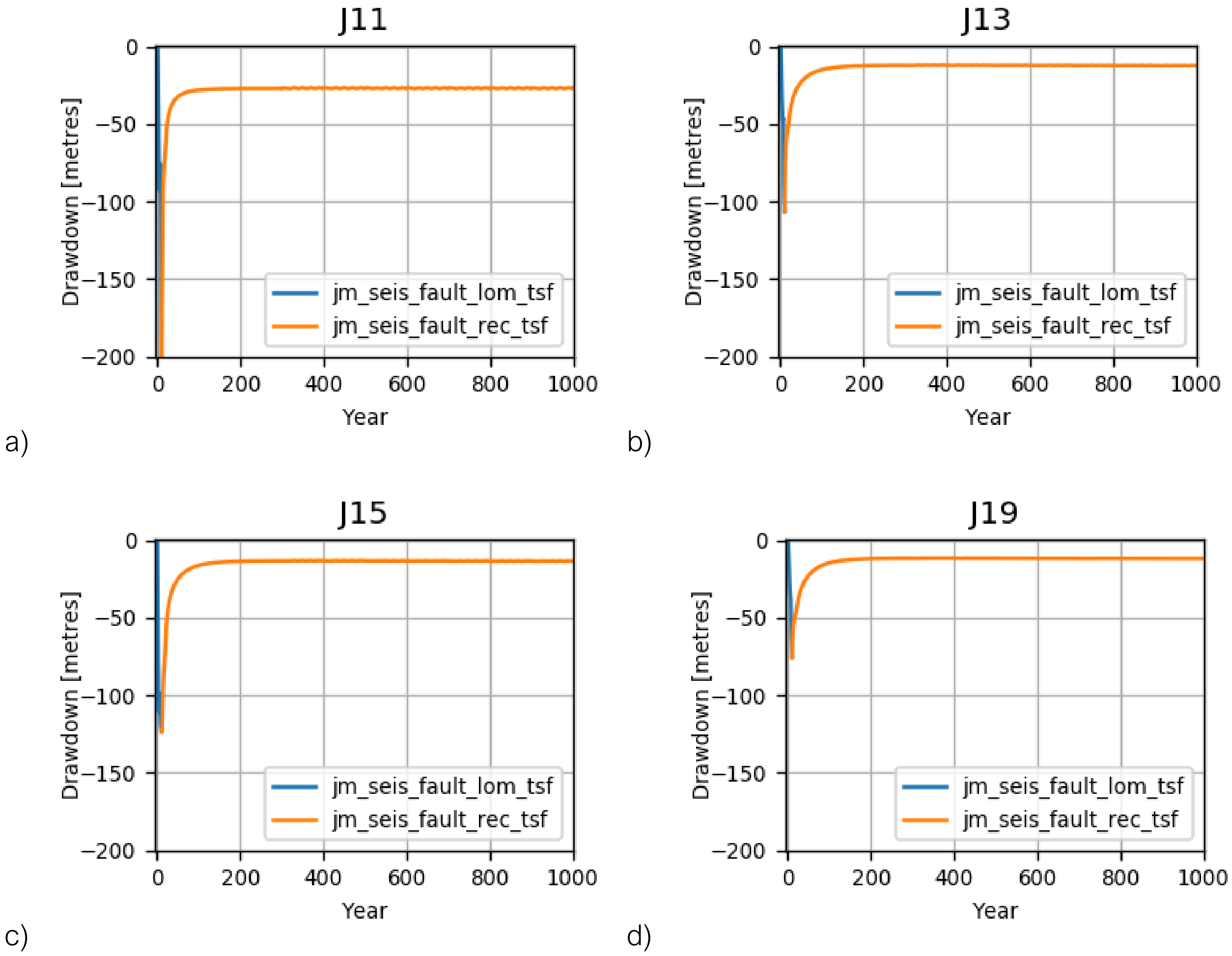
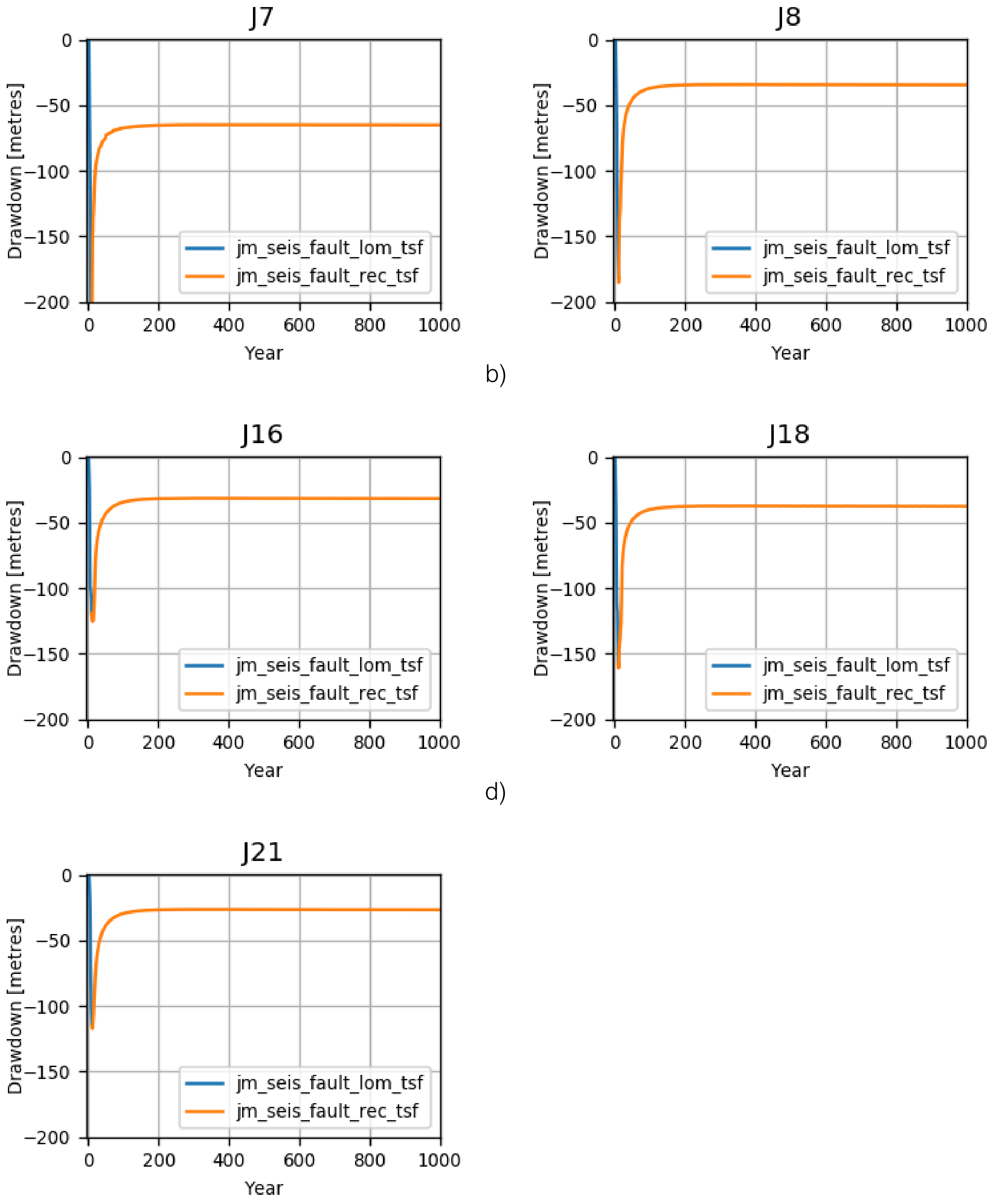
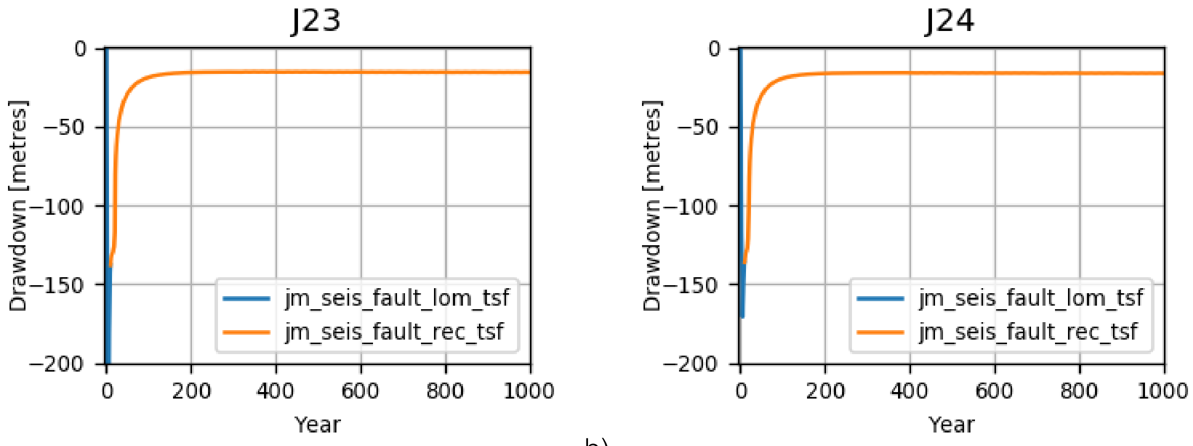


Figure 7-18 Groundwater levels at monitoring sites near the Bellbird pit and underground mine.



a) b) c) d) e)

Figure 7-19 Groundwater levels around the Reward pit and underground mine.



a) b)

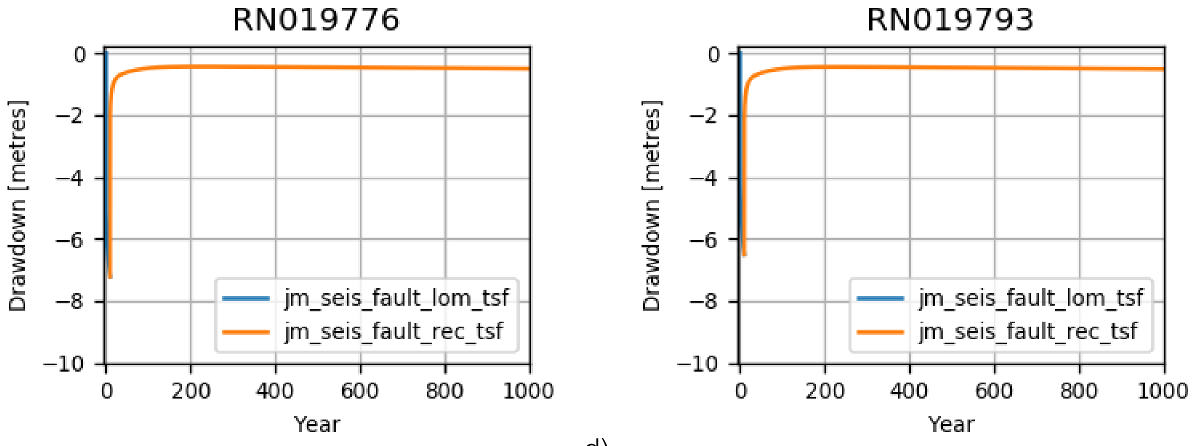
Figure 7-20 Groundwater levels at monitoring sites near the Rockface underground mine.

7.2.2. Post-closure process water supply impacts

Groundwater levels are presented for the 2 bores (RN019776 and RN019793) located at 50 metres from each of the process water supply production bores are presented below in Figure 7-21.

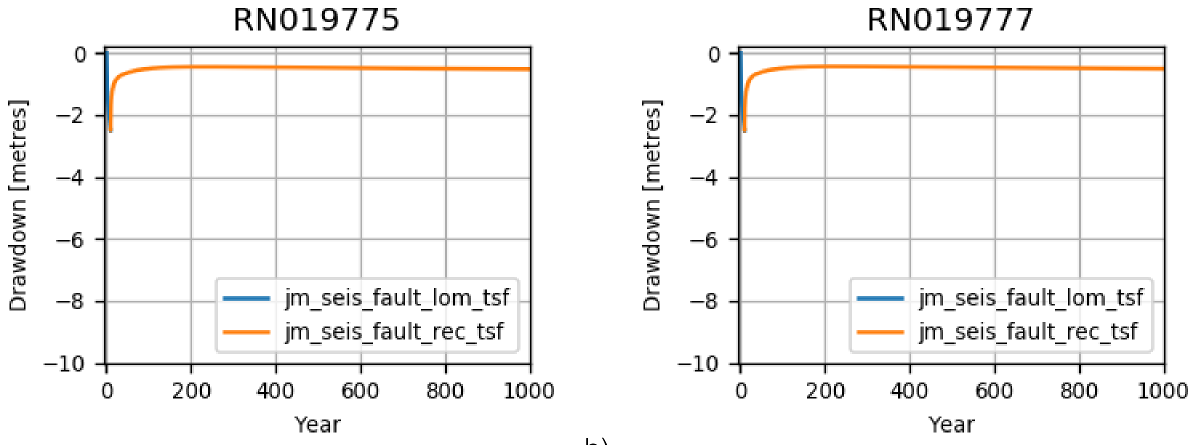
Groundwater levels are presented for the 2 bores (RN019775 and RN019777) located away from the footprint of the process water supply are presented below in Figure 7-22.

In both cases the groundwater levels recover to within a metre of initial values.



c) d)

Figure 7-21 Groundwater level response at the process water supply Lucy Creek observation bores to the north of the mine site a) RN019775 and b) RN019776.



a) b)

Figure 7-22 Groundwater level response at the process water supply Lucy Creek observation bores to the north of the mine site a) RN019775 and b) RN019777.

7.2.3. Post-closure impacts at existing users

Maperte

The water supply bore at Maperte is about 18 km to the northeast of the mine site.

Groundwater levels are reported in the model at the two production bore RN016283. The forecast drawdowns are presented below in Figure 8-5. The forecast drawdown under all parameter realisations is much less than 0.5 metres.

