Appendix 11 Risk assessment: Potential Impacts of Groundwater Changes to Groudwater Dependant Ecosystems (GDEs) (GHD, February 2017)

Arafura Resources Limited

Nolans Project - EIS Supplement

Risk assessment: potential impacts of groundwater changes to Groundwater Dependent Ecosystems (GDEs)

February 2017

Executive summary

GHD has been engaged by Arafura Resources Limited (Arafura) to complete an assessment of the potential impacts of the proposed Nolans Rare Earths mine in central Australia, on Groundwater Dependent Ecosystems (GDEs).

Groundwater extraction is proposed to occur from the Nolans Mine Site for mine pit dewatering and within the Southern Basins borefield for process and potable water. In addition to active pit dewatering during mining, passive dewatering during groundwater rebound (the period following pumping) and ongoing dewatering via evaporation were considered.

This has been assessed based on data from flora, fauna and groundwater studies of the area (GHD 2016a, GHD 2016b, GHD 2016c), and mapping of vegetation types to determine the area of individual vegetation types potentially impacted under different groundwater drawdown scenarios (Desert Wildlife Services 2016), following groundwater extraction at the site. Groundwater extraction is proposed to occur from the Nolans Mine Site for pit dewatering (within the Ti-Tree Water Control District) and within the Southern Basins (borefield) for process and potable water.

This assessment uses the existing hydrogeological (groundwater) study for the Nolans Project Environmental Impact Statement (EIS) (GHD 2016a), and specifically, makes use of the groundwater drawdown models. This report covers the Nolans mine site, processing site and borefield with the major emphasis on assessment the impacts of groundwater extraction from the borefield during operation, but also incorporating the cumulative effects of extraction of groundwater from the mine site both during operation and beyond closure.

As no formal risk assessment process for GDEs exists for the Northern Territory, it was decided that the most appropriate method for determining the potential impacts of groundwater changes to GDEs of the Nolans Project area was to follow the risk assessment guidelines for groundwater dependent ecosystems developed by NSW Office of Water (Serov et al. 2012). The NSW Office of Water *risk assessment guidelines for groundwater dependent ecosystems* was chosen as this was seen as the most comprehensive, systematic, current and relevant method to assess the effects of changes to groundwater on GDEs.

The main steps of the ecological valuation and risk assessment process are to:

1. Identify the type and location of GDEs;
2. Infer or determine groundwater dependency;
3. Identify High Ecological Value Assets of aquifer;
4. Determine ecological value of GDEs and the associated aquifer;
5. Determine the impact of an activity to identified GDEs;
6. Determine the magnitude of the risk to identified GDEs;
7. Apply the GDE Risk Matrix; and
8. Determine appropriate management actions.

The risk assessment result is: **Moderate Value / Moderate to High Risk**. Further information and monitoring is required to confirm the risk level.

Groundwater drawdown within the borefield area will create a situation in which some vegetation communities are likely to need to adjust to changes in soil moisture availability in the soil profile. It is difficult to predict whether these changes would impact tree condition with the limited data available. Impacts in the short-term may be expected, particularly if pumping occurs in drought years when trees are more heavily reliant on groundwater as their water source, during which time ability of trees to access water may decrease and may result in a decline in tree condition. Such impacