08

Groundwater

8. Groundwater

8.1 Introduction

A detailed groundwater impact assessment report is provided in Appendix K of this EIS and an acid, metalliferous or saline drainage (AMD) assessment and management plan is provided in Appendix L.

Section 5.3 of the TOR for the preparation of an environmental impact assessment issued by the NT EPA for the project provided the following environmental objectives in relation to groundwater resources:

> *Proposed extraction of water will be within the sustainable limit of the aquifer or water supply to fulfil the Project needs over the predicted life-of-mine, without causing adverse environmental or social impacts.*
>
> *Water resources will be protected both now and in the future, such that ecological health and land uses, and the health, welfare and amenity of people are maintained.*

This chapter addresses the potential impacts of the project on groundwater resources, including the risk of AMD generation and the potential impact of groundwater extraction from the borefield. This chapter also considers the cumulative effects of extraction of groundwater from the mine site during operation and beyond closure as required in the TOR for the project.

8.2 Methodology

A summary of the approach and limitations to the groundwater impact assessment in the study area is summarised below and more detail is provided in Appendix K.

A hydrogeological investigation was undertaken on the Nolans Project using inputs from:

- previous studies on the Ti Tree Basin
- field studies at the mine site and
- field studies of the Southern Basins and Margins Area.

A dataset was developed from mineral exploration drill holes and investigation water bores. Of these, 75 water bores were drilled specifically as part of the Nolans Project.

A numerical groundwater flow model was developed based on these hydrogeological investigations. This was calibrated to steady state observed conditions and used to predict future conditions over time. This model provides the following outcomes:

- An estimate of future conditions
- Potential impacts and a quantification of the key impacts at key locations across the study area under the influence of the project operating conditions and under closure conditions
- Conceptual flows which consider:
  - Boundary conditions
  - Recharge
  - Evapotranspiration and
  - Groundwater extraction.

Modelled impacts to groundwater availability are considered from the perspective of groundwater flows (volumes over time), groundwater elevations (heads), groundwater flow direction and groundwater drawdown. In addition, the modelled impacts are considered in terms of impacts to groundwater chemistry and quality.

A desktop review of historical geochemical data and detailed geochemical analysis was undertaken to characterise waste rock and ore in terms of hazardous material and potential to develop AMD at the Nolans mine site.

A summary of the approach and limitation to the AMD assessment in the study area is summarised below and more detail is provided in Appendix L.

To gain an understanding of the relative rate of acid production and neutralisation over time as well as the mobility of metals in leachate testing the following key tasks were undertaken:

- Static AMD testing has been carried out on 200 samples (Stage 1) of potential waste rock and
- Splits from 25 of the Stage 1 samples were selected from each of the major rock types and from samples showing the highest indication of AMD risk as well as generally representative samples.

8.3 Existing environment

The following sections describe the groundwater resources identified in the study area and discuss the relative value of these resources in the local and regional context.

8.3.1 Extent of hydrogeological study area

The study area (Figure 8-1) is defined as covering the following four key groundwater areas (from north to south):

- The Ti Tree Basin
- Nolans mine site and surrounding fractured rock aquifer/basement
- The area referred to collectively as the Southern Basins
- The area where the Ti Tree Basin borders or abuts the Southern Basins which is referred to as The Margins.

The study area measures approximately 200 km east to west and 125 km north to south, and occupies a total of 19,000 km^2. In this report, these groundwater areas are collectively referred to as the groundwater system.

8.3.2 Topography

The topography of the study area is dominated by a flat plain, ranging from approximately 650 m AHD to 570 m AHD (over 120 km heading west) in the Southern Basins and from 650 m AHD to 505 m AHD (over 85 km heading north east) in the Ti Tree Basin. Above this plain, the Hann Range and Reaphook Hills rise up to approximately 150 m, and peaks of the Reynolds Range and Yalyirimbi Range up to almost 500 m above the plain

8.3.3 Study area climate

The study area climate consists of low rainfall (refer Appendix K) and high summer maximum temperatures (average of 37°C) and low minimum winter temperatures (average 6°C), typical of central Australian arid climates.

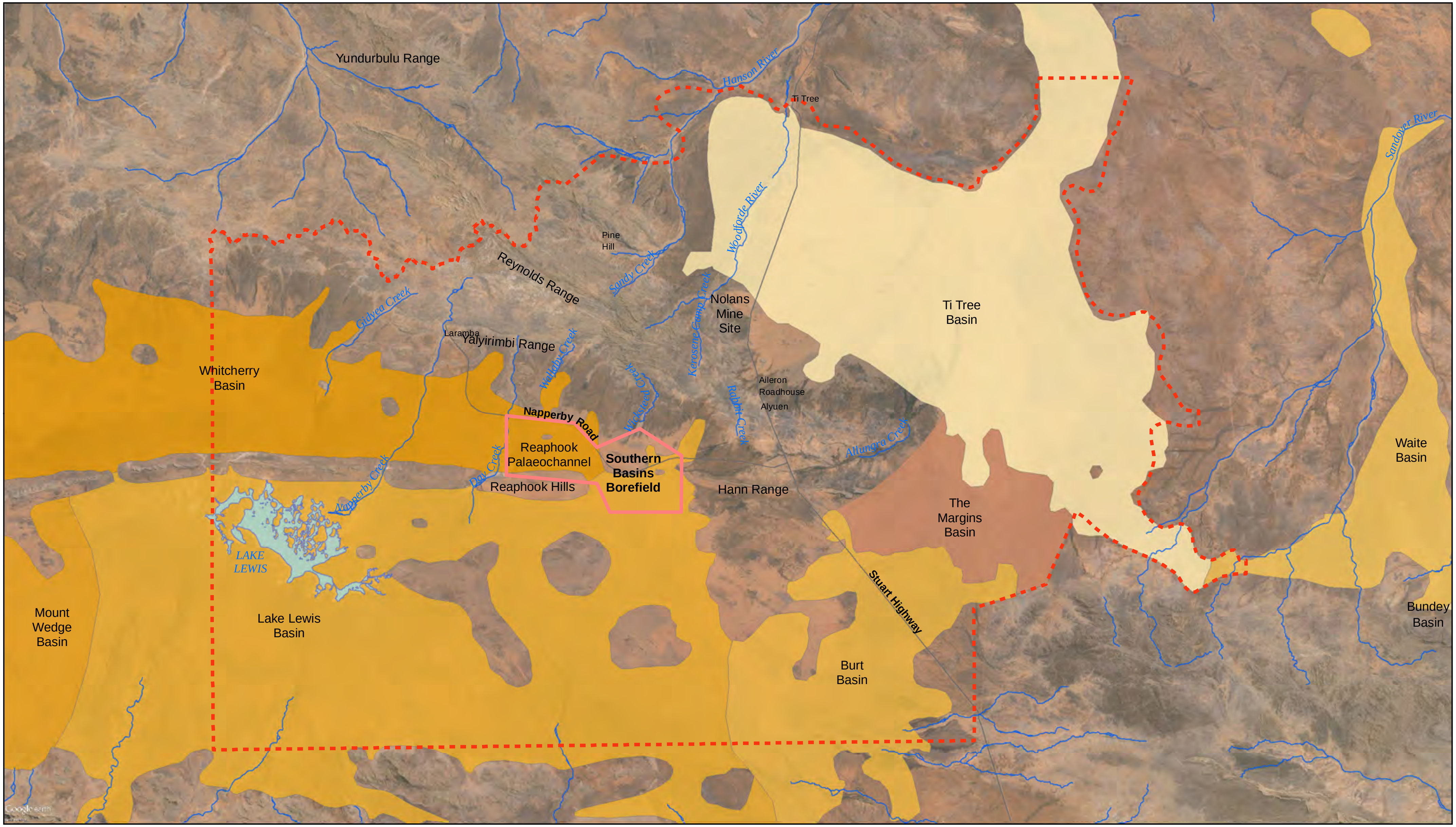
Precipitation averages approximately 320 mm/year but importantly for groundwater recharge, precipitation can fall as large rainfall events. Using the Territory Grape Farm weather station data (Appendix K), rainfall events were examined over a 28-year period. Twelve events were recorded for 60 mm or more per day, and 19 events were above 50 mm per day. Considering multiple day events (over five consecutive days), there are two occurrences exceeding 250 mm. Considering the low average rainfall, these events are significant as it is likely that most groundwater recharge and stream flow events result from rare, high-rainfall events rather than steady annual recharge. Ride (2014) documents a monthly rainfall of 100 mm or more being required to result in surface water flow in the Ti Tree Basin.

8.3.4 Basins

The basins (Southern Basins and Ti Tree Basin) in the study area are hydrogeologically similar (although not identical) to each other and to adjacent basins across central Australia. Unlike the Ti Tree Basin, which has been studied in detail and used extensively as a groundwater source, the Southern Basins in the study area have not previously been investigated in detail nor have they been used extensively as a groundwater source.

The Southern Basins encompass Cenozoic sedimentary basins previously referred to as the Whitcherry Basin, the Mount Wedge Basin, the Burt Basin and Lake Lewis Basin (Figure 8-2).

The Southern Basins are considered to be connected to the Ti Tree Basin in an area referred to as The Margins. Despite the connection, The Margins are primarily a subtle groundwater divide with water flowing north of the divide to the Ti Tree Basin and south of the divide to the Southern Basins. To the east, the Ti Tree Basin is connected to the Waite Basin (and then Bundey Basin) and to the north it is believed to be connected to the Hanson Palaeovalley (Figure 8-2).



1:1,000,000 @ A4

0 10 20 30 40

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 53

N

LEGEND

- Roads
- Waterways
- Groundwater Study Area
- Southern Basins Borefield
- Lake Lewis
- Ti Tree Basin

Distant Basins and Palaeovalleys

- Bundey Basin
- Waite Basin

Southern Basins

- Burt Basin
- Lake Lewis Basin
- Mount Wedge Basin
- Whitcherry Basin
- The Margins

Arafura Resources Limited
Nolans Project
Environmental Impact Statement

Job Number	4322301
Revision	0
Date	13 Apr 2016

Hydrogeological study area

Figure 8-1

G:\43\22301\GIS\Maps\4322301_023_HydrogeologicalStudyArea.mxd

Level 5 66 Smith Street Darwin NT 0800 Australia T 61 8 8982 0100 F 61 8 8981 1075 E drwmail@ghd.com W www.ghd.com

Data source: Google Earth Pro - Imagery (Date extracted: 14/05/2015). GA - Roads, Waterways, Lake Lewis, Placenames (2015). GHD - Groundwater Study Area, Southern Basins Borefield (2015). Created by: CM

1:3,000,000 @ A4

0 25 50 75 100

Kilometres

Map Projection: Universal Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 53

N

LEGEND

- Groundwater Study Area
- Southern Basins Borefield
- Lakes

Distant Basins & Palaeovalleys

- Ti Tree Basin
- Bundey Basin
- Hanson Basin
- Mackay (Wilkinkarra)
- Waite Basin

Southern Basins

- Burt Basin
- Lake Lewis Basin
- Mount Wedge Basin
- Whitcherry Basin
- The Margins

Arafura Resources Limited
Nolans Project
Environmental Impact Statement

Job Number	4322301
Revision	0
Date	13 Apr 2016

Key regional basins and palaeovalleys

Figure 8-2

G:\43\22301\GIS\Maps\4322301_024_RegionalBasinsPalaeovalleys.mxd

Level 5 66 Smith Street Darwin NT 0800 Australia T 61 8 8982 0100 F 61 8 8981 1075 E drwmail@ghd.com W www.ghd.com

Data source: Google Earth Pro - Imagery (Date extracted: 14/05/2015). GA - Roads, Lakes, Placenames, Palaeovalleys (2015). GHD - Groundwater Study Area, Southern Basins Borefield (2015). Created by: CM

8.3.5 Surface water features

Surface water features important to the study area are also presented in Figure 8-3. The important surface water drainage features within the study area flow only as a result of precipitation falling within the study area. Surface water flows originate in the catchments of the Reynolds Range and Yalyirimbi Range. These flows typically result in terminal creeks (i.e. their flow does not make it to a secondary water feature, i.e. a lake or river) including the named features Gidyea Creek, Day Creek, Wallaby Creek, Wicksteed Creek, Kerosene Camp Creek, Rabbit Creek and Allungra Creek. Napperby Creek is the exception in that it discharges to the endorheic basin, the ephemeral Lake Lewis, following periodic high rainfall events. Likewise, the Woodforde River also discharges to the Hanson River downstream (north) of the study area. No significant surface water drainage features originate from the Hann Range, Reaphook Hills or in the low-lying dune country of the relatively flat plains of the Ti Tree Basin and Southern Basins.

8.3.6 Water users

Groundwater from the basins is the primary source of drinking water in the study area. Power and Water Corporation provide groundwater to communities at Ti Tree, Pmara Jutunta, Laramba (Napperby); and the Central Desert Regional Council provides water to the Alyuen Community, Aileron Station Homestead and Aileron Roadhouse. Groundwater is also used for domestic purposes at the other stations' homesteads in the study area, notably Napperby Station Homestead and Pine Hill Station Homestead.

Pine Hill Station Homestead is adjacent to a large permanent/semi-permanent surface water hole visible on aerial imagery, and it is understood Napperby Station Homestead sources drinking water from a permanent/semi-permanent surface water source located in the adjacent hills.

In addition to this domestic use, groundwater is important for the following uses:

- Stock water - primarily for cattle, is extracted from groundwater within the basins and basement rocks across the study area; and
- Irrigation for agriculture - extracted from the Ti Tree Basin mainly for table grapes and mangoes at Ti Tree Farms.

Environmental users of water (not necessarily groundwater) in the study area include riparian vegetation, vegetation on the plains and in the hills, as well as fauna. With no permanent surface water across the study area, vegetation and fauna are either capable of surviving in between rainfall events or are able to tap into groundwater. Depths to groundwater levels are known to be shallow in isolated areas across the study area, but over the vast majority of the area are generally well below the reach of most vegetation (i.e. greater than 15 m). The following environmental users of groundwater have been identified:

- Riparian vegetation (dominated by *Eucalyptus camaldulensis*, colloquially referred to as river red gums) line the larger creeks and rivers in the study area. These larger creeks and rivers with riparian vegetation include, but may not be limited to, Napperby Creek, Day Creek and Woodforde River (Figure 8-1). It is conceivable that such riparian vegetation could tap groundwater (potentially even at depths greater than 15 m) and therefore these areas are potential groundwater dependant ecosystems, and are considered in this impact assessment.
- Water appears to be important for vegetation in floodout areas and at the toe of hills and ranges where runoff is highest. These areas are primarily dominated by *Acacia aneura* (mulga) woodland. These areas are considered in this impact assessment.

- Lake Lewis and surrounds is considered a site of conservation significance at a rating of National Significance. Due to this significance, Lake Lewis is considered in this impact assessment, despite the lake itself being a significant distance (30 km) from the borefield.
- Where water pools in basement rock-holes along drainage lines or in depressions in the outcropping rock mass, these provide a source of water for environmental use until evaporation depletes the water. Such features are present in the hills and ranges across the study area and these features are considered in this impact assessment, despite their distance from extraction points and their low permeability settings.

Water users are depicted in Figure 8-4.

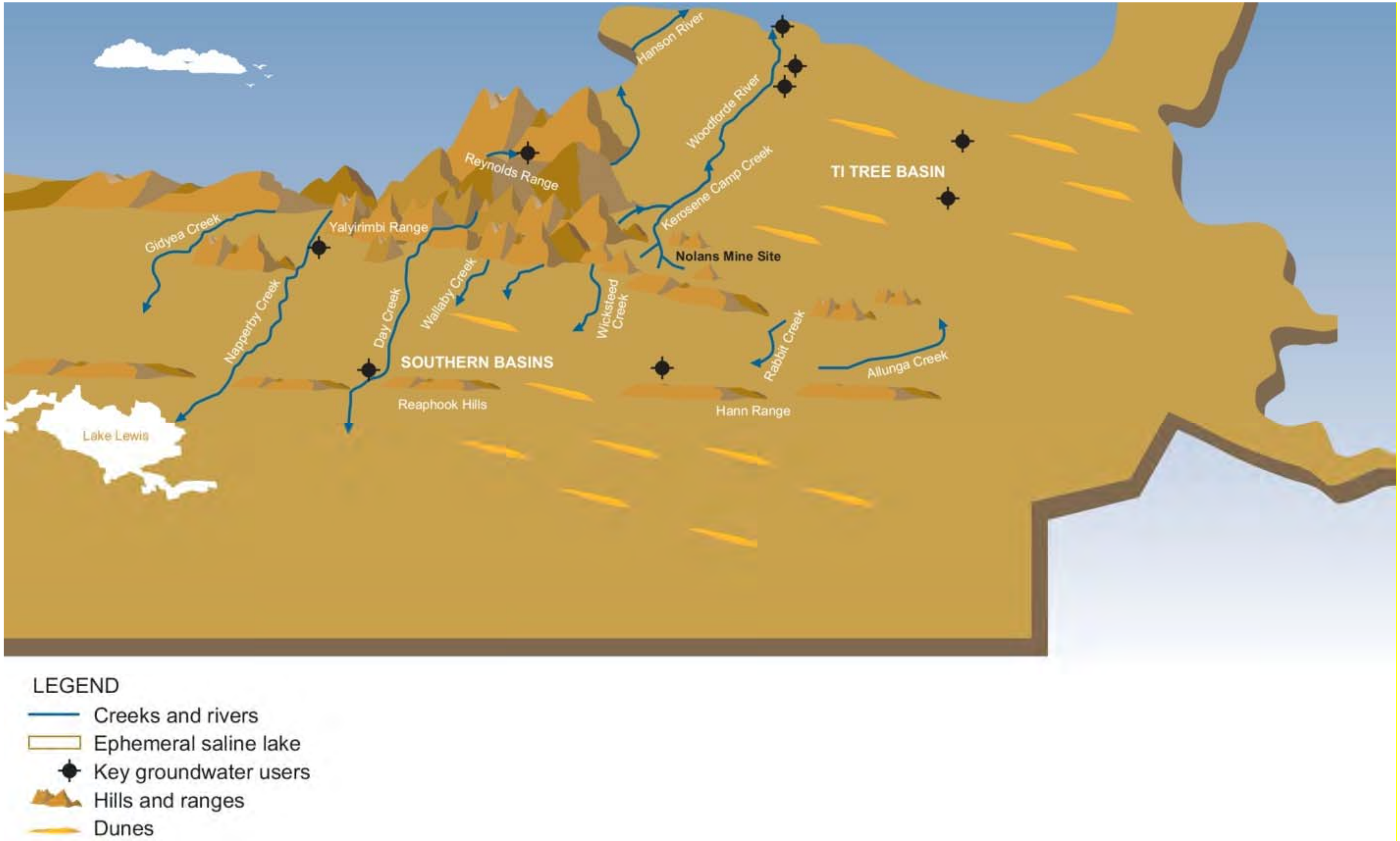


Figure 8-3 Study area surface water features

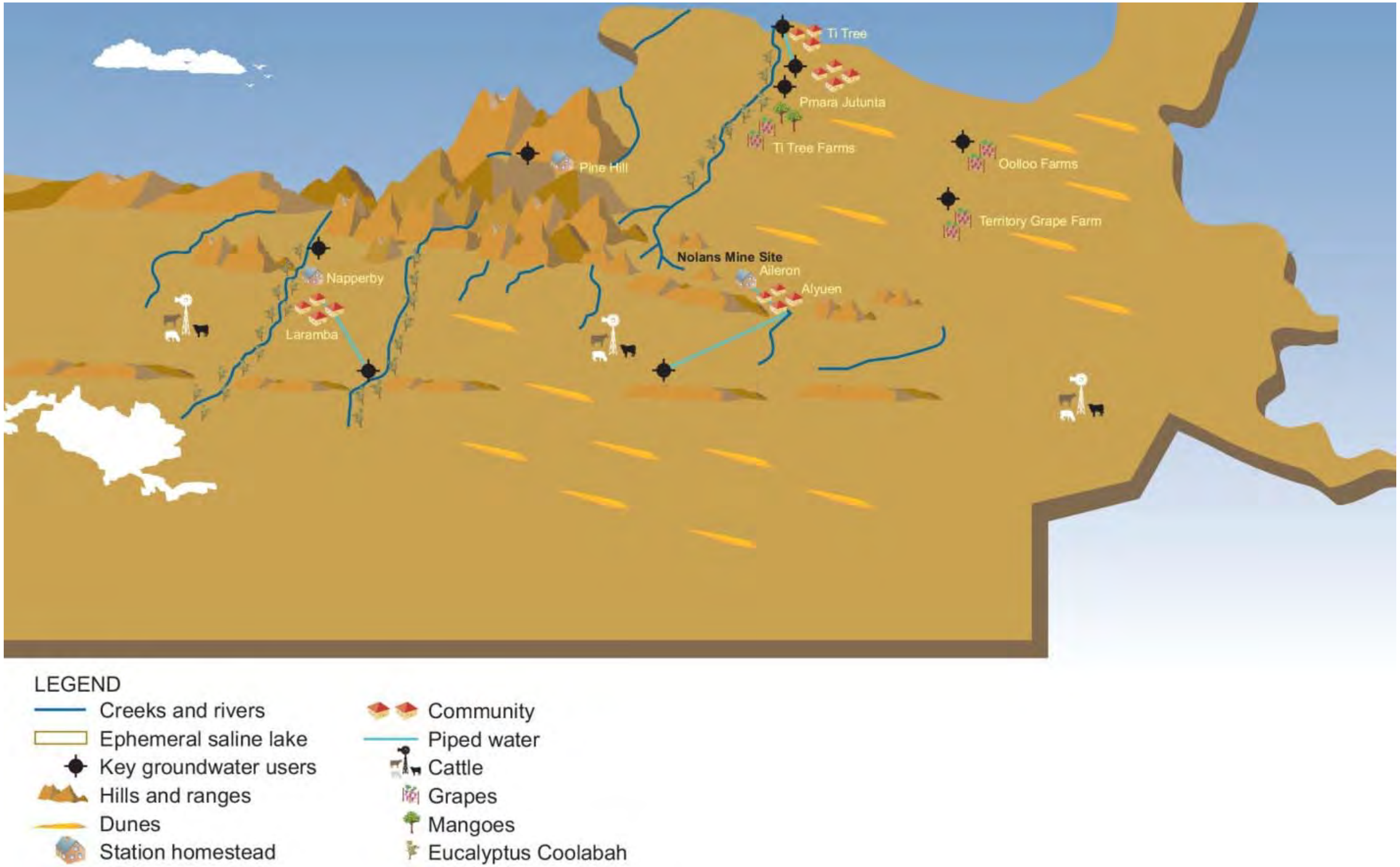


Figure 8-4 Study area water users

8.3.7 Conceptual water flows

Conceptual flows are represented in Figure 8-5 and are divided into the following groups:

- Boundary conditions
- Recharge
- Evapotranspiration and
- Groundwater extraction.

Boundary conditions

Upper no flow boundaries are the topographic high of the ranges and no flow boundaries of the basin boundaries. The divide between the Ti Tree Basin and the Southern Basins is a connected groundwater high, and thus no boundary condition is applied.

The Southern Basins have three key groundwater flow outputs (Figure 8-5):

- North of the Reaphook Hills westward through the deep aquifer
- South of the Reaphook Hills westward through the aquifer and
- Potentially through discharge at surface into Lake Lewis.

No surface water, significant to the hydrogeological assessment, flows into the study area but surface water leaves the system through the Hanson River and Woodforde River.

Recharge

Recharge throughout the Ti Tree Basin has been the subject of multiple studies and the groundwater assessment (Appendix K) makes use of the previous findings and estimates. Throughout this broader study area, classification of recharge (Figure 8-5) includes recharge through:

- Fractured rocks of the ranges and hills
- Alluvial fans and plains immediately adjacent to the ranges and hills where runoff infiltrates into the plains and
- Infiltration from Lake Lewis and areas locally referred to as 'swamps' and 'clay pans', following inundation events.

Evapotranspiration

The most evident illustration of evapotranspiration is the ephemeral, saline Lake Lewis where water clearly leaves the system as evaporation. Diffuse evapotranspiration occurs across the study area from vegetation, soil (as well as sediments and rock) and water bodies. Additionally, where water tables are shallow, trees (primarily mulga in the study area), shrubs and grasses (i.e. spinifex) are likely to tap groundwater and provide areas of higher evapotranspiration.

Groundwater extraction

Groundwater is extracted from the Ti Tree Basin for irrigation, stock and domestic purposes as discussed above in Section 8.3.6 and these locations are represented in Figure 8-4 at the key bores. Elsewhere in the study area, localised small-scale groundwater extraction occurs for stock and domestic purposes. An additional groundwater extraction of 4.5 GL/year for a 43-year period is proposed for the Nolans Project. The impact of this extraction is the focus of this study.