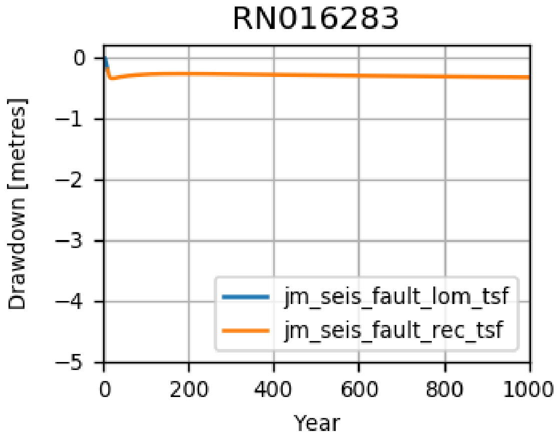


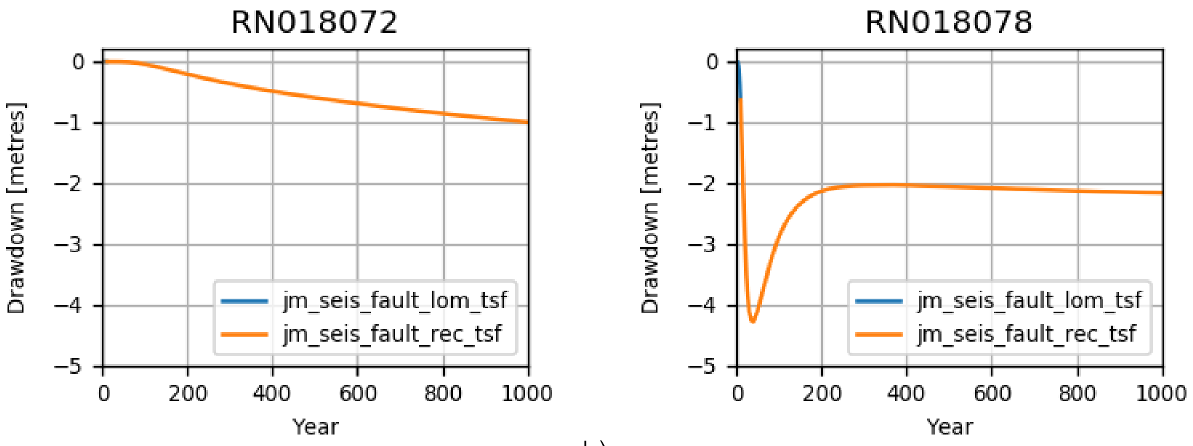
Figure 7-23 Groundwater level response at existing bore to the northeast of the mine site near Maperte RN016283.

Orrtipa Thurra

The closest water supply borefield is at Orrtipa Thurra, about 18 km to the southwest of the Jervois Mine site. Groundwater levels at the borefield are reported in the model at RN018072, presented below in Figure 7-11 a) for the 10 year LOM.

Groundwater levels between the community borefield and the Jervois Mine site are reported at RN018078. The response at RN018078 over the 10 year LOM are presented below in Figure 7-11 b).

The impact of groundwater drawdown associated with the pit-lake sinks is apparent on both of the bore hydrographs with long term drawdown approaching about 1 – 2 metres at Orrtipa Thurra (RN018072) and about 2 metres at the stock bore RN018078.

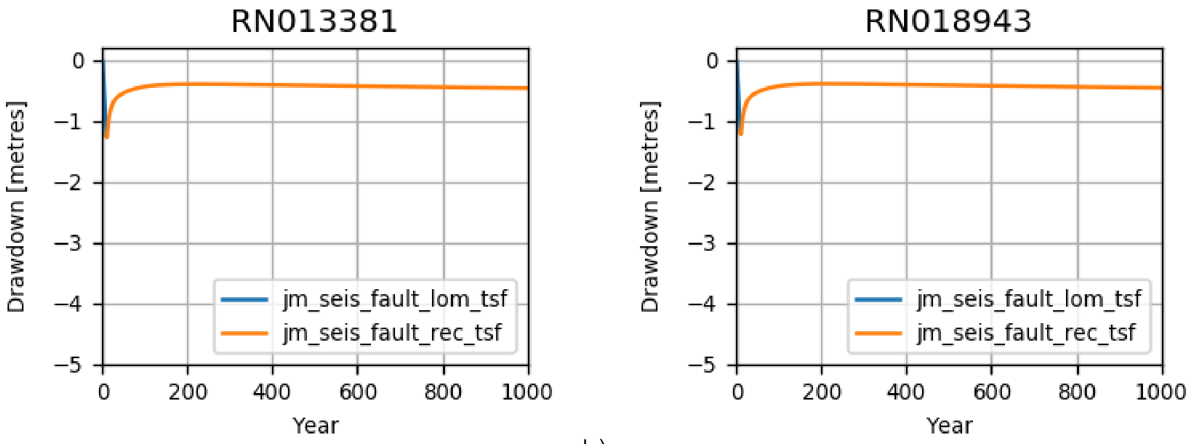


a) b)

Figure 7-24 Groundwater level response at existing observation bores to the southeast of the mine site near Orrtipa Thurra a) RN018072 and b) RN018078.

Lucy Creek Station

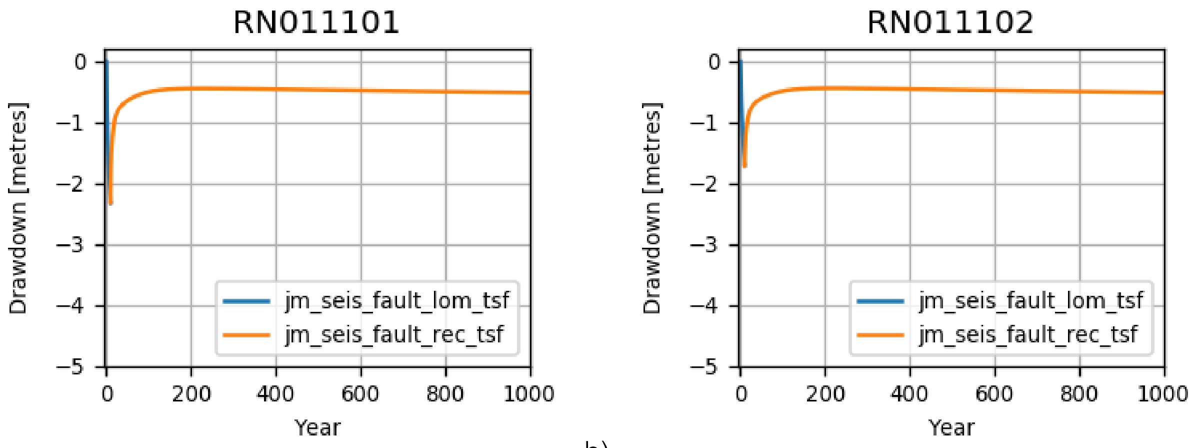
Two bores RN013381 and RN018943 adjacent to the Lucy Creek Station homestead are used to assess the impacts from the water supply pumping. Both show drawdown of less than 1 metre over the LOM period, which continues for about 10 years following mine closure and cessation of pumping at the borefield and then recovers to about 0.5 m below initial levels within about 50 years post-mining.



a) b)

Figure 7-25 Groundwater level response at existing observation bores to the southeast of the mine site near Orrtipa Thurra a) RN013381 and b) RN018943.

Groundwater levels for the 2 pastoral bores (RN011101 and RN011102) closest to the water supply borefield are presented below in Figure 7-26. The groundwater level response is similar at each site, showing a decline by less than 3 metres over the 10 year LOM period. Following closure of the mine the groundwater levels at the observation bores recover to 90% of their pre-pumping levels in less than 5 years and then recover to about 0.5 m below initial levels after about 50 - 60 years.



a) b)

Figure 7-26 Groundwater level response at the process water supply at the closest pastoral bores a) RN011101 and b) RN011102.

7.2.4. 200 years post-closure pit-lake formation

After 200 years since the start of mining (ie 190 years recovery) the water level in the Bellbird pit-lake is 275 – 285 mAHD, Reward pit-lake is 245 – 255 mAHD and Reward South is 250 – 260 mAHD and all are fairly stable. The drawdown contours at year 200 (ie after 190 years of recovery) are presented below in Figure 7-27.

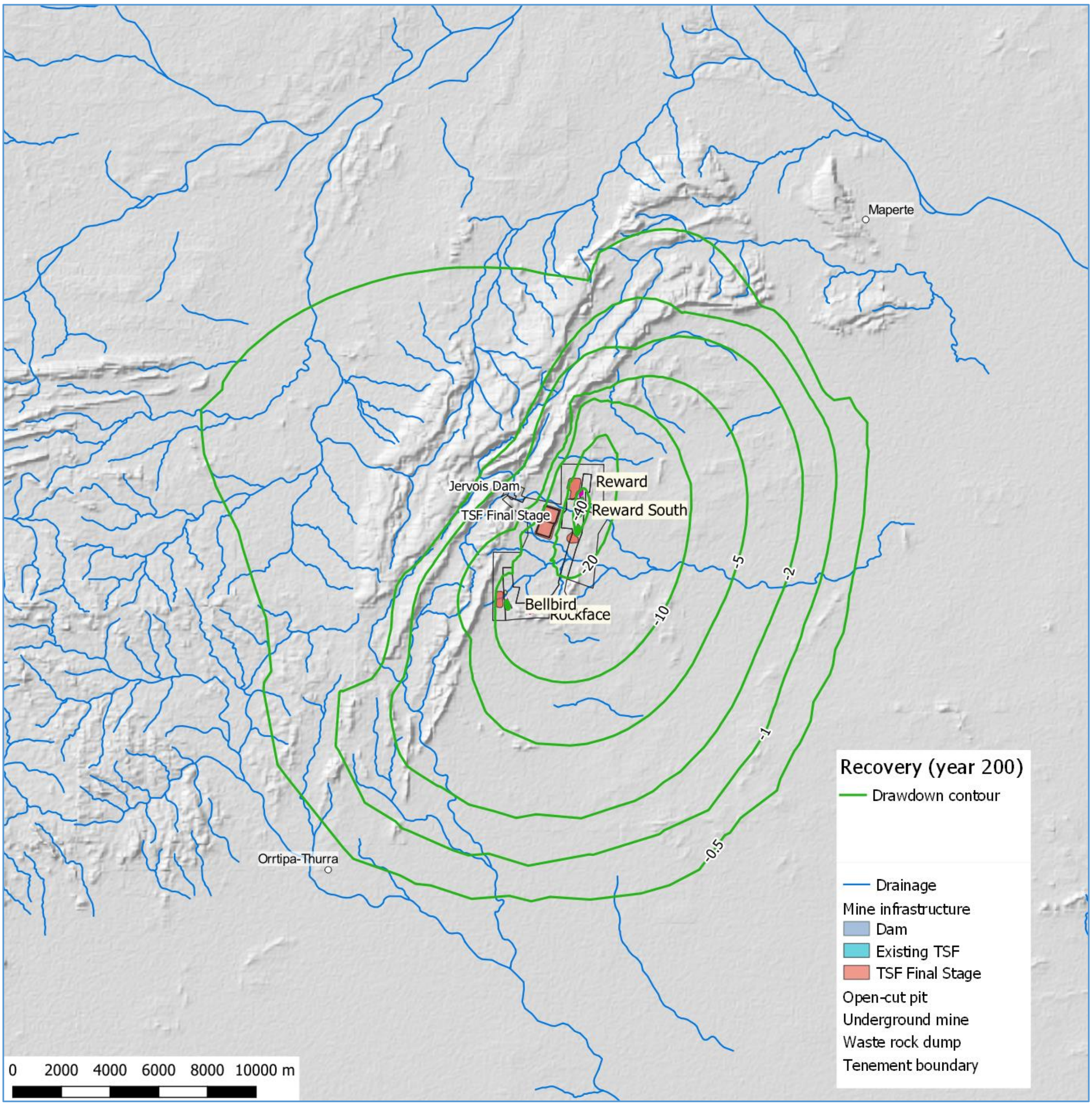


Figure 7-27 Post closure final drawdown contours after 190 years of recovery (200 years from start of mining).

7.2.5. 1000 years post-closure pit-lake formation

After 1000 years since the start of mining (ie 990 years recovery) the water levels in the pit-lakes are very much the same as listed in the previous section. The drawdown contours at year 1000 (ie after 990 years of recovery) are presented below in Figure 7-27, indicating that regional drawdown effects have expanded significantly, with the 2m drawdown contour at about 15 km from the mine site in the north, east and south directions, but only about 4 km in the west direction.

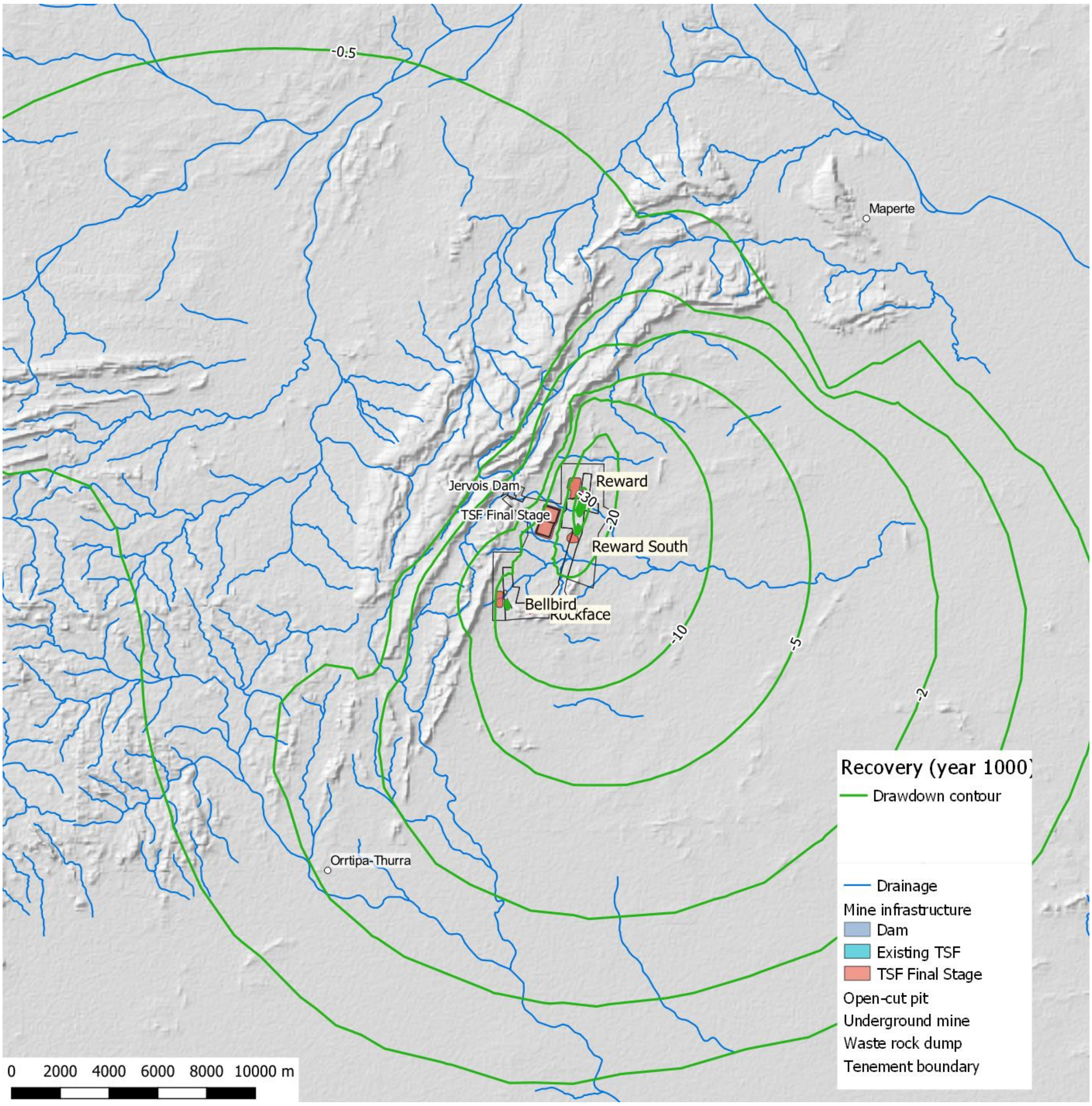


Figure 7-28 Post closure final drawdown contours after 990 years of recovery (1000 years from start of mining).

7.3. Impacts to existing users

7.3.1. 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 also be used to delineates 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 7-3 Random walk particle tracking dispersive parameters.

Parameter	Value	Unit
Effective porosity	0.01	[-]
Longitudinal dispersivity	10	[1/m]
Transverse dispersivity	1	[1/m]

7.3.2. End of LOM particle tracking

The fate of particles seeded beneath the waste rock dumps (WRD) and TSF at the end of LOM are presented below in Figure 7-29. All particles seeded beneath the Bellbird WRD terminate at the Bellbird pit-lake or move towards the groundwater low associated with the recovery of Rockface. Particles seeded beneath the Reward and Reward South WRDs and the TSF terminate at the Reward pit-lake.

It should be noted that it is currently assumed that no additional recharge (associated with leakage from the waste rock) is assigned within the footprint of the WRDs. Including enhanced recharge may result in a mound developing beneath the WRDs although it is unlikely that this will alter the ultimate fate of the particles sourced from these areas.

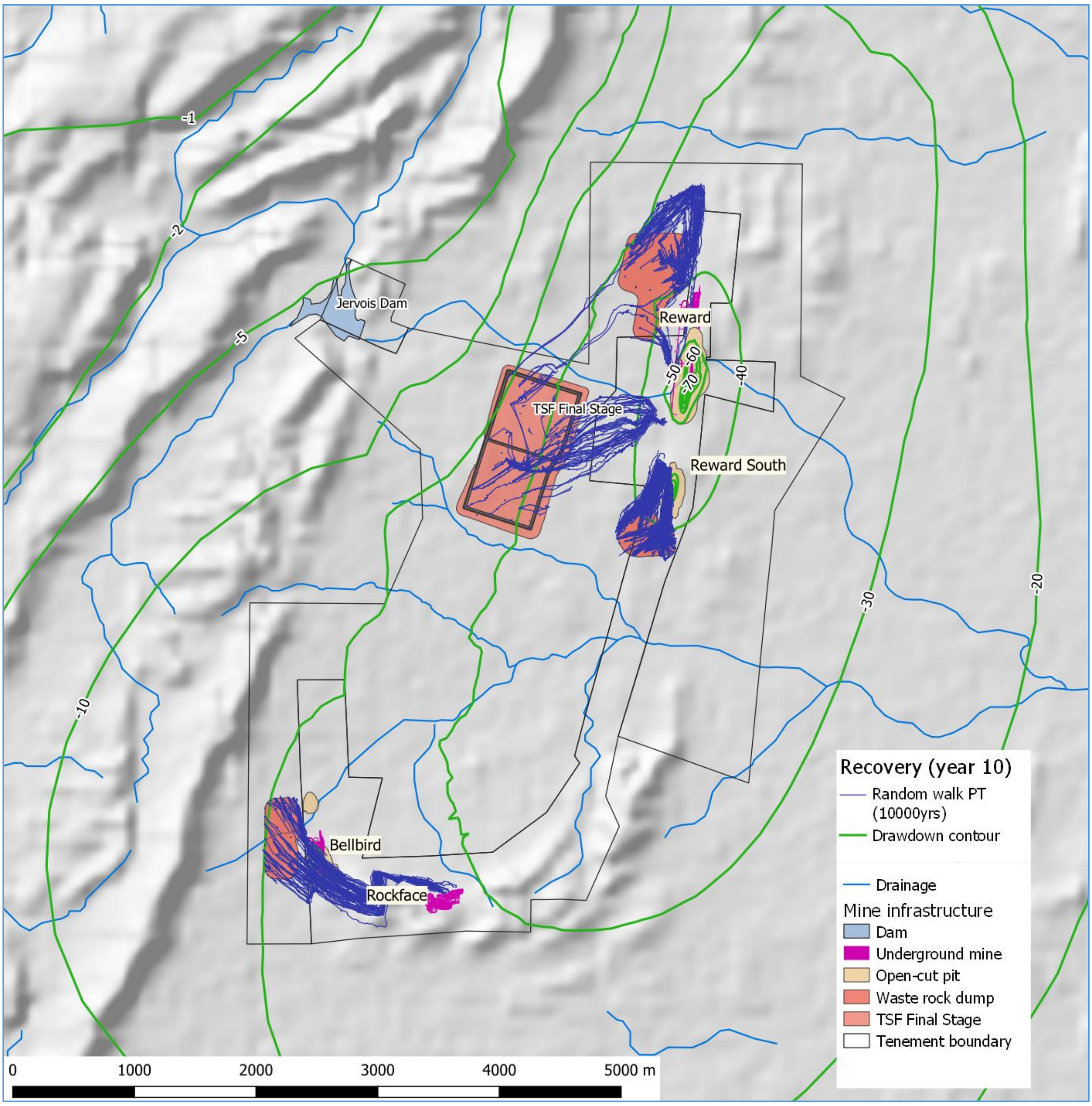


Figure 7-29 Random walk particle tracking and drawdown contours from the end of LOM year 10 (3650d).

7.3.3. Post closure particle tracking

Random walk particle tracking has also been used to investigate the fate of particles beneath the proposed waste rock dumps (WRDs) and TSF following closure of the mine. 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 exception that particles are captured by the Reward, Reward South and Bellbird pit-lakes.

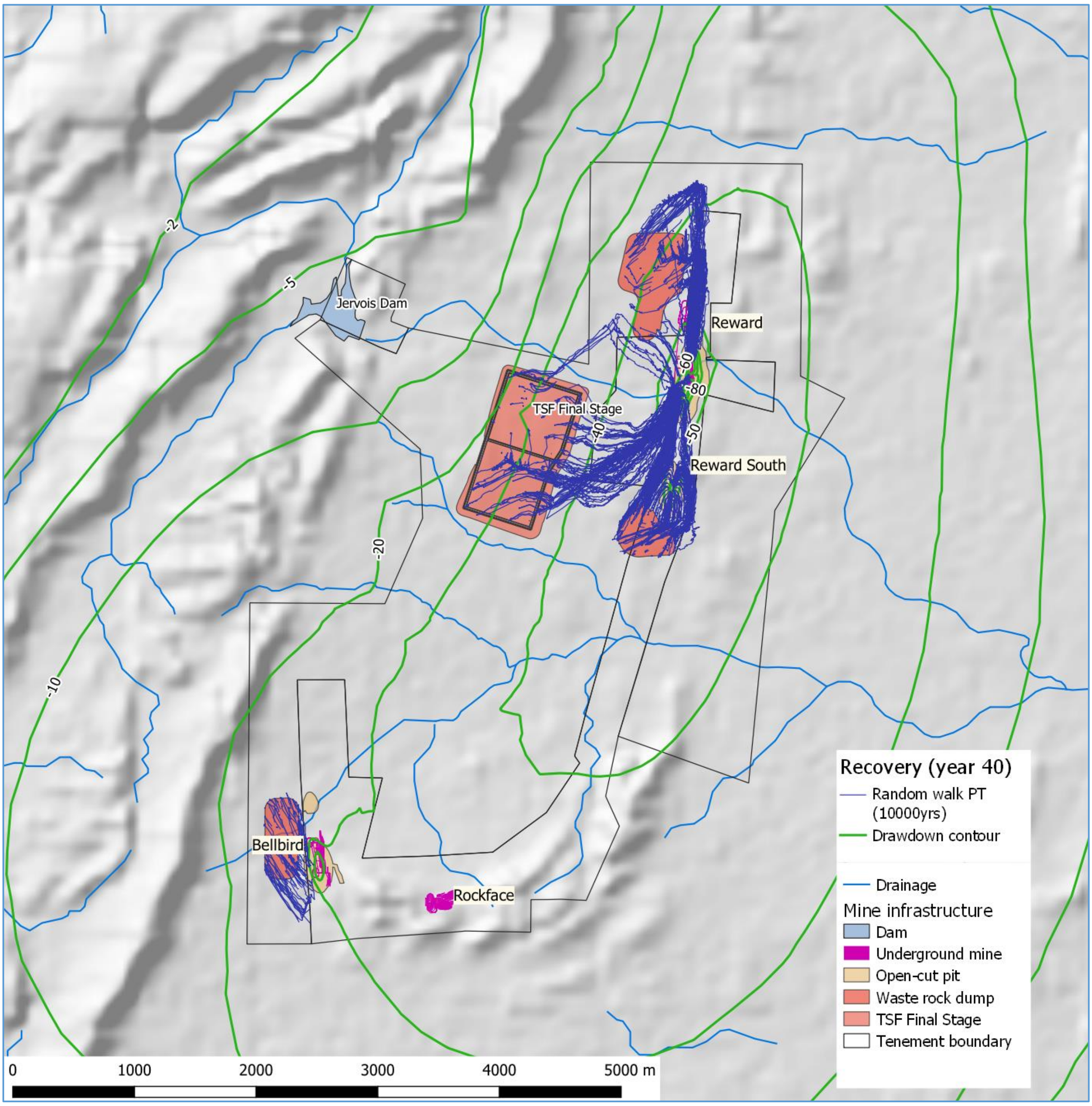


Figure 7-30 Random walk particle tracking and drawdown contours at year 40 (ie 30 years since mining ceased).

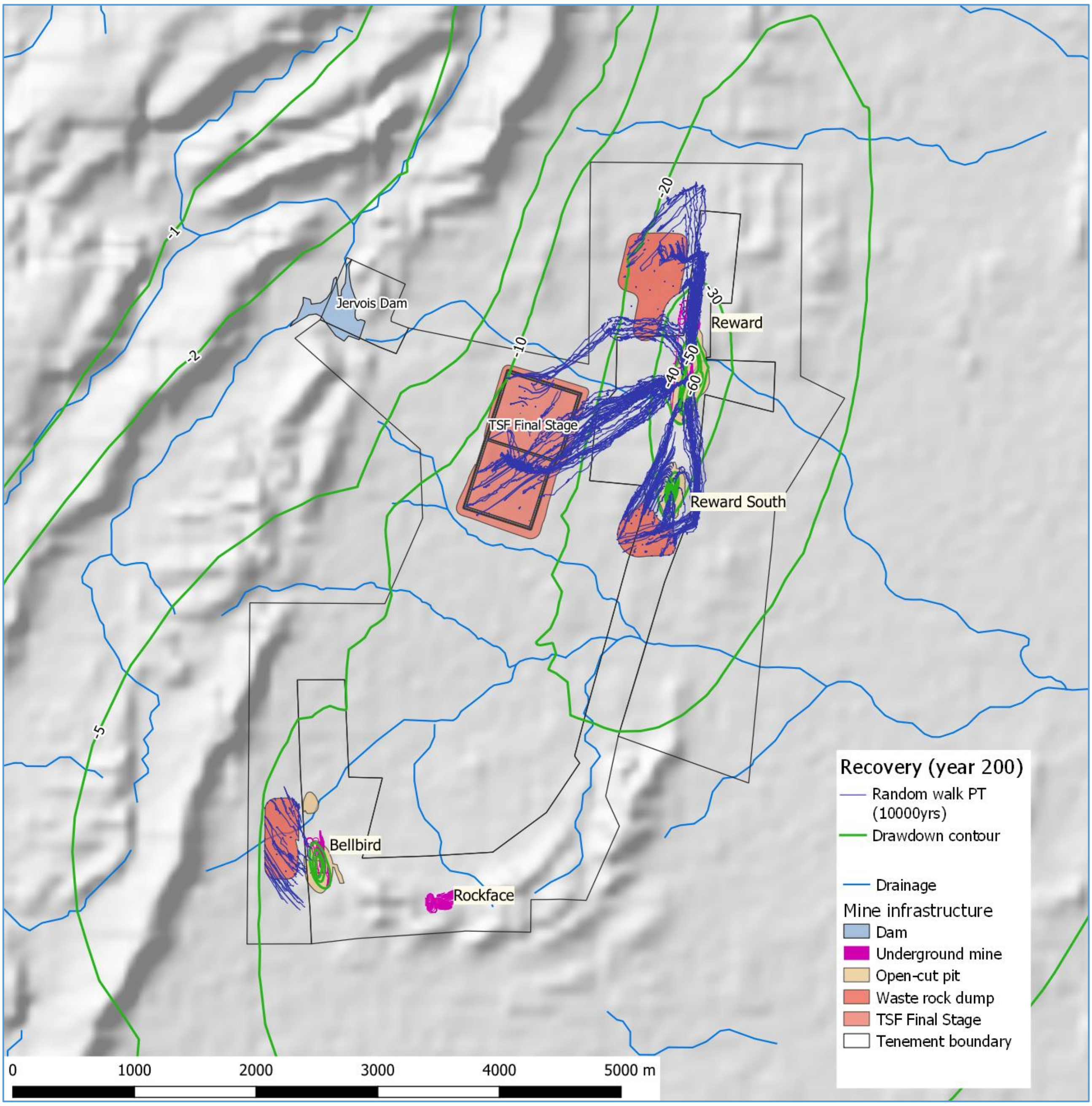


Figure 7-31 Random walk particle tracking and drawdown contours at year 200 (ie 190 years since mining ceased).

7.3.4. Conclusions

Seepage from the tailings storage facility (TSF) to the water table is expected although it is considered to present a low risk to groundwater beyond the mine site. Particle tracking techniques indicate that the cone of drawdown associated with dewatering of the mines and the post-closure development of the Reward pit-lake will effectively capture seepage sourced from TSF preventing the migration of TSF seepage off-tenement.

Impacts on Orrtipa-Thurra community water supply (18 km) are unlikely to occur due to the distance from the mine site and the limited extent of drawdown (~0.5 metres after 200 years and ~1.0 metres after 1000 years).