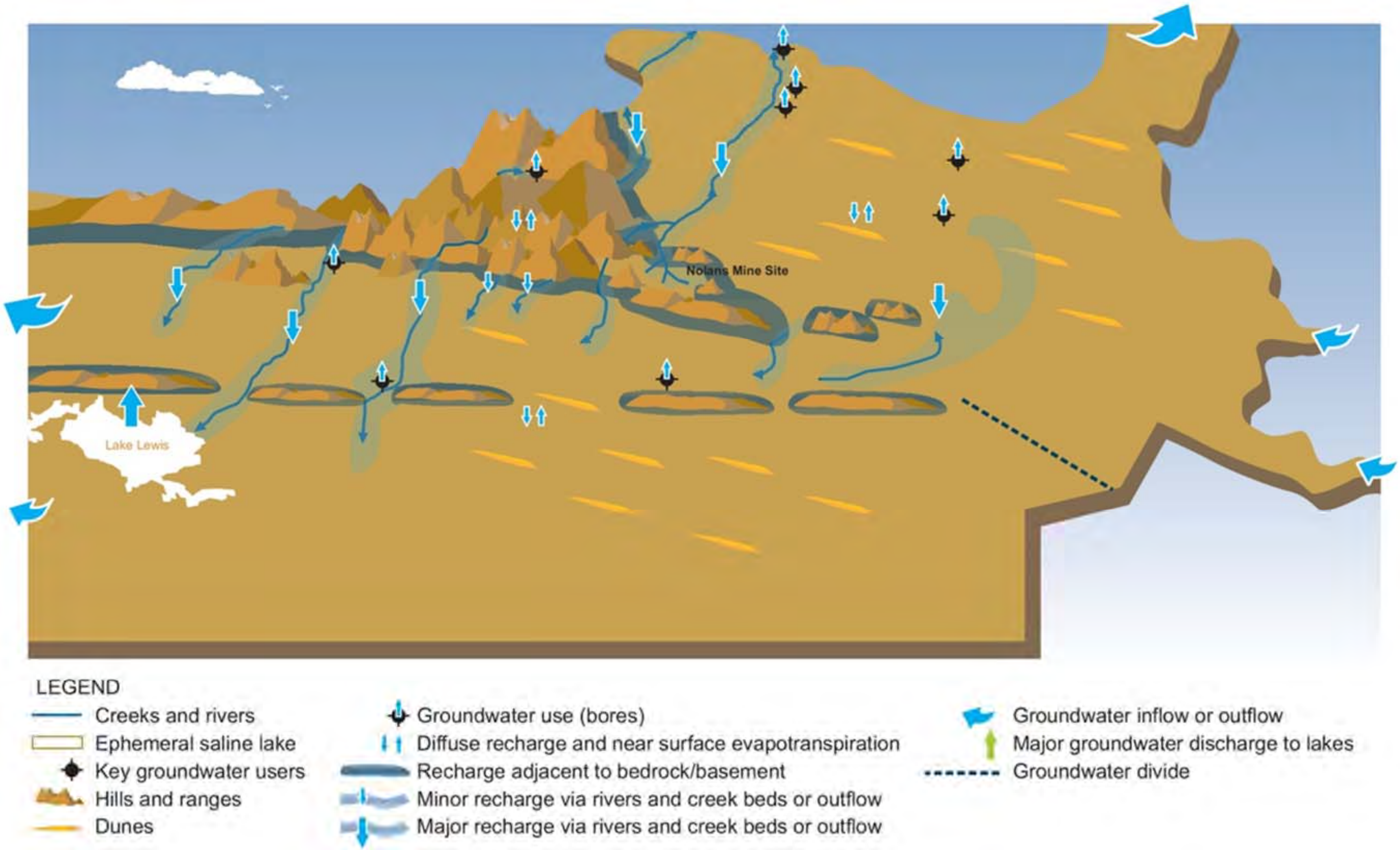


Figure 8-5 Study area conceptual water flows

8.3.8 Groundwater chemistry

A groundwater sampling and analyses dataset consisted of 158 samples from 71 bores (the dataset is summarised in Appendix K). The groundwater chemistry plotted by aquifer type displays a broad spread of water types, but there is a linear trend likely to be resulting from increases in chloride (Cl) content which may be associated with the evolution of groundwater, potentially driven by evaporation.

Groundwater quality (and chemistry) is variable in all units, however the general trend is that alluvial, shallow fluvial, and calcrete aquifers are ‘fresher’ than the Reaphook Palaeochannel aquifer and the upper Ti Tree Basin aquifer, which in turn are ‘fresher’ than basement aquifers. There are exceptions to this, but the general trend for the conceptual model is hypothesised to be that groundwater quality:

- Deteriorates with proximity to basement rocks (due to dissolution associated with weathering) and discharge locations (due to evaporation and subsequent concentration of constituents) and
- Improves marginally with proximity to preferential recharge locations (i.e. the Day Creek and Reaphook Range intersection) and where diffuse recharge is not associated with runoff from basement rocks (i.e. the centres of basins and The Margins area).

8.4 Groundwater modelling

A numerical groundwater model was built to represent the:

- Existing groundwater system (a steady-state numerical groundwater flow model)
- Groundwater system under the influence of the project’s operating conditions (a predictive transient numerical groundwater flow model)
- Groundwater system under closure conditions (a long-term [1,000 year] predictive transient numerical groundwater flow model).

The model is calibrated to groundwater level information and not groundwater flow information. The model relies on boundary conditions and material hydraulic conductivity information based on assumptions and estimations from previous investigations and those made during the field program.

According to the Australian Groundwater Modelling Guidelines, models are suitable for the following key specific uses (refer to Appendix K for more information):

- Predicting long-term impacts of proposed developments in low-value aquifers
- Estimating impacts of low-risk developments
- Understanding groundwater flow processes under various hypothetical conditions
- Provide first-pass estimates of extraction volumes and rates required for mine dewatering
- Developing coarse relationships between groundwater extraction locations and rates and associated impacts.

The model is designed to test two primary stresses (sources of flow in or out of the model) that will be added to groundwater system as a result of the Nolans Project. These are:

- The mine (modelled as drain cells to represent and quantify sump pumping, i.e. flows are outputs from the model)
- The borefield (modelled as well cells to represent bore pumping, i.e. flows are inputs to the model).

Secondary stresses include stock bores, Ti Tree Basin bore pumping for horticultural irrigation, and community bores (Pmara Jutunta, Alyuen and Laramba). These bores are included in the transient model as constant-rate stresses, such that the impacts of the mine and borefield can be isolated from these pre-existing stresses.

Tertiary stresses include recharge and evapotranspiration. Like the bores, recharge and evapotranspiration are included in the transient model as constant-rate stresses, such that the impacts of the mine and borefield can be isolated.

The modelled solution represents a non-unique solution. A different combination of parameters could be applied resulting in an equally valid prediction which could result in impacts with differing magnitudes; however, the modelling does provide a valuable tool capable of quantifying the impacts based on reasonable documented inputs.

Obtaining a temporal dataset (ideally through the deployment of a fleet of water level loggers) and calibrating the transient model to a temporal dataset should be considered the next step in refining the groundwater model.

8.5 Assessment of potential impacts

This section examines the potential impacts the Nolans Project will have on groundwater quality, chemistry and drawdown.

8.5.1 Modelled flows

The groundwater flow regime is predicted to significantly change in the mine area and result in a permanent sink (i.e. perpetually discharging low point) due to evaporation exceeding pit water inflow.

The predicted mine dewatering peaks at 4,000 m^3/day (46 L/s or 1,450 ML/year) and steady-state post-closure inflows at approximately 700 m^3/day (8 L/s or 250 ML/year). The primary source of the water is from the basement rocks and only a minor proportion is from the Ti Tree Basin. In previous assessments, the basement water has not been considered a contribution to the Ti Tree Basin or Southern Basins, however, in reality it is likely to make some minor contribution.

Despite the 8 L/s of long-term modelled pit inflow, there was no significant change in the Ti Tree outflow. The modelled outflow only decreased by 0.03% representing a peak change of 4 m^3/day or 0.05 L/s at the end of the 1,000-year closure modelled period.

Flowthrough of the Ti Tree Basin is unlikely to be impacted at a measureable or observable amount. Flowthrough and availability for evapotranspiration within the Southern Basins is likely to be lower but not by an amount that a material impact is envisaged.

8.5.2 Modelled groundwater elevation and flow directions

The modelled groundwater flow regime displays almost no change (i.e. no impact) at the model (regional) scale when viewed from a flow direction or groundwater head perspective. At this scale, the impacts to flow direction and groundwater head are very localised to the mine area and adjacent to the Southern Basins borefield bores in the Reaphook Palaeochannel area while in operation.

No reversal of groundwater flow direction occurs anywhere within the model area during mining, except for immediately adjacent to the pit and immediately adjacent to the borefield bores (but not across aquifer, i.e. groundwater flow in the borefield aquifers is still westwards despite the pumping).

The modelled area of reversal at the end of the 1,000-year closure period extends within the basement rocks radially from the mine for approximately four kilometres towards the Aileron Station Homestead and Aileron Roadhouse area.

The modelled area of inflow towards the pit is limited to an area with the following average radii measured from the centre of the pit (which itself has an average radius of approximately 0.75 km):

- After 10 years of mining, approximately 1 km
- After 20 years of mining, approximately 1.5 km
- After 30 years of mining, approximately 2 km
- At the end of mining, approximately 2.5 km
- After 100 years of closure, approximately 4 km and
- After 1,000 years of closure, approximately 5 km and extending northwest along the basement rocks.

This demonstrates that the modelled extent of the inflow cone during mining is limited in extent to almost only the area actually disturbed by mining (i.e. much of this area is beneath the waste rock dumps and TSF.

8.5.3 Modelled drawdown at the mine site

The drawdown associated with mine site groundwater extraction is presented visually in Figure 8-6 to Figure 8-10. The modelled groundwater drawdown is very large at the pit site, but is likely to have very steep gradient due the low permeability of the rock mass surrounding the orebody.

Peak pit groundwater inflows of 4,000 m^3/day (46 L/s), equates to approximately 260 m of drawdown in the mine area at the completion of mining. Steady state post closure inflows to the pit of approximately 70 m^3/day (8 L/s), equates to approximately 80 m of drawdown during closure as the water rebounds to a level where groundwater flow equates to evaporation.