8 Predictive uncertainty

8.1. Introduction

Uncertainty analysis builds upon, but is distinct from, sensitivity analysis. Whereas sensitivity simply evaluates how model outputs change in response to changes in model input, uncertainty analysis is a more encompassing assessment of the range of model predictions for a possible range in parameter values.

The main outcome of the modelling study is the impact of groundwater drawdown at the identified receptors (notably water supply and stock watering bores at Lucy Creek and nearby communities). The propagation of drawdown is related to the aquifer hydraulic diffusivity. Aquifer diffusivity for confined aquifer systems is the ratio of aquifer transmissivity (T) to storage (S) and it is the ratio of T and S (or, for unconfined systems, hydraulic conductivity K to specific yield Sy) that controls the timing of depletion and not the values of T and S (or K and Sy) individually.

Hydraulic stresses propagate faster through aquifers with higher values of hydraulic diffusivity than through aquifers with lower values of hydraulic diffusivity. For example, the rate of depletion at any given time caused by a pumping well in a system with a transmissivity of 1000 m^2/d and a storage coefficient of 0.01 would be the same as in a system with a transmissivity of 100 m^2/d and a storage coefficient of 0.001, assuming all other factors are equal. The hydraulic diffusivity of confined aquifers is typically several orders of magnitude greater than that for unconfined aquifers. This difference results from the much larger storage capacity of the unconfined aquifer (as represented by the value of specific yield) compared to that of the confined aquifer (as represented by the storage coefficient). The concept of diffusivity can therefore lead to non-uniqueness of parameter combinations, especially if there is some uncertainty associated with the transmissivity and storage parameters.

Higher values of hydraulic diffusivity increase the speed at which responses to stresses such as pumping propagate through an aquifer. Aquifer depletion therefore generally will occur much more rapidly in confined aquifers than in unconfined aquifers.

A final point concerning the propagation of hydraulic stresses within an aquifer is that the rate of propagation of a hydraulic perturbation is not the same as the velocity with which a volume of groundwater actually travels through an aquifer or the associated residence time of groundwater in the aquifer. Groundwater movement is substantially slower than the propagation of hydraulic stresses through most types of aquifers, particularly those that are the source of most large-scale groundwater withdrawals.

In this case, the focus of the uncertainty analysis is to provide confidence in the results and examine some of the concerns regarding the extents of drawdown impacts in the carbonate aquifer system.

The aspects of the model, which are uncertain with respect to drawdown propagation are:

- Hydraulic conductivity of the aquifer material
- Specific yield of the aquifer material.

To examine parameter uncertainty on the forecast drawdown associated with the process water supply the hydraulic conductivity and storage coefficients were adjusted for the Cambrian carbonate rocks and the rocks of the Arunta Region (model zone 3), which include the Bonya Metamorphics.

8.2. Process water supply borefield

The effects of parameter uncertainty on the impacts of the process water supply were examined by running the model with only the process water supply, primarily to improve run times. A more comprehensive uncertainty analysis has been undertaken for the process water supply because the water resources of the carbonate aquifer system has greater beneficial uses than the water resources of the meta-sediments hosting the mine site.

8.2.1. Carbonate aquifer system parameter definitions

The hydraulic parameters exhibit a level of uncertainty in the range of hydraulic parameters due to the limited number of studies on the aquifers in the area (a typical problem for groundwater studies). The hydraulic parameters of these formations are poorly constrained and a probabilistic approach is warranted, using a range of values to characterise the likely range of drawdowns and quantify the uncertainty of the predictions. The adopted values used in each model run are presented below in Table 8-1.

The parameter sets were generated using the PEST utility RANDPAR. Each parameter was centred on its calibrated value and the allowable range determined by a user supplied value for the standard deviation of the parameter value (for hydraulic conductivity, the log-transformed value). The standard deviation value was chosen to provide a reasonable range in each parameter and generally providing values that spanned at least 2 orders of magnitude. The parameter ranges probability distributions are presented in Appendix A.

Although the analysis is not exhaustive, it does provide insights to the areas where further work could reduce the uncertainty regarding the possible impacts on the groundwater resource.

Hydraulic conductivity

Each parameter was centred on its calibrated value and the allowable range determined by a user supplied value for the standard deviation of the log transformed parameter value. The standard deviation value was chosen to provide a reasonable range in each parameter and generally providing values that spanned 2 orders of magnitude.

The hydraulic parameters that are to be changed during the analysis (i.e. hydraulic conductivity and storage coefficient) are assumed to be either normally or log-normally distributed. Material properties that are directly related to hydraulic conductivity appear to have a log-normal distribution (Neuman, 1982). On the other hand, the distribution of porosity is usually regarded to exhibit a normal distribution.

The hydraulic conductivity range considered in the 100 realisations are presented below in Table 8-1.

These values are considered to be representative of the carbonate aquifer and are consistent with the values measured during the recent drilling investigation and the values implemented in DENR's model of the Southern Georgina Basin (Knapton, 2017).

Storage coefficient

The storage coefficient has been normally distributed with a maximum of 0.1 and a minimum of 0.01, as this provides a distribution that spans the expected values considered to be representative of the semi-confined / unconfined carbonate aquifer. These values are consistent with the values implemented in DENR's model of the Southern Georgina Basin (Knapton, 2017).

Table 8-1 Parameter ranges used in the uncertainty analysis.

Parameter	Range		Unit
	Min	Max	
k1	0.065	10.0	m/d
K2	0.004	5.864	m/d
k4	0.003	0.805	m/d
k5	0.010	3.657	m/d
k6	0.080	10.0	m/d
k7	0.001	0.197	m/d
k8	0.005	2.052	m/d
sy1	0.012	0.1	-
sy2	0.012	0.1	-
sy4	0.009	0.1	-
sy5	0.013	0.1	-
sy6	0.011	0.1	-
sy7	0.015	0.1	-
sy8	0.012	0.1	-

8.2.2. Process water supply drawdown contours

Groundwater drawdown contours associated with the Jervois process water supply are presented at the end of mining for the range of realisations considered.

The drawdowns have been plotted using the 5th, 25th, 75th and 95th percentile values. The 95th percentile values indicate that it is **very** likely that predicted drawdowns will be less than the values shown. Conversely, the 5th percentile values indicate that it is **very** likely that predicted drawdowns will be greater than the values shown. Similarly, it is likely that the predicted drawdown will be greater than 25th but less than the 75th percentile values. The **very** likely range of drawdowns falls between the 5th and 95th percentile drawdowns, while the likely range falls between the 25th and 75th percentiles.

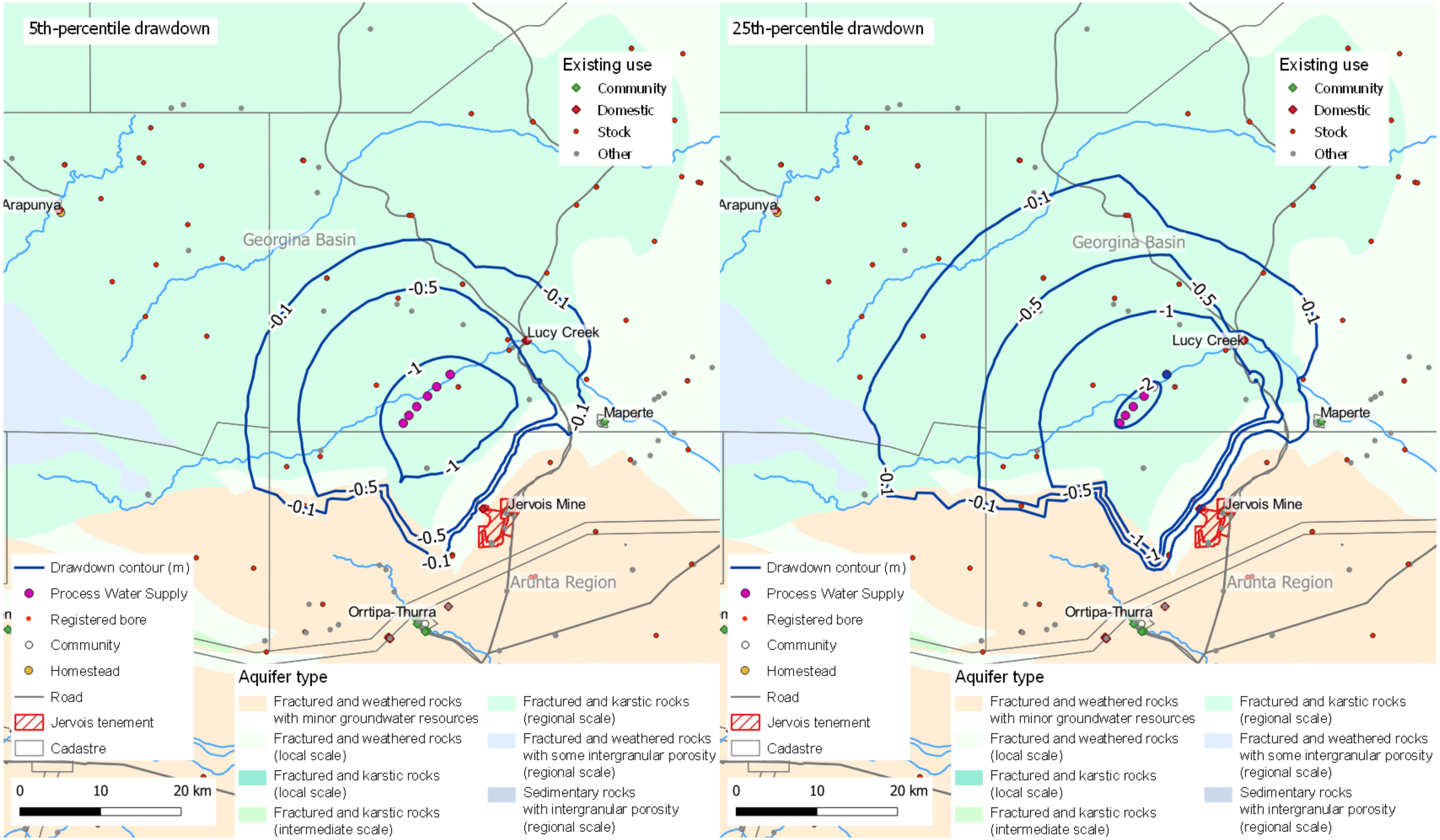


Figure 8-1 Drawdown due to the process water supply at end of mining for 5th percentile and 25th percentile (drawdowns likely more than values shown).

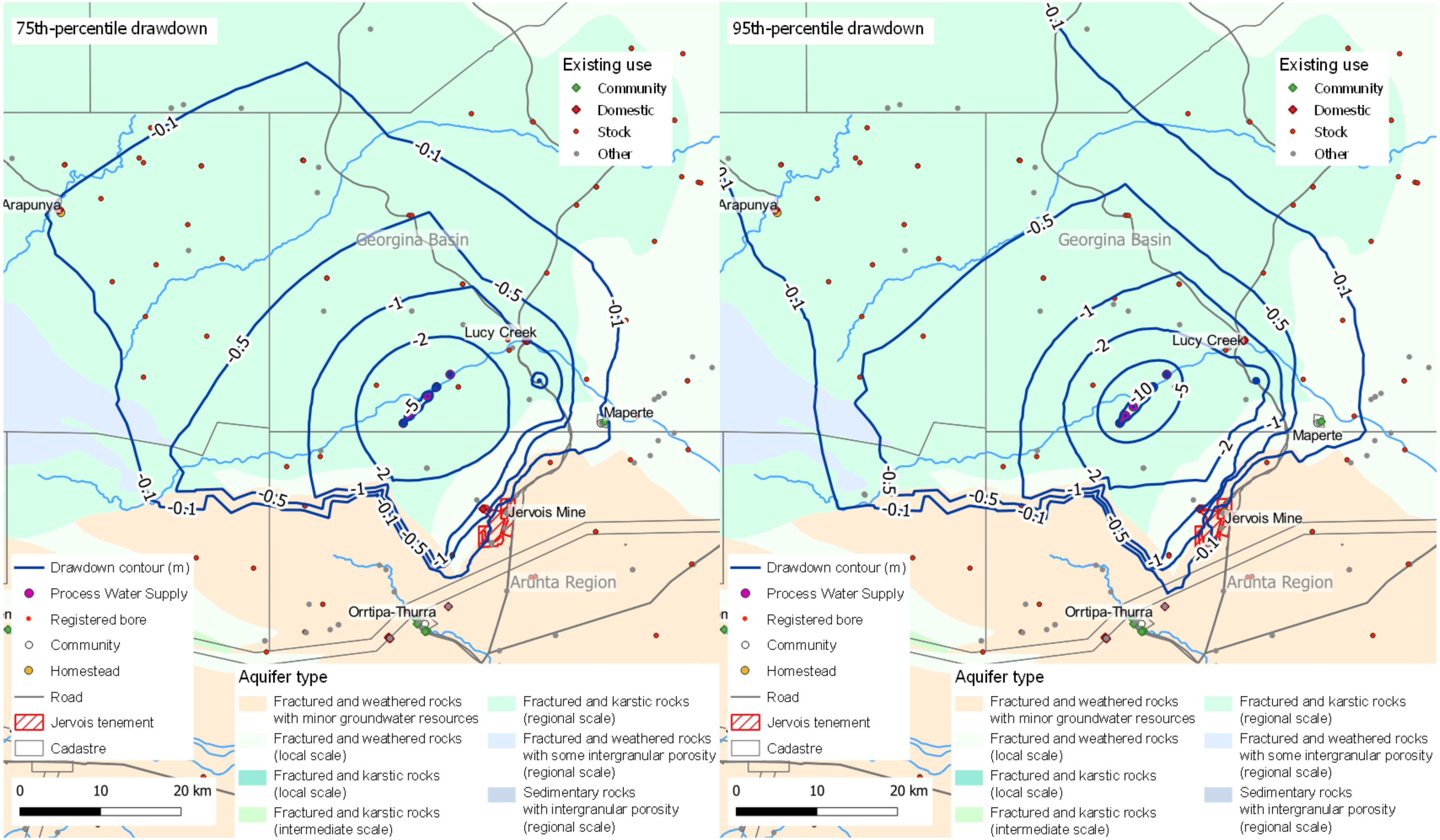


Figure 8-2 Drawdown due to the process water supply at end of mining for 75th percentile and 95th percentile (drawdowns likely less than values shown).

8.2.3. Existing user drawdown response

The drawdown response at specific locations have been extracted for all 100 realisations considered and are presented as individual traces (grey lines), the median drawdown response is plotted as a bold blue line. The 5th, 25th, 75th and 95th intervals are also plotted as red lines for reference.

Lucy Creek Station

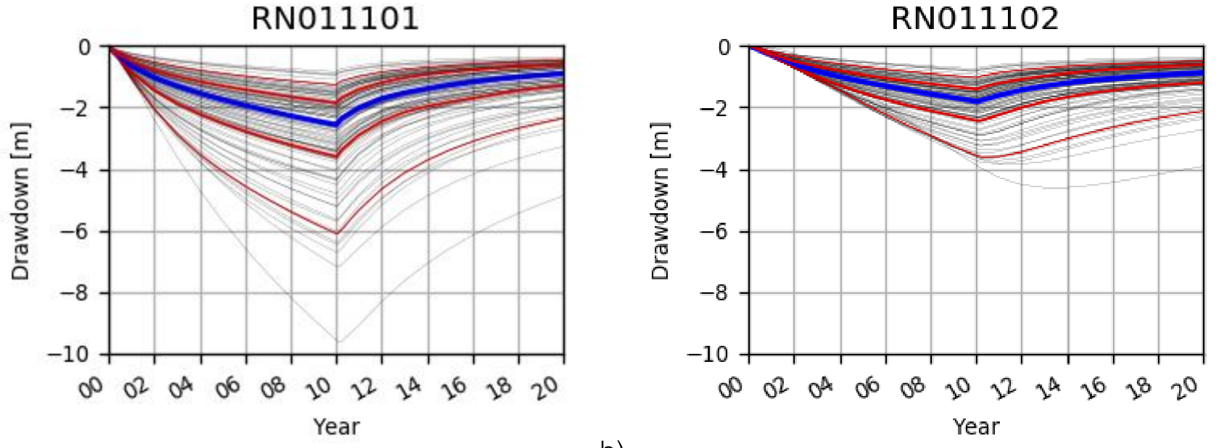
RN013381 and RN018943 (Figure 8-4) are adjacent to the Lucy Creek Station homestead have been used to report impacts on the water supply. Both show a subtle declining trend with a median (blue line) of about 1 metre over the LOM period.

The two closest Lucy Creek Station stock watering bores RN011101 and RN011102 (Figure 8-3) have been used to report impacts on the pastoral water supply.

The maximum likely impact at the two sites representing the Lucy Creek water supply bores is about 6 metres at the end of mining with a median drawdown of about 2 metres.

The two stock watering bores RN011101 and RN011102 show greater drawdown due to the closer proximity to the Jervois water supply pumping bores.

After 10 years post mining, the water levels recover to about 50% of the drawdown at the end of mining.



a)

b)

Figure 8-3 Groundwater level response at existing observation bores to the north of the mine site near Lucy Creek homestead a) RN013381 and b) RN018943.

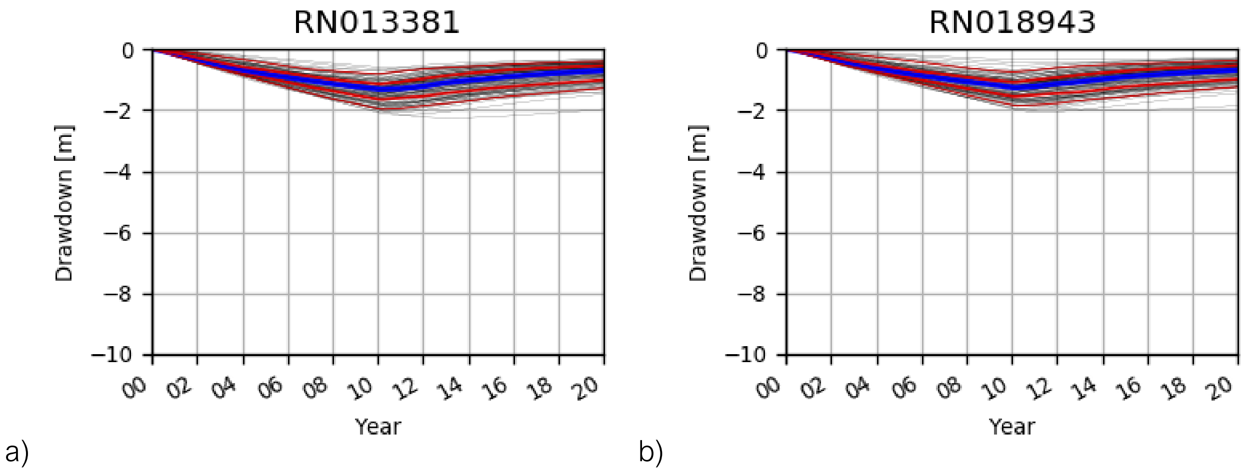


Figure 8-4 Groundwater level response at existing observation bores to the north of the mine site near Lucy Creek homestead a) RN013381 and b) RN018943.

Maperte

The Maperte water supply bores are located about 17 km to the northeast of the mine site and about 17km to the southeast of the Jervois process water supply borefield. Groundwater levels are reported in the model at the production bore RN016283. The forecast drawdown is presented below in Figure 8-5, indicating much less than 1 metre under all parameter realisations.

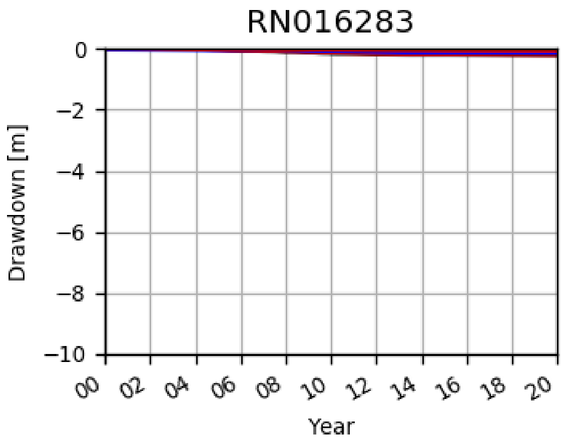


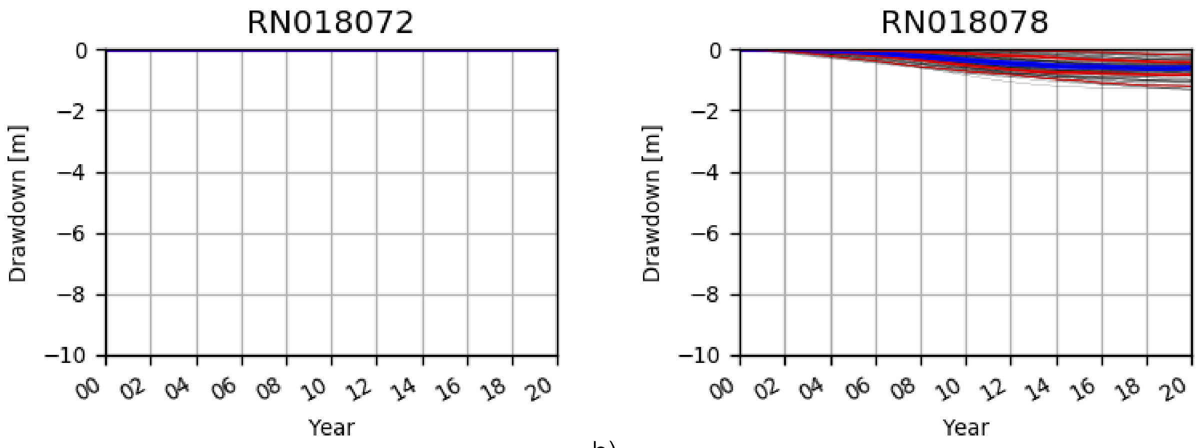
Figure 8-5 Groundwater level response at existing observation bores to the northeast of the mine site near Maperte outstation RN016283.

Orrtipa Thurra

The water supply borefield at Orrtipa Thurra is about 18 km to the southwest of the Jervois Mine site. Groundwater levels at the borefield are reported in the model at RN018072. The response at RN018072 over the 10 year LOM are presented below in Figure 7-11 a).

Groundwater levels between the community borefield and the Jervois Mine site are reported at RN018978. The response at RN018078 over the 10 year LOM are presented below in Figure 7-11 b).

The impact of mine process water supply is not apparent at the Orrtipa Thurra bore RN018072 and is less than 2 metres drawdown at RN018078 for all realisations.



a) b)

Figure 8-6 Groundwater level response at existing observation bores to the southeast of the mine site near Orrtipa Thurra a) RN018072 and b) RN018078.

8.3. Mine site inflows

8.3.1. Parameters

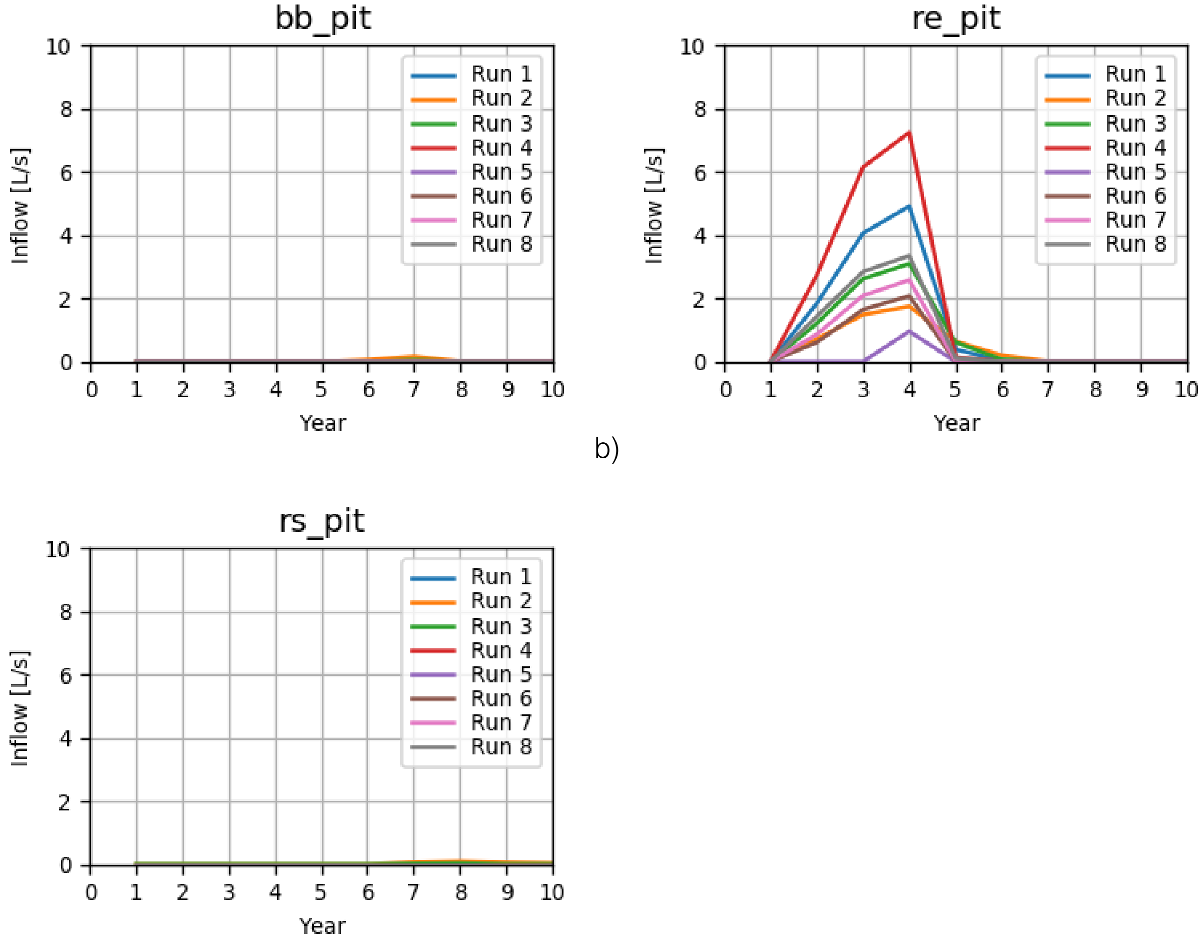
The parameter sets used in the mine site uncertainty analysis included variations to the 'J-fold' hydraulic conductivity and the specific yield values for the model zones 9-24 presented in Figure 5-4. The parameter variations are presented below in Table 8-2.

Table 8-2 Parameter variations used in the uncertainty analysis.

Realisation	Parameter changes
1	Original parameters
2	Hyd. Cond. x 0.2
3	Hyd. Cond. x 0.5
4	Hyd. Cond. x 2
5	Hyd. Cond. x 5
6	Specific yield x 0.2
7	Specific yield x 0.5
8	Specific yield x 2

8.3.2. Forecast LOM pit inflows

Inflows to the pits as L/s have been determined during the life of mine for the parameter sets described in Table 8-1 and are presented below in graphical form in Figure 8-7 a) b) and c) for Bellbird Reward and Reward South respectively. The magnitude of inflows is consistent with the calibrated model parameterisation with only marginal increases in forecast pit inflows, with the most realisations reporting slightly less groundwater inflow to the pits,



a)

b)

c)

Figure 8-7 Predicted pit inflows (L/s) during life of mine to a) Bellbird pit b) Reward pit and c) Reward South pit.

8.3.3. LOM Underground working inflows

Inflows to the underground mines have been determined during the life of mine and are presented as L/s graphically below in Figure 8-8 a), b), c) & d) for Bellbird, Reward, Rockface and combined underground mines respectively. Inflows increase from commencement of mining and reach a peak during year 7 at about 6.3 ML/d (74 L/s). The results are quite sensitive to increasing or decreasing the hydraulic conductivity values, but not to changing the aquifer storage parameter.

Run 4 and 5 show variations in estimated inflows at all underground mine sites, which are related to changes in the hydraulic conductivity of the Bonya Metamorphics rocks. Mine inflows are forecast to decrease (Run 2) by a factor of about 40% due to a decrease in hydraulic conductivity, conversely mine inflows are forecast to increase (Run 4 and 5) by a factor of about 40% and 300% due to increasing the hydraulic conductivity by a factor of 2 and 5 respectively.