Riparian vegetation

Groundwater levels are predicted to be lower within the drawdown cone associated with the open pit, and the riparian vegetation immediately adjacent to the mine area will be directly, and irreversibly, impacted by this, both upstream and downstream in Kerosene Camp Creek.

The impact will likely be the result of groundwater drawdown as described above, but also the complete removal of periodic surface water flow, either directly via creek flow or indirectly during recharge to groundwater, due to the creek diversion works associated with mining operations.

The extent of the impact to riparian vegetation will be greatest immediately adjacent to the pit and decrease radially with distance from the pit. A reasonable estimate for the down gradient extent of this has been made, based on the both the modelled drawdown cone and the point where Kerosene Camp Creek receives additional surface water flow from adjacent catchments (which is likely to in part mask this impact) at the confluence with Nolans Creek. This length of Kerosene Camp Creek beyond the mining area, that is unlikely to capable of maintaining the current riparian vegetation, is less than one kilometre.

At this point the groundwater model predicts a drawdown of two metres during mining but approaches 20 m in the long-term closure model (1,000 years). This impact may, in part, be masked by recharge from continued surface water inflow beyond the confluence of Nolans Creek but this has not been explicitly incorporated into the modelling.

Stock water use

The small aquifer largely confined to the orebody at the mine pit will be almost completely removed during mining operations. Aileron Station water supplies near the pit will be impacted by the proposed mine dewatering and remain impacted beyond mine closure. At other existing bores in basement aquifers and adjacent materials, the drawdown impacts are likely to be minor in the long term but not materially affected by mine drawdown during their anticipated operational life.

At Pine Hill Station, groundwater for stock water in the Kerosene Well area eight kilometres downstream of the mining lease (bores RN010759 and RN012624) is beyond the cone of depression during mining. It is conceivable that these local resources may be impacted due to the pit void limiting flowthrough beyond mine closure; however, groundwater modelling predicts no impact at the Pine Hill Station Homestead and nearby outstation.

Groundwater availability for stock use within the Ti Tree Basin itself is highly unlikely to be measurably impacted. Despite the 8 L/s of long-term modelled pit inflow, there was no significant change in the Ti Tree outflow.

Irrigation for horticulture and viticulture

Groundwater availability for irrigation for horticulture and viticulture within the Ti Tree Basin is highly unlikely to be measurably impacted. The same measure for water availability for stock use has been applied to water availability for irrigation for horticulture within the Ti Tree Basin. The groundwater modelling indicates that, for example, the Ti Tree Farms area is beyond the cone of depression during mining, and beyond any measureable drawdown impact during the 1,000-year closure modelled period.

Drinking and domestic water

Like the above uses, drinking water supplies within the Ti Tree Basin including those at Pmara Jutunta, private farms and station homesteads are not likely to be impacted by drawdown associated with mine dewatering.

There are no drinking water users in the mine area and existing groundwater is not of a quality that drinking water could be a future beneficial use.

It is understood that drinking water for Aileron Station Homestead, Aileron Roadhouse and Alyuen Community is currently sourced from the Southern Basins.

At the location of existing basement bores in the Alyuen Community and the Aileron Station Homestead and Aileron Roadhouse area, that may have previously been used for drinking water, groundwater levels may be impacted in the long term by mine drawdown. It should be noted that these waters are not currently considered to be of a quality to have a beneficial use as drinking water.

8.5.4 Modelled drawdown at the borefield

The Southern Basins borefield is planned to be operated at approximately 13,000 m^3/day (150 L/s or 4,700 ML/year). Modelled drawdown in the water table from the operation of the Southern Basins borefield peaks at approximately six metres the centre of the borefield. The drawdown associated with borefield groundwater extraction is presented visually in Figure 8-6 to Figure 8-10.

The modelled groundwater drawdown is very large in terms of its extent. As such the flow rates should not be considered 'sustainable' in the long term (i.e. indefinitely) as it is unlikely to be replaced by recharge at the same rate as the proposed abstraction rate. However, despite it being unsustainable in the long term, the borefield is considered an appropriate use of the aquifer provided borefield abstraction ceases at the end of mining and processing operations and the aquifer be allowed to recover. The minor current and potential future uses should not be impacted in a material manner, although it is recognised that some drawdown at nearby stock and drinking water sources is likely to occur.

In the vicinity of the Laramba and Napperby groundwater supply area, modelled drawdown from the borefield peaks in the order of 1.3 m and rebounds rapidly once pumping ceases (Appendix K). This drawdown could result in minor incremental increases in pumping costs and minor decreases to yields in existing bores. Groundwater supply bores in such settings are commonly designed and operated with tens of metres of contingency for drawdown (to minimise impacts of drawdown from the operating bore itself) and this is the case at the Laramba groundwater supply area. The modelled drawdown therefore will be very unlikely to have any material impact on the volume of water available to supply Laramba and Napperby at either the actual bores or within the overall aquifer. Even if demand at Laramba and Napperby were to increase substantially, the modelled drawdown would be very unlikely to have any material impact on the water availability from the Laramba and Napperby groundwater supply area, and be very unlikely to be a limiting factor for water supply. In any event, given the setting, it is not the aquifer itself but the number of bores, current yields or size of pipelines (or other infrastructure) that are likely to be limiting factors for supply, to be able to meet potential significant increases in demand.

Riparian vegetation

Modelled drawdown from the borefield peaks in the order of 1.5 m in the vicinity of Day Creek (Appendix K) and rebounds rapidly once pumping ceases.

Water table level observations in an adjacent bore indicate water levels at up to 28 m below ground level. If riparian vegetation is currently dependent on the groundwater at this location, tree roots must be capable of extracting water from greater than 20 m deep, even accounting for the river bank and collar heights. If vegetation is capable of extending its root systems to such depths it is hypothesised that it is reasonable to expect that it could gradually extend its root system a further 1.5 m over the predicted 41-year drawdown period during mining.

There are no planned surface works in the Day Creek catchment that are likely to affect the recharge to either the surficial alluvials or the deeper aquifer material. If the vegetation is reliant on shallower or more temporary sources of water, there is no indication that there are any works proposed (including pumping of the borefield) that would alter these conditions.

Like Day Creek, there are no planned surface works in the Napperby Creek catchment that are likely to affect recharge to the area. However, unlike Day Creek, the modelled drawdown cone does not extend with significant magnitude to the Napperby Creek area during operations, but doubles in magnitude in the approximate 50 years following closure (Appendix K) as the aquifer recovers at the centre and extends laterally. The magnitude however is half that predicted at Day Creek and therefore it is reasonable to assert that even less impact (if any) is expected at Napperby Creek.

Floodout vegetation

In the Southern Basins, there may be minor localised impacts to floodout vegetation and/or soaks due to a decrease in groundwater availability for evapotranspiration. The impact will be determined by the current groundwater dependence and how the difference in availability of groundwater affects floodout vegetation and soaks. Given the scale of distance, the minor drawdowns predicted, the percentage differences in groundwater available and the gradual nature of the predicted changes, it is assumed that this impact will be low.

In the Reaphook Palaeochannel area of the Southern Basins the modelled difference in groundwater available for evapotranspiration peaks at approximately 100 years after closure. This is well after the pumps in the borefield in the modelled scenario have ceased but corresponds with the period the drawdown cone is still expanding laterally but decreasing in its vertical extent at the epicentre. The peak decreases in groundwater availability for evapotranspiration in the Reaphook Palaeochannel area is 12% or 306 m^3/day (3.5 L/s) and this rebounds to approach steady state at a decrease of approximately 1% or 31 m^3/day (0.36 L/s).

Lake Lewis and surrounds

The key indication for impact to Lake Lewis is whether the area is within the modelled drawdown cone but also if modelled net discharges to the area are affected.

The predicted drawdowns are negligible in the Lake Lewis area and not likely to be measureable. Despite this, the groundwater available for evapotranspiration, like in the Reaphook Palaeochannel area to the north, is likely to be impacted in the Lake Lewis area. The peak decreases in groundwater availability for evapotranspiration in the Lake Lewis area of the Southern Basins is 3% or 712 m^3/day (8 L/s) and this rebounds to approach steady state with a decrease of approximately 0.5 % or 103 m^3/day (1 L/s).

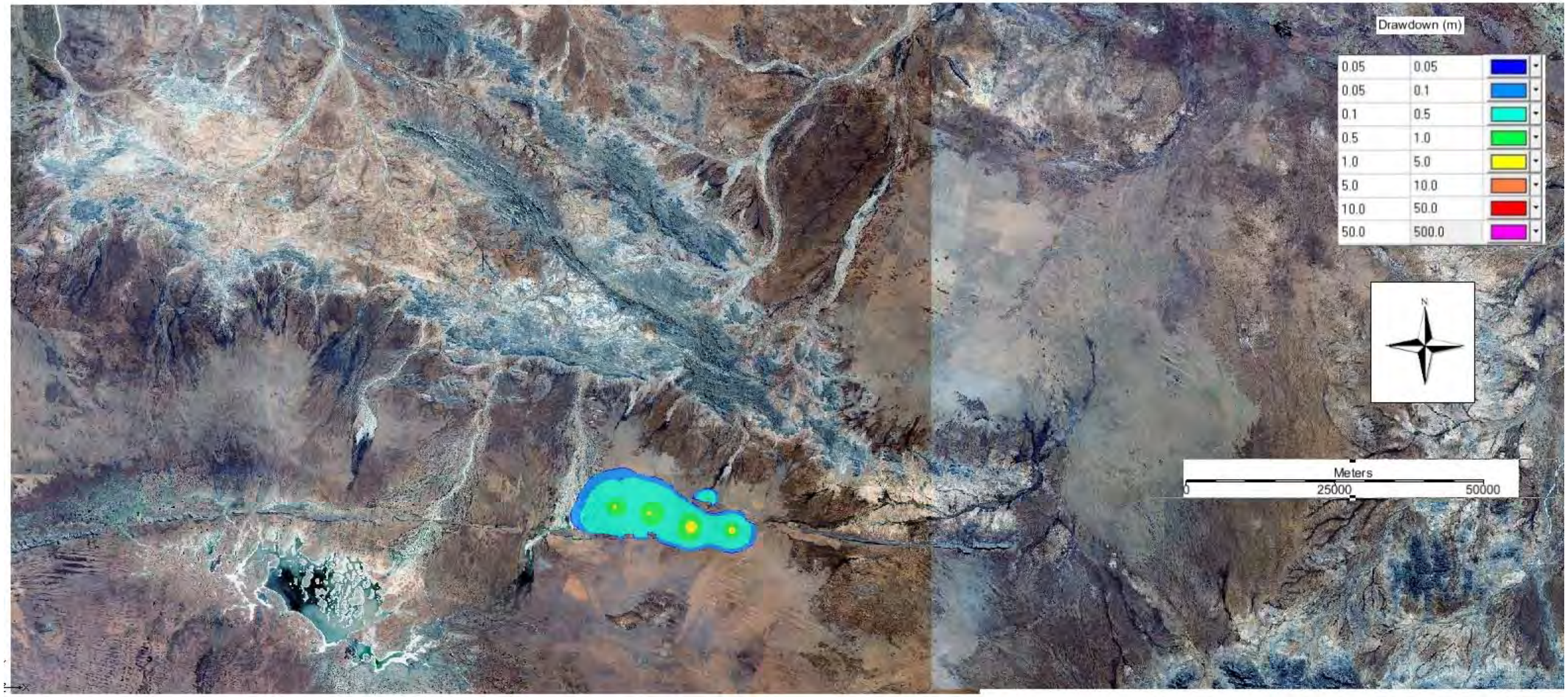


Figure 8-6 Modelled drawdown at commencement of mining 1/1/2020

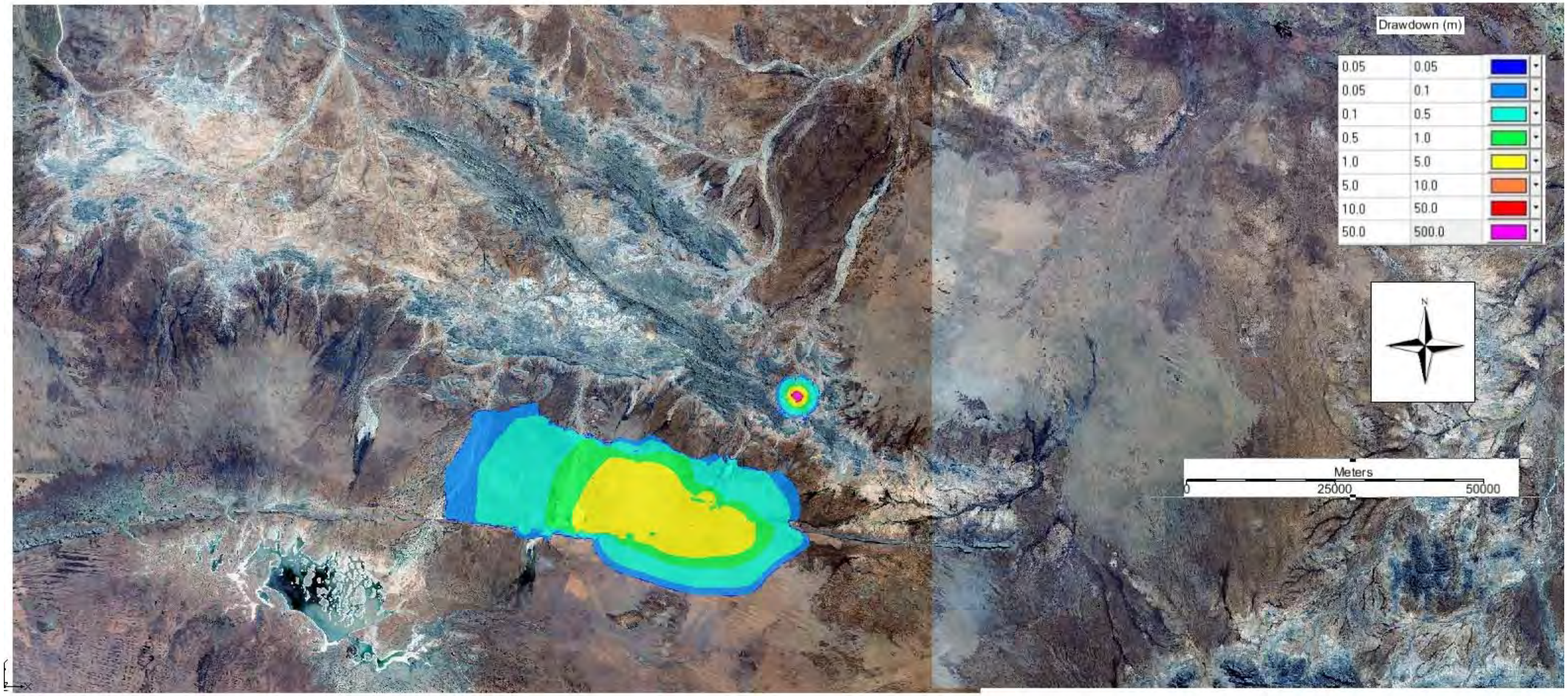


Figure 8-7 Modelled drawdown at approximately mid-way through mining 1/1/2040, 20 years after commencement of mining