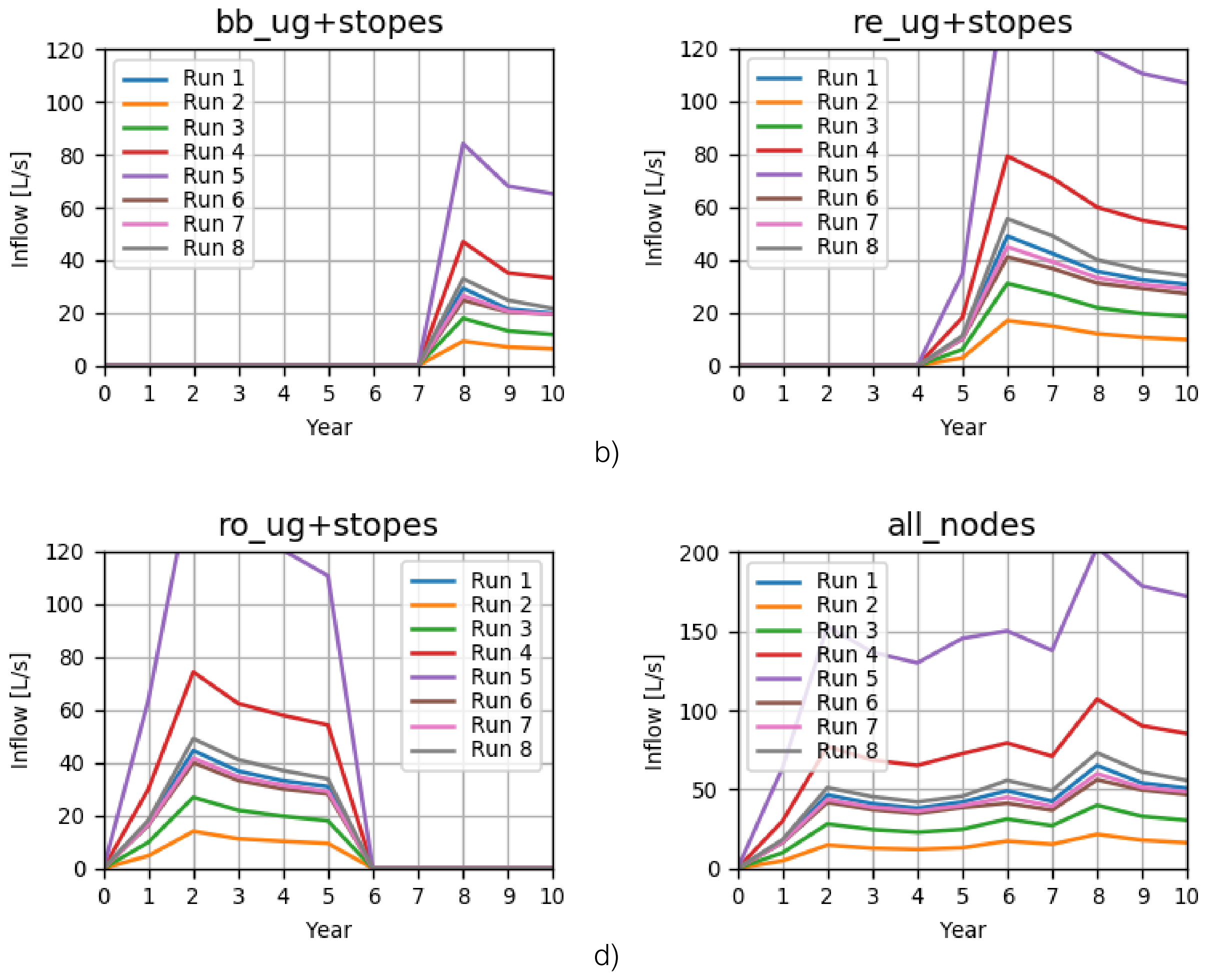


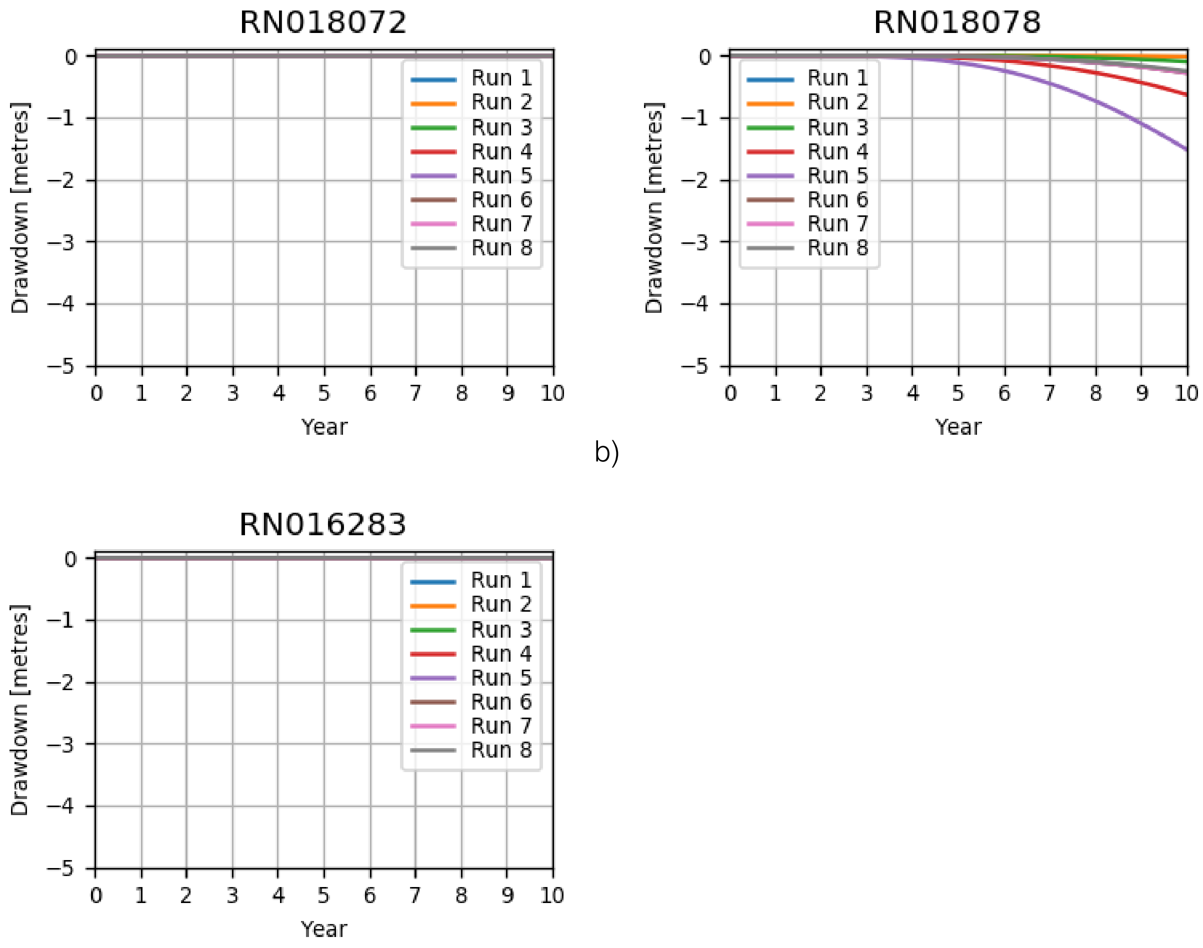
Figure 8-8 Predicted pit inflows (L/s) during life of mine to a) Bellbird underground, b) Reward underground, c) Rockface underground and d) Combined underground inflows (note combined inflow scale is different to other plots).

8.3.4. Water level impacts at existing users

Drawdown impacts at the two community water supplies were extracted for each of the parameter realisations considered. The drawdown hydrographs are presented below in . RN018072 at Orritipa Community shows no drawdown impacts at the end of mining.

The water supply borefield at Orrtipa Thurra is about 18 km to the southwest of the Jervois Mine site. Groundwater levels at the borefield are reported in the model at RN018072. The response at RN018072 over the 10 year LOM are presented below in Figure 8-9 a). The drawdown hydrograph shows no drawdown impacts at the end of mining.

Groundwater levels between the community borefield and the Jervois Mine site are reported at RN018078. The response at RN018078 over the 10 year LOM are presented below in Figure 8-9 b). Groundwater levels at this site do show some variation from the calibrated model results (Run1) with the increased impacts associated with the realisations employing the increased hydraulic conductivity values (Run4 & Run5).



a)

b)

c)

Figure 8-9 Forecast groundwater level impacts related to parameter uncertainty of ‘J-fold’ formations.

8.3.5. Post closure pit-lake

The uncertainty analysis has only been completed for the LoM scenario. Current time limits have precluded the analysis of how uncertainties may affect the development of the pit-lake.

8.3.6. Conclusions

The uncertainty analysis indicates that the uncertainty in hydraulic conductivity of the Fractured Rock impacts on the estimated groundwater inflows to the underground mine excavations. Impacts on Maperte and Orrtipa-Thurra community water supplies are unlikely to occur due to the distance from the mine site (18 km) and the limited extent of drawdown (RN018078 indicates <0.5 metres at a distance of 5 km).

9 Groundwater impact assessment

9.1. Groundwater affecting activities

9.1.1. Process water supply

The process water supply comprises six production bores abstracting up to 4.5 ML per day (63 L/s, 2 GL/year) for 10 years. Bores have been completed into the Georgina Basin Carbonate Aquifer at a site 20km to the north of the mine site.

The borefield currently consists of 6 bores averaging 10.6 L/s, although this is dependent on the analysis of the results from the groundwater investigations completed in mid-June 2019.

Borefield construction was completed in a staged approach as per the recommendations by CloudGMS (2018a):

1. Investigation drilling to identify suitable borefield location (completed);
2. Drilling and aquifer testing of each production bore (completed reporting by August 2019); and
3. Optimisation of pump specification and flow rate from each bore based on aquifer test result (completed reporting by August 2019).

If required, an increased number of bores will fit within the planned borefield footprint. The spacing between bores will be reduced.

9.1.2. Mine Pit Excavation

The excavation of the mine pits will extend below the water table (refer to section 3.11). The water table at the mine site has been measured at 320 - 330 mAHD (20 – 30m below ground level). The maximum pit depth at Bellbird is 100 m below ground surface, Reward is 140 m below ground surface and Reward South is 100 m below ground level this corresponds to RLs of 261 mAHD, 215 mAHD and 242 mAHD respectively. Bellbird will intersect the current groundwater table at the end of year 6, Reward will intersect the groundwater table after the end of year 1 and Reward South will intersect the water table between the end of year 6 and the end of year 7.

The Bellbird and Reward underground mines will be constructed beneath the water table and can expect groundwater inflows at commencement of excavations. Rockface will commence decline construction above the water table, however, the excavation will intersect the water table in the first half of year 1 in the mine schedule.

The drives distal to the ore are expected to be excavated into non-acid forming (NAF) rocks and to have seepage water quality similar to the samples obtained from the mine site monitoring bores J7 & J8.

The geochemical assessment conducted by EGi (2018) identified that the stopes and drives close to the ore are likely to be sulphidic and PAF, and underground seepage of groundwater from these zones is expected to be ultimately acidic, although cement backfill may offset this to some degree (EGi, 2018).

9.1.3. Waste rock dumps

Waste rock dumps will be developed adjacent to each open pit 1) to the west of Bellbird pit 2) to the west of Reward pit and 3) to the west of Reward South pit (refer to section 3.11). The waste rock is expected to be deposited dry, however, minor leakage from incident rainfall may occur.

Water extract testing indicates that the majority of waste rock materials will not liberate significant acid, salinity or metals/metalloids.

9.1.4. Tailings storage facility

The mine operation tailings will be stored in a tailings storage facility (TSF) to the west of Reward pit (refer to section 3.11).

Although the TSF will be designed with underdrainage to intercept and recycle seepage, some tailing liquor will seep from storage in the TSF to the groundwater table. This may result in some increase in groundwater level and change to the chemical composition of groundwater.

Seepage pathways that may allow the transport of contaminants from the TSF include:

- Fractures in the weathered bedrock; and
- Fractures or faults within the fresh bedrock.

Seepage from the TSF can migrate vertically through the disposed tailings and then through the unsaturated zone to the water table.

Once seepage from the TSF has entered the water table, it can migrate laterally in the direction of groundwater flow, possibly discharging to the natural environment.

9.1.5. Spills

Spills of processing reagents and hydrocarbons (fuel, lubricants) present a risk of groundwater contamination, though the depth to the water table of 20 – 30 metres provides a natural risk mitigation. Spills are considered a soil contamination risk rather than groundwater contamination.

Standard storage and handling protocols (bunded storage, spill kits etc) will be implemented.

9.2. Receptors

9.2.1. Pastoral Water Supply Bores

Lucy Creek Station, Arapunya Station and the northern portion of Jervois Station use bores completed in the Georgina Basin Carbonate aquifer for stock and domestic purposes. Lucy Creek Station utilises groundwater from the Georgina Basin Carbonate aquifer and is located 10 km from the water supply borefield.

The closest stock bores to the process water supply bores are RN011101, RN011102 and RN013274 which are about 1.5 km from the closest production bore.

9.2.2. Community Water Supply Bores

The nearest community water supply bores are:

- Maperte community water supply 17 km to the northeast of the mine site
- Orrtipa-Thurra (Bonya) Community water supply 17.5 km to the southwest of the mine site

Orrtipa-Thurra (Bonya) Community water supply and Jervois Station utilise groundwater from the Fractured Rock aquifer and the bores are located more than 30 km and 50 km from the planned process water supply borefield respectively.

9.2.3. Groundwater Dependant Ecosystems

There are no mapped groundwater dependant ecosystems (GDEs) within at least 40 kilometres of the process water supply borefield and the depth to groundwater (>15 metres) generally precludes ecosystem use, Low identified the possibility of the presence of deep-rooted species along Arthur Creek which may be considered facultative GDE species.

. However, as discussed further below, due to the depth to groundwater it is likely that the riparian vegetation along Arthur Creek near Lucy Creek Homestead are accessing groundwater.

Table 3-1, Table 3-2 and Table 3-8 present the depth to water measured at bores within the study area. The closest sites that record water levels within 15 m of the ground surface are to the west of Lucy Creek station homestead RN011495, RN012993, RN013689, RN013381, and RN18943 located about 10km east of the process water supply borefield. The bore reports for these sites indicate a standing water level of 6 – 9 m below ground surface. In this area the ground surface elevation is relatively low (<320 mAHD) and coincides with the location of the Lucy Creek Fault Zone which is interpreted to impede groundwater flow to the east, resulting in a shallow water table. The drawdown from the process water supply is expected to be about 2 metres which will result in impacts that are less than the criteria adopted by DENR.

Groundwater levels in the mine site are generally greater than 20 metres below ground level Two (2) sites have historically shown groundwater levels less than 5 m below ground level and are associated with Unca Creek. However, all but one of the groundwater levels obtained during the 2018 groundwater investigation were greater than 14 – 15 metres below ground level, which in addition to the very low permeability of the underlying rocks, suggests that the 2 shallow groundwater levels associated with Unca Creek may be disconnected from the regional groundwater system. Therefore groundwater drawdown in the fractured rock aquifer is expected to have limited effect on groundwater availability to riparian vegetation and ensuring the surface water flow regimes is maintained is more important.