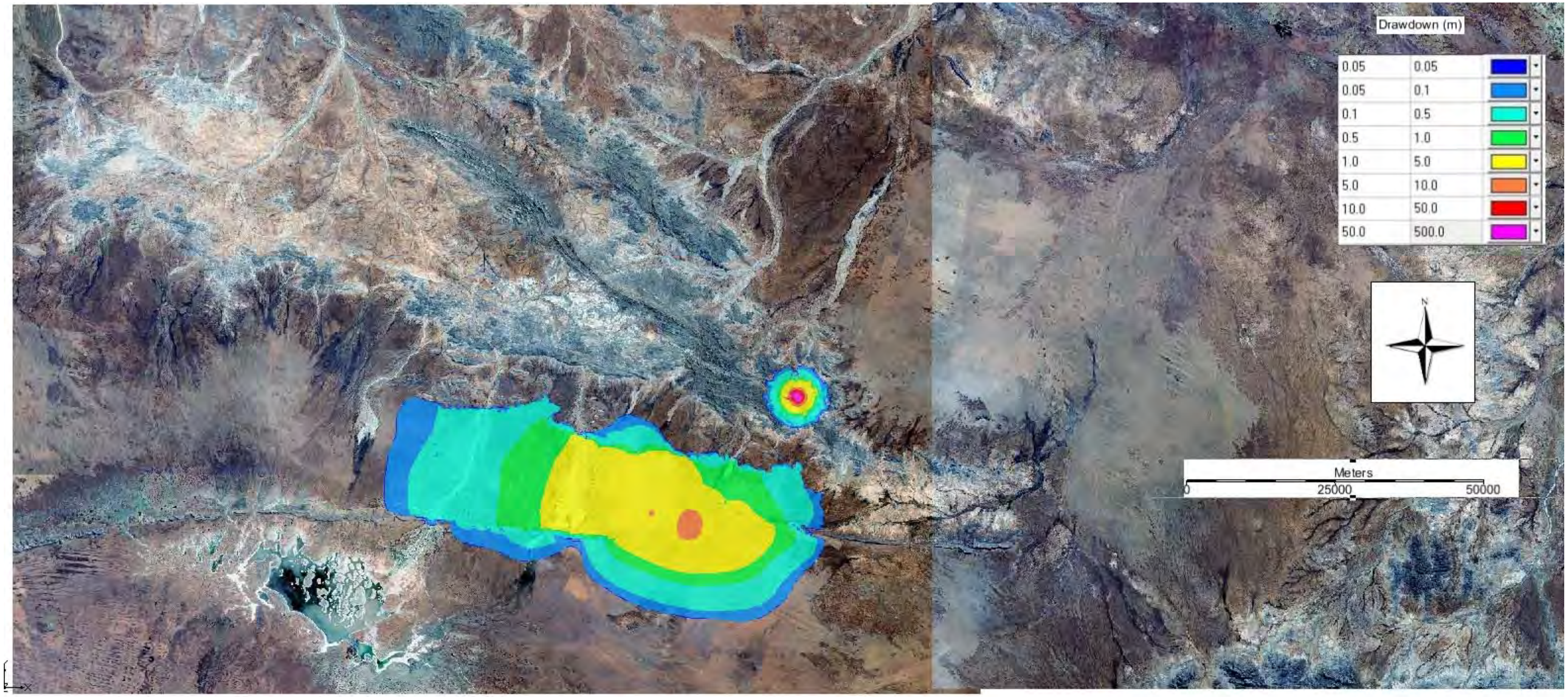


Figure 8-8 Modelled drawdown at end of mining 1/1/2060

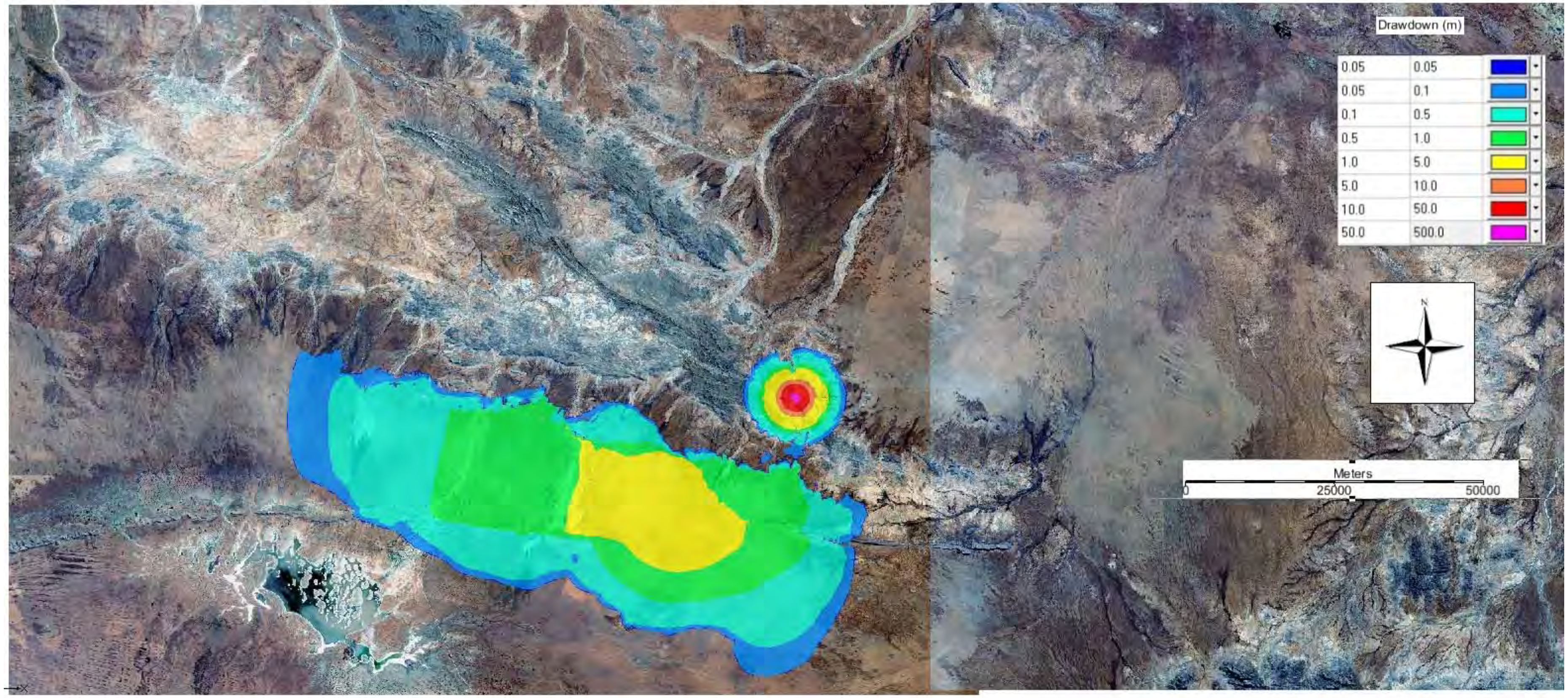


Figure 8-9 Modelled drawdown at 100 years of closure 1/1/2160

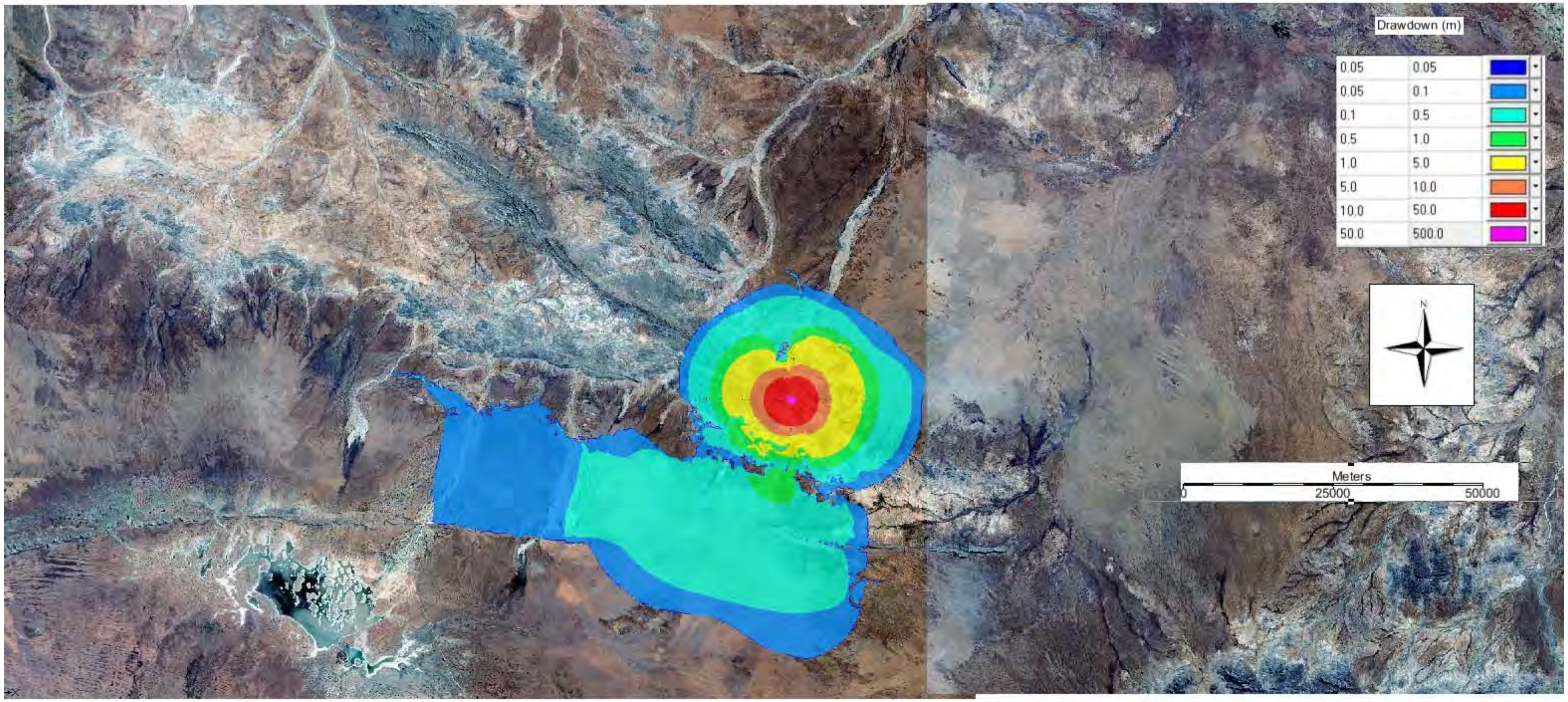


Figure 8-10 Modelled drawdown at 1,000 years of closure 1/1/3060

8.5.5 Groundwater chemistry and quality

The modelled groundwater flow regime displays almost no change (i.e. no impact) at the model (regional) scale when viewed from a flow direction or groundwater head perspective. As such, there is no justification for any speculation of material changes in groundwater chemistry or quality within the aquifer.

Despite this, conceptually there still remains the minor potential for hypothesised impacts based on the following:

- Extraction of groundwater from the Southern Basins could result in more groundwater with lower quality flowing from storage within the basement rocks
- Extraction of groundwater from the Southern Basins could draw fresher water associated with recharge from Day Creek eastwards altering the quality of drinking water available for extraction.

The aquifer under the influence of the proposed Southern Basins borefield pumping regime is likely to be under significantly more dynamic conditions than at present and under such conditions, a more uniform groundwater chemistry may develop.

Mine area

The chemistry of groundwater flowing towards the mining pit is unlikely to be materially different from the existing groundwater chemistry in the area. Once mining ceases, groundwater near the pit will begin the process of rebounding. A pit lake will form and the pit will slowly, partially fill until the water level reaches equilibration where the net evaporation is equal to natural groundwater inflow. This will then result in a process where water quality will slowly deteriorate and over time results in a hypersaline pit lake. Flow will be radially towards the pit lake and thus contribute to the concept of a zero discharge site. The likely chemistry of this pit lake has not been modelled; however, it is highly likely to be of no beneficial use.

In the highly unlikely event that the pit is filled and decants either to the surface water bodies or groundwater system (i.e. the pit lake rises above adjacent groundwater levels to the point where it is no longer behaving as a sink), this contaminated water could discharge. The mine closure design should ensure that all surface water runoff is diverted around and away from the pit so that the pit remains a groundwater sink.

Acid and metalliferous drainage

Characterisation of Nolans waste rock and ore was undertaken for AMD predictions using chemical analysis, XRF and static and kinetic AMD testing. Further details are presented in Appendix L.

A total 154 static AMD tests comprising static net acid generation/net acid producing potential (NAG/NAPP) tests were carried out. Of the 154 samples, 25 samples represented pegmatite, 34 mineralisation, 25 gneiss and 70 schist. Only one sample out of 154 subjected to NAG/NAPP testing was identified as potentially acid forming (PAF). The tests indicated a very low risk of acid generation either during short-term storage of ore, or long-term storage of waste rock. A conservative threshold of 0.15% sulfur was recommended for confirmation NAG testing during operation.

Leachate salinity was low and fluoride was only slightly elevated in one sample but at a concentration consistent with ambient groundwater, hence the risk of generating saline or fluoride-rich leachate is low.

Seepage from ore or waste rock could contain elevated concentrations of some metals (particularly Zn, Al and Cr) and leached samples consistently exceeded ANZECC & ARMCANZ

(2000) Freshwater Aquatic Ecosystems 95% threshold and ambient groundwater concentrations. However, all leachate samples were within ranges acceptable for stock watering, where guidelines are provided in ANZECC & ARMCANZ (2000), including those for uranium and gross alpha and beta radiation, based on the total thorium and uranium content.

It is unlikely that leachate from the waste rock dumps will impact on existing poor quality groundwater or ephemeral surface water quality, when typical dilution factors are considered. Based on the overall chemistry of the waste rock and ore, the risk of acid, metalliferous or saline drainage is low and the material can generally be managed as non-acid-forming.

The AMD Management Plan (Appendix L) provides for separate storage of all potentially acid-forming material, or blending of any potentially acid-forming material with non-acid-forming and acid-consuming material. This management process will ensure that any residual AMD impacts can be minimised.

The AMD assessment shows that with appropriate design and operational control measures (refer section 8.6) the residual AMD risk on site is very low. This residual risk will be monitored to confirm that waste rock dump design and operational controls and management measures are effective.

Processing site, tailings and residue storage facilities

As all storage facilities are designed as zero discharge facilities (i.e. evaporation controlled), they will be designed or managed such that they do not breach or decant either to the surface water bodies or seep into groundwater systems.

A breach or seepage of contaminated water from the processing site is likely to be in direct contact with the Southern Basins aquifer either via the shallow Quaternary material or along the interface between the Quaternary or Cainozoic material and the underlying basement material. Particle travel distances have been calculated based on assumed effective porosity values and key outputs from the model. These calculated particle travel distances are in the order of 100 m in a year or 10 to 20 km over the 1,000-year closure period. If the flow was to be through basement material alone, then particle travel distance is only in the order of hundreds of metres over the 1,000-year closure period. Monitoring bores near the processing site will allow detection of potential contamination and allow mitigation measures to be implemented to limit these potential impacts.

A breach or decant at the TSF would represent a similar outcome, however, depending on the scale, duration and timing, could be self-managed by the down-gradient pit acting as a groundwater sink. Like the processing site, a potential mechanism would be flow in the unsaturated Quaternary material or along the interface with the underlying basement material (i.e. along the Nolans Creek drainage line). These calculated particle travel distances are in the order of 50 m in a year, and as such flow would, within years, leave the site towards the north. In contrast, particle travel distances if flow was only within the basement material were calculated at less than 100 metres of flow outwards over the entire mining and early closure period before turning inward towards and ultimately being captured by the pit. As with the processing site, monitoring bores will be located near the TSF to allow detection of such an event and enable appropriate mitigation / management measures to be implemented.

These facilities will be designed to an appropriate standard and managed. They will be monitored during operation and through closure in order to maintain the long-term security of the tailings, residues and associated liquors.

8.6 Mitigation and monitoring of impacts

Monitoring the impact as well as monitoring to validate the predicted impacts will be required. Mine facilities will have a network of groundwater monitoring bores installed. The bores will be monitored for water levels, water chemistry and water quality as per the Water Management Plan (Appendix X).

In addition, the borefield will be monitored for water levels, water chemistry and water quality. As a minimum existing bores will be included for monitoring of the aquifer during and after the pumping period and for the monitoring of key specific potential impacts as outlined in Table 8-1.

Table 8-1 Proposed Southern Basins borefield monitoring

Location	Aquifer	Monitoring for potential Impact
West of Day Creek	Reaphook Palaeochannel	Day Creek
East of Day Creek	Reaphook Palaeochannel	Day Creek and Laramba/Napperby drinking water supply
Gap between Hann Range and Reaphook Hills	Reaphook Palaeochannel	Drawdown towards the south
South of gap between Hann Range and Reaphook Hills	Reaphook Palaeochannel	Southern extent of drawdown
Centre of Southern Basins borefield	Reaphook Palaeochannel	Epicentre of borefield drawdown
Centre of Southern Basins borefield	Reaphook Palaeochannel	Epicentre of borefield drawdown
Immediately north east of Southern Basins borefield	Reaphook Palaeochannel	Drawdown immediately towards the north east
Immediately east of Southern Basins Borefield	Reaphook Palaeochannel	Drawdown immediately towards the east
North eastern extent of Southern Basins	Alluvials	Drawdown towards the east
North of Southern Basins borefield	Reaphook Palaeochannel	Drawdown towards the north
North of Southern Basins borefield	Basement	Drawdown towards the north
North eastern extent of Southern Basins	Basement	North eastern extent of drawn

Implementation of the following management plans (Appendix X) would occur prior to construction commencing and would include groundwater management and protection:

- Mine Management Plan
- Sediment and Erosion Control Plan
- Water Management Plan including a groundwater monitoring program.

Measures to prevent potential spills from impacting groundwater will include:

- Development and implementation of a hazardous substances management plan

- Provision of self bunded storage for 110 per cent of the largest storage volume, in accordance with Australian Standards
- No underground piping would be included in the proposal design.

The mine pit will include the following features to minimise contamination of water resources:

- Potentially acid forming (PAF) material encapsulation cells within ex-pit waste rock dumps, if PAF is encountered
- Dumps and fill areas profiled to shed and capture runoff
- Clean, dirty and contaminated water drainage systems
- Surface water management basins
- Selective materials handling and placement using mine schedule and geochemical model
- Controlled and managed site drainage and release
- Compaction of construction material and waste rock.

To monitor for potential breaches of the slurry pipeline from the processing plant, the plant would include:

- Notification of disruption to flow to minimise impacts from spill
- Flow meters
- Pressure sensors
- Shift based visual inspections
- Design - spray deflectors on welded joints and
- Periodic visual inspections of pipeline corridors, to occur twice per shift.

To prevent seepage of tailings and residue water containing metals at levels potentially exceeding guideline thresholds the following measures will be considered:

- Selection of appropriate risk category and adherence to relevant design standards for the provision of adequate storage capacity and freeboard allowance
- Provision of a seepage interception and collection system
- Embankment piezometers and survey pins, regular dam inspections
- Adherence to prescribed maximum operating level and retention of freeboard
- Monitoring program for phreatic levels within embankments
- Testing to confirm chemical properties
- Thickener on concentrator to reduce volume of entrained water entering the tailings storage facility
- Supernatant reclaim
- Ongoing AMD sampling and analysis
- Multi-stage neutralisation process (pH control).

Throughout mining, the following hydrogeological studies will be undertaken:

- Ongoing hydrogeological monitoring and analysis ad
- Validation, re-calibration and additional predictive groundwater flow modelling.

Sampling and analysis will be undertaken as detailed in the site procedure in the AMD Management Plan. The results will be used to validate AMD risk and management strategies in subsequent revisions of the document.

Additional testing and monitoring will be undertaken in the pre-production phase. This will include:

- Identification of suitable capping/encapsulation material and testing for dispersion, exchangeable cation, and general capping geotechnical parameters
- Additional laboratory testing
- Column and or barrel leach tests to commence to provide long-term leachate generation information and
- Additional metals to be added to laboratory and field analyses, if required, to cover the range of potentially elevated or mobile metals.