The impact on potential stygofauna for this project is dewatering of the aquifer habitat in proximity to the process water supply borefield. Stygofauna surveying was completed at the project site in 2019 and a single commonly found species was encountered. The level of expected reduction in habitat, in the context of the size of the possible habitat, is considered insignificant. The impact to stygofauna from groundwater drawdown is considered low.

The Project process water supply will result in water table drawdown of about 2 m over an area of less than 110 km^2. The area of drawdown represents less than 0.04 % of the total Georgina Basin extent (~330,000 km^2), and the depth of drawdown is a small fraction of the more than 100 m thickness of the aquifer within the basin. The impact is temporary since water levels will largely recover once mining is complete and the process water supply borefield ceases to pump.

9.3. Project Water Supply Impact Study

9.3.1. Modelling Approach

Numerical groundwater modelling results detailed previously in sections 7 and 8 were used to identify the probable magnitude and extent of the induced drawdown due to groundwater abstraction for the mine process water supply and dewatering of mine excavations and assess the impacts on existing users.

9.3.2. Drawdown at Receptors

Several pastoral bores are within 2 km from the process water supply borefield (RN011101, RN011102 & RN013274), while the bore near Lucy Creek homestead (RN011495) is about 10 km from the planned process water supply borefield.

The borefield for Maperte outstation represented by RN016283 is located about 18 km from the planned mine site.

The borefield for Orrtipa-Thurra Community represented by RN018072 is located about 18 km from the planned mine site.

The results from the drawdown analysis suggest that, for the 10 years scheduled life of mine, it is probable that a maximum drawdown of 4 – 5 metres can be expected at the closest pastoral bores (RN011101, RN011102 & RN013274) and drawdown of less than 1 – 2 metres (forecast at the Lucy Creek stock bores RN013381 and RN018943) will be observed at the Lucy Creek homestead bore (RN011495) which has had an available drawdown of 11 metres based on a total depth (TD) of 18.6mBGL and standing water level (SWL) 7.6mBGL at 13/12/1976.

Drawdown of less than 1 metre is observed at the Maperte outstation bore represented by RN016283.

No drawdown is observed at the Orrtipa-Thurra community borefield represented by RN018072 during the LoM and is expected to be less than 1 metre after a prolonged period due to the the slow expansion of the drawdown associated with the pit-lakes.

The drawdown contours are presented previously in Figure 7-6 to demonstrate the lateral extent of the drawdown cone at the end of mining (year 10). The minimum drawdown contour is plotted at 0.5 metres, which is considered the extent that a response would be able to be measured/resolved in a practical way using manual methods such as a dipper and allowing for errors such as variations in atmospheric pressure.

9.3.3. Conclusions

The principal aquifer system, the Georgina Basin Carbonate Aquifer (GBCA) targeted for the proposed the Project process water supply borefield is an extensive, regional aquifer. Groundwater extraction will cause declining water levels in the aquifer which will have impacts on existing groundwater users.

The Project water supply borefield will extract water at 2 GL/annum for 10 years however this water use is a very small fraction of the stored volume in the aquifer, which is a massive regional scale resource.

Figure 7-24 a) presented in section 7.2.3 shows the range of predicted drawdown at Orrtipa-Thurra community water supply bore. The drawdown due to mining activities are considerably less than 1 metre.

Groundwater modelling techniques consistent with best practice guidelines were applied to assess the likelihood of water level drawdown impacting existing groundwater users due to groundwater abstraction from the GBCA system for the life of mining operations. The extraction is within the capacity of the aquifer and removes a very small fraction of the immense volume in storage. Water table drawdown impacts at the nearest sensitive receptors (Lucy Creek domestic water supply and stock watering bores) are unlikely to exceed 3 m. This drawdown will not reduce water availability for these users due to the very significant available drawdown at each site. There are no mapped Groundwater Dependant Ecosystems identified within the zone of drawdown. Riparian vegetation may be accessing the regional groundwater, however, it is more likely that this vegetation is reliant on the water available in the alluvial sediments associated with the larger creeks and hence the very limited extent of vegetation beyond the river channels.

This extraction poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and community water supplies.

9.4. Mining activities impact assessment

9.4.1. Mine Excavations

The Project mine excavations extend below the water table and groundwater levels are expected to decline due to the dewatering of these features. Groundwater drawdown in areas along Unca Creek where vegetation reliant on shallow groundwater are found is expected to exceed the criteria adopted by DENR. However, the shallow groundwater along Unca Creek is likely to be perched (in alluvial sediments overlying the much less permeable rocks) and disconnected from the regional groundwater system.

It is likely that the shallow alluvial sediments receive and temporarily store periodic surface run-off that recharges the local shallow/perched system that is not connected to the regional water table. The long-term health of the trees is therefore related to the maintenance of the surface water flow regime.

The assessment also found that it is unlikely that drawdown due to mine dewatering will result in material impacts at any other receptor. This extraction poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and community water supplies.

The geochemical assessment conducted by EGi (2018) identified that the stopes and drives close to the ore are likely to be sulphidic and PAF, and underground seepage of groundwater from these zones is expected to be ultimately acidic. Dewatering of pits and underground workings, however, is likely to require active management during operations to ensure water quality of receiving drainage meets compliance. This could entail water storage on site, water treatment, and/or controlled discharge during wet periods at set dilution ratios (EGi, 2018).

9.4.2. Waste rock dumps

Geochemical analysis results suggest that most waste rock from pit and underground development will be non-acid forming (NAF) and environmentally benign, and will not require specific management for control of acid rock drainage (ARD) (EGi, 2018). However, there will be a portion of PAF (including PAF-LC and NAF-HS) that will require selective handling and management to prevent ARD into the long term. Long term options could include:

- in pit or underground disposal below recovery water table levels;
- selective underground disposal of PAF as part of backfill; or
- construction of an infiltration control cover system in-pit or ex-pit.

Subaqueous disposal is the most secure option for controlling sulphide oxidation and acid rock drainage (ARD), but the feasibility of this mechanism will depend on long term recovery groundwater and pit water levels, and the volume of PAF mine materials this can accommodate.

Currently pit-lake water levels are not predicted to recover substantially, therefore, placement of PAF waste rock underground along with cement backfill is preferred to surface dumping (EGi, 2018).

Post-mining streamline analysis (refer to section 7.3) indicates that the ultimate fate of any seepage from the WRDs, will be captured by the groundwater sink features formed by the pit-lakes.

Water quality modelling will be required to better define the likely impacts during operations and closure on groundwater from the various mine components with varying management options.

9.4.3. Tailings storage facility

Tailings liquor associated with the TSF is likely to be PAF and the proposed TSF will require management to prevent acid rock drainage (ARD) and will require an infiltration control cover system for closure. To address these issues the TSF will be designed with underdrainage to intercept and recycle seepage, however, some seepage is expected to flow through the unsaturated zone to the water table. During operations the process water will dominate seepage quality. The process water supply water is of potable quality and better than the groundwater in the vicinity of the Project mine site, which is suitable for stock watering.

Water table rise (mounding)

Groundwater mounding is not expected to be a significant impact. Tailings will be placed in the TSF above ground surface and seepage will be minimised by the underdrain system to intercept and recycle seepage. Some seepage is expected to flow through the unsaturated zone to the water table at about 20 - 30 m below ground surface. The design criteria for the TSF is 1 kL/Ha/day 0.1mm/d) and the estimated hydraulic conductivity of the rocks beneath the TSF are unlikely to infiltrate at a rate greater than this.

A mound is expected to form beneath the TSF with saturated conditions expected to exist within the footprint of the TSF. However, the permeability of the rocks will result in steep gradients away from the TSF and groundwater levels beyond the immediate footprint of the TSF will rise by only a few metres with no rise in groundwater levels expected beyond 100 metres from the TSF.

Mounding is not expected to result in surface expression of groundwater or tailing seepage to surface in proximity to the tailings storage facility. Groundwater observation bores have been installed during September-October 2018 to monitor groundwater levels and groundwater quality.

Post mining the mound will dissipate to the initial groundwater levels as the additional source from the mine process stream is removed.

Impacts of tailings seepage

Baseline Groundwater Quality

Currently there is limited site specific groundwater quality data in the area of the TSF, although baseline groundwater monitoring sites have been installed (September-October 2018) for this purpose. Groundwater samples in the vicinity of the Project footprint (Table 3-7) meet the water quality requirements for Stock and Industrial use only due to elevated TDS (>1000 mg/L), Fluoride, Iron and Sulphate.

Tailing leachate water quality

Tailings from fresh ore processing will have moderate S values of around 1%S, but are still likely to be PAF. Tailings showed enrichment in a similar suite of metals/metalloids as the waste rock and ore, including Ag, Bi, Be, Cd, Co, Cs, Cu, Fe, Mn, Pb, S Mo, Se, Tl, W and Zn. Some mobilisation of Cd, Co, Cu, SO4, Mn and Zn can be expected during the lag period.

Water quality modelling has been undertaken to better define the likely impacts during operations and closure on groundwater from the various mine components with varying management options. It is expected that during operations the process water will dominate seepage quality, and will be alkaline. After closure, once the process water has eventually seeped away, the tailings will oxidise and start producing acid. The proposed cover reduces the transport of the oxidation products by reducing infiltration, but does not stop the oxidation, but greatly reduces the load reporting to the groundwater system.

Fate of TSF seepage

The TSF will require a secure low permeability base to prevent leaching of process water and oxidation products during operations, and is likely to require an infiltration control cover system for closure. The potential for paste backfill of tailings into underground workings should be assessed to help reduce the inventory of tailings requiring surface management.

- Clarify TSF base design and permeability, and investigate options for tailings infiltration control cover systems, taking into account the effects of high intensity rainfall events.
- Assess the potential for paste backfill of tailings into underground workings to help reduce the inventory of tailings requiring surface management
- Carry out preliminary water quality modelling to better define the likely impacts during operations and closure on surface and groundwater from the various mine components with varying management options.

Seepage from the TSF to the water table is expected, however, particle tracking presented in section 7.3 indicate that the fate of seepage from the TSF will ultimately be to the Reward and Reward South pit-lakes.

The seepage from the TSF poses a low risk to other users with respect to reducing water quality of adjacent pastoral bores and community water supplies.

9.4.4. Spills

Spills of reagents or fuels presents a very low risk to groundwater at this site due to the relatively deep water table ~20 – 30 m below ground surface). Spills constitute a soil impact rather than groundwater. Hazardous materials should be stored and handled in accordance with standard guidelines (e.g. bunded storage, provision of spill kits etc).

10 Conclusions

10.1. Process water supply borefield

The principal aquifer system, the Georgina Basin Carbonate Aquifer (GBCA) targeted for the proposed Jervois Base Metals Project process water supply borefield is an extensive, regional aquifer. Groundwater extraction will cause declining water levels in the aquifer which will have impacts on existing groundwater users.

Groundwater modelling techniques consistent with best practice guidelines were applied to assess the likelihood of water level drawdown impacting existing groundwater users due to groundwater abstraction from the GBCA system for the life of mining operations. The assessment found that it is unlikely that drawdown of more than 3 m will result at any receptor. This extraction poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and domestic water supplies.

The project process water supply borefield will extract a water at 2 GL/annum for 10 years (20GL) however this water use is a very small fraction of the stored volume in the aquifer which is a massive regional scale resource (~1,320,000 GL assuming a specific yield of 0.04, a saturated thickness of 100m and an area of ~330,000 km^2).

10.2. Mine pit and underground excavations

Impacts of mine activities on the Fractured Rock groundwater system have been quantified using numerical groundwater modelling techniques consistent with best practice guidelines. Dewatering of the Fractured Rock groundwater system due to mining activities will cause declining water levels in the vicinity of the mine tenement.

The assessment found that total groundwater inflows to the 3 open-cut pits and 3 underground mines is expected to peak at around 60 – 70 L/s.

Post closure the excavations are expected to fill with groundwater. The underground mines will fill to near the pre-mining levels and the pits will form lakes where the final pit-lake water levels will be dependent on the balance between groundwater inflows and evaporation from the pit-lake surface.

The assessment also found that it is unlikely that drawdown due to mine dewatering will result in material drawdown impacts at any receptor. This extraction poses a low risk to other users with respect to reducing yields of adjacent pastoral bores and community water supplies.

10.3. Waste rock dump seepage

Seepage from the waste rock dumps present a low risk to groundwater at this Project due to the mostly benign nature of the waste rock. Limited seepage from the WRDs to the water table is expected as the rock piles will be dry. Particle tracking techniques indicate that the cone of drawdown associated with dewatering of the mines and the post-closure development of the Bellbird and Reward and Reward South pit-lakes will effectively capture any seepage sourced from WRDs preventing the migration of seepage off-tenement.

10.4. Tailings seepage

Supernatant water associated with the TSF is likely to be PAF. The TSF will be designed with underdrainage to intercept and recycle seepage, however, some seepage is expected to flow through the unsaturated zone to the water table. The design criteria for the TSF is 1 kL/Ha/day 0.1mm/d) and the estimated hydraulic conductivity of the rocks beneath the TSF are unlikely to infiltrate at a rate greater than this. A mound is expected to form beneath the TSF with saturated conditions expected to exist within the footprint of the TSF. However, the permeability of the rocks will result in groundwater levels beyond the immediate footprint of the TSF to rise by a few metres with no rise in groundwater levels expected beyond 100 metres from the TSF.

Changes to the groundwater quality within the footprint of the TSF are likely, however, particle tracking techniques indicate that the cone of drawdown associated with dewatering of the mines and the post-closure development of the Reward and Reward South pit-lakes will effectively capture seepage sourced from the TSF and prevent the migration of TSF seepage off-tenement.

11 Bibliography

Barnett, B. et al., 2012. *Australian groundwater modelling guidelines.,* Waterlines report 82: National Water Commision, Canberra.

Bennett, M. R., McGloin, M. V., Schmid, S. & Schaubs, P., n.d. *Jervois Cu-Ag-Pb-Zn-Au mineral field,* s.l.: s.n.

CloudGMS, 2018a. *Jervois Base Metals Mine EIS Groundwater Impact Assessment,* Adelaide: Unpublished.

CloudGMS, 2018b. *Jervois Base Metals Project Lucy Creek Water Supply Investigation,* Adelaide: Unpublished.

CloudGMS, 2019. *Jervois Mine Site Groundwater Investigation Field Report,* Adelaide: Unpublished.

CSIRO, 2012. *New insights into the chemical and isotopic composition of rainfall across Australia. ,* Australia: CSIRO Water for a Healthy Country Flagship.

DENR, 2018. *Western Davenport Water Allocation Plan 2018 – 2021,* Darwin: Unpublished.

Diersch, H. J., 2015. *FEFLOW Finite Element Modeling of Flow, Mass and Heat Transport in Porous and Fractured Media.,* Heidelberg: Springer.

Doherty, J., 2016. *PEST Model-Indepedent Parameter Estimation User Manual Part I: PEST Software.* 6th ed. Brisbane: Watermark Numerical Computing.

Dunster, J., Kruse, P., Duffett, M. & Ambrose, G., 2007. *Geology and resource potential of the southern Georgina Basin. Digital Information Package DIP007,* s.l.: Northern Territory Geological Survey,.

EGi, 2018. *Geochemical Assessment of the Jervois Base Metal Project, Northern Territory,* Balmain, NSW: Environmental Geochemistry International Pty Ltd.

Farr, T. G. et al., 2007. The Shuttle Radar Topography Mission.. *Reviews of Geophysics,* 45(2).

Freeman, M., 1986. *Huckitta, Northern Territory (Second Edition). 1:250 000 geological map series explanatory notes, SF 53-11.,* Northern Territory Geological Survey,: Darwin.

Greene, D. C., 2010. Neoproterozoic rifting in the southern Georgina Basin, central Australia: Implications for reconstructing Australia in Rodinia. *Tectonics,* Volume 29.

Keywood, M. et al., 1997. The accession of chloride to the western half of the Australian continent.. *Australian Journal of Soil Research,* Volume 35, p. 1177-89.

Knight Piésold, 2015. *Tailings Management and Infrastructure Pre-Feasibility Study Update,* East Perth: Unpublished.

Kruse, P., Dunster, J. & Munson, T., 2013. Chapter 28: Georgina Basin. In: M. Ahmad & T. Munson, eds. *Geology and mineral resources of the Northern Territory.* Northern Territory Geological Survey: Special Publication 5.

McCullough, C. D. et al., 2012. *Pit lakes as evaporative 'terminal' sinks: an approach to best available practice mine closure..* International Mine Water Association, s.n.

QDSIT, 2015. *Guideline for the Environmental Assessment of Subterranean Aquatic Fauna. ,* s.l.: Queensland Government Department of Science, Information Technology and Innovation. .

Rau, G. et al., 2018. Quantifying compressible groundwater storage by combining cross-hole seismic surveys and head response to atmospheric tides.. *Journal of Geophysical Research: Earth Surface,* Issue 123.

Ride, G., 1971. *Groundwater Investigation for the Attutra Ore Treatment Plant.,* Northern Territory Government, Water Resources Assessment: Report WRA71002.

Ride, G., 2016. *Groundwater and Surface Water Desktop Report, KGL Jervois Base Metal Mine Development, Jervois, NT,* Prepared for KGL Resources by Ride Consulting.: s.n.

Shewchuk, 2005. *TRIANGLE: a two-dimensional quality mesh generator and Delauny triangulator.,* Berkley: University of California, Computer Science Division.

Villeneuve, S. et al., 2015. Groundwater recharge via infiltration through an ephemeral riverbed, central Australia. ,. *Journal of Arid Environments,* Volume 117, pp. 47-58..

WA-EPA, 2003. *Consideration of subterranean fauna in groundwater and caves during environmental impact assessment in Western Australia (Guidance Statement 54).,* s.l.: Environmental Protection Authority..

WA-EPA, 2007. *Sampling methods and survey considerations for subterranean fauna in Western Australia (Guidance Statement 54a) draft. Perth, ,* s.l.: Environmental Protection Authority..

WA-EPA, 2012. *A review of subterranean fauna assessment in Western Australia. Environmental Protection Authority, Perth. ,* Environmental Protection Authority: Perth.

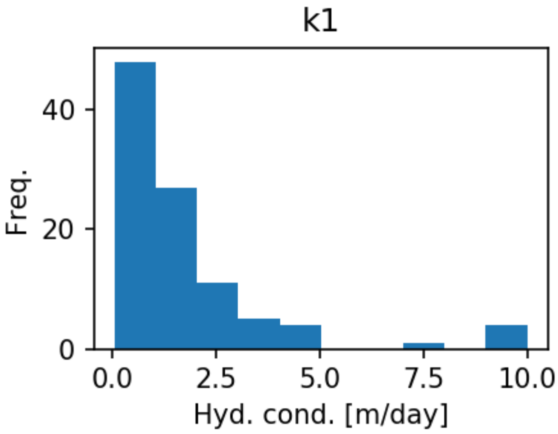
WA-EPA, 2016. *Consideration of Subterranean Fauna in Environmental Impact Assessment in WA: Environmental Assessment Guideline No. 12,* s.l.: s.n.

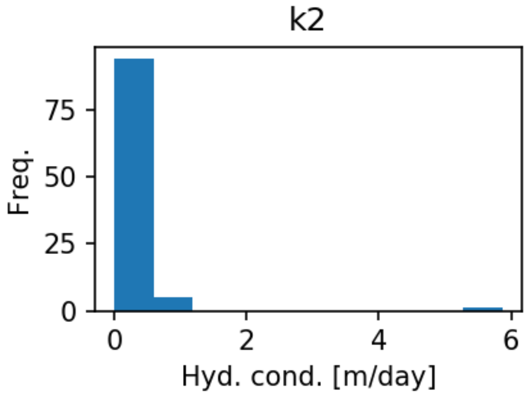
12 Document history and version control

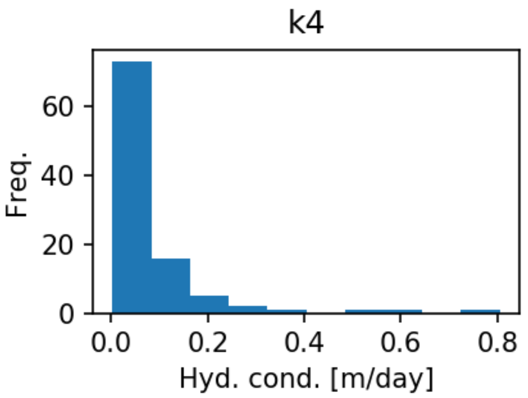
VERSION	DATE RELEASED	APPROVED BY	BRIEF DESCRIPTION
0.1	28/06/2019	AK	Draft
0.2	03/07/2019	AK	Draft with comments from Nitro Solutions and KGL
0.3	09/07/2019	AK	Minor edits regarding GDEs

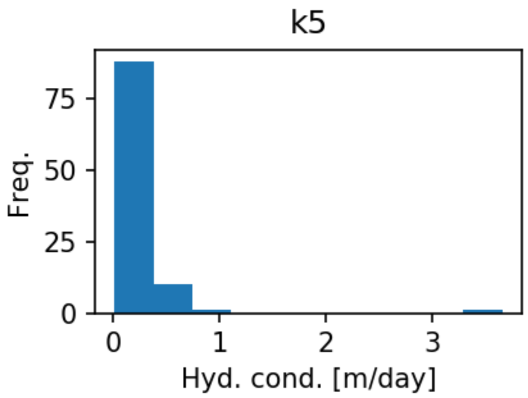
Appendix A. Parameter histograms

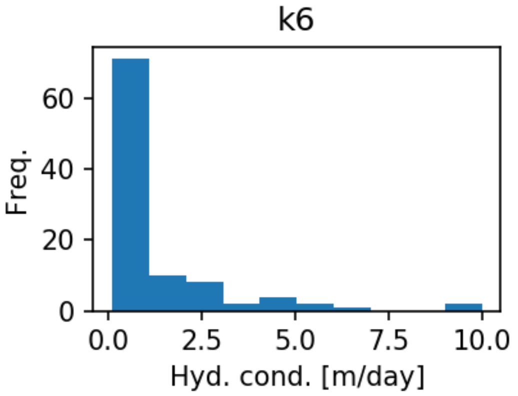
Hydraulic conductivity probability distributions assigned to corresponding model zones (ie k1 is assigned to model zone 1).

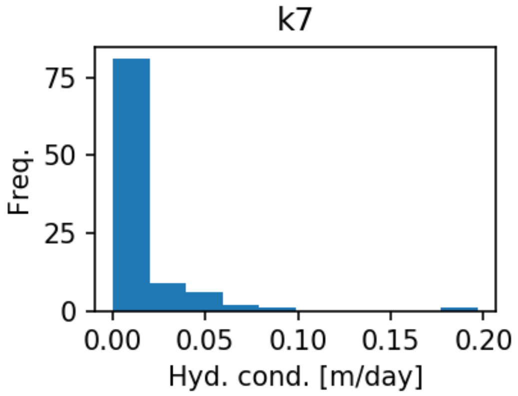


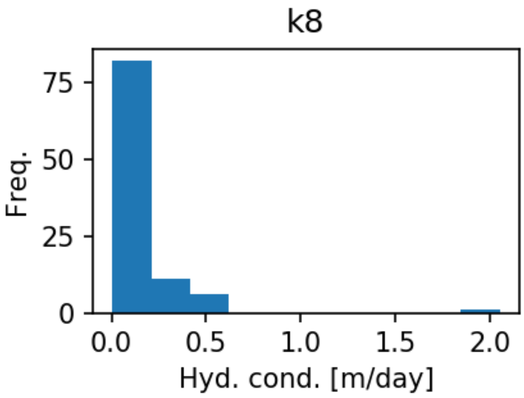




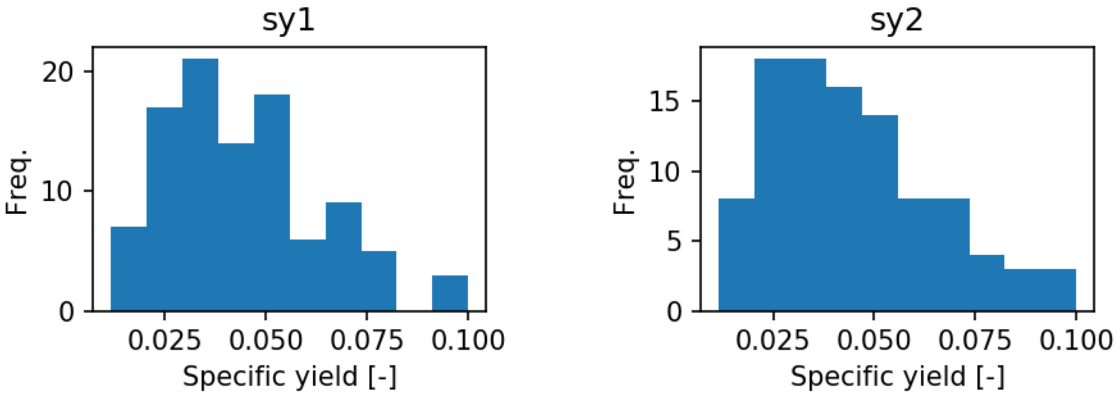


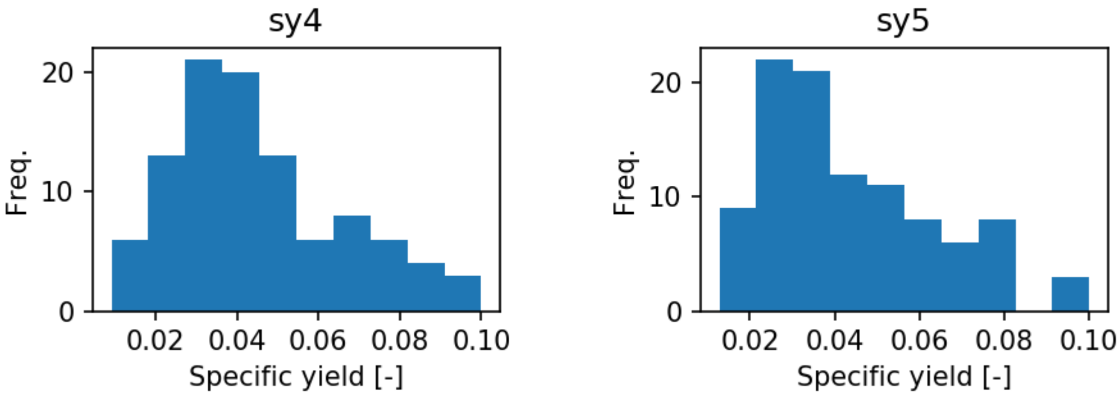


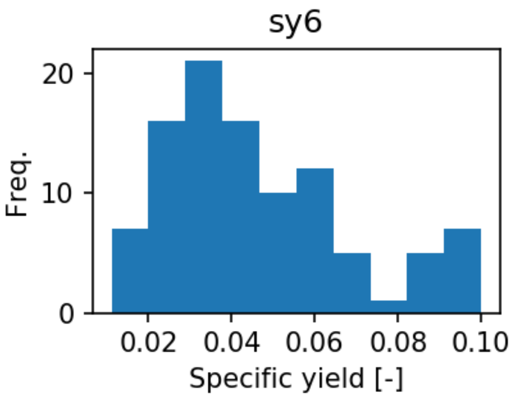


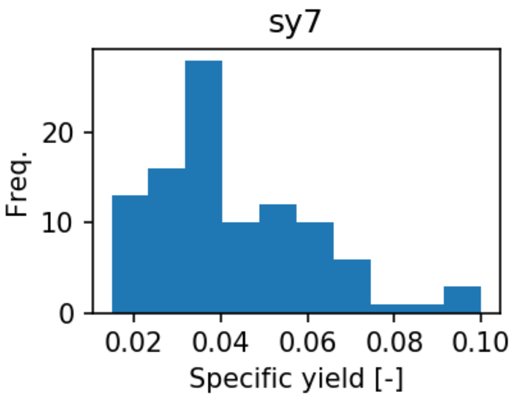


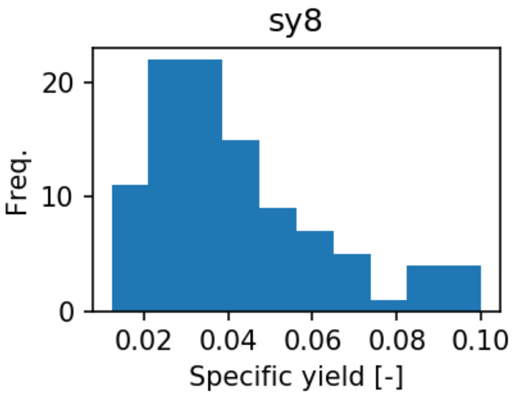
Specific yield parameter probability distributions assigned to corresponding model zones (ie sy1 is assigned to model zone 1).






sy6
Freq.
0
10
20
0.02
0.04
0.06
0.08
0.10
Specific yield [-]


sy7
Freq.
0
10
20
0.02
0.04
0.06
0.08
0.10
Specific yield [-]


sy8
Freq.
0
10
20
0.02
0.04
0.06
0.08
0.10
Specific yield [-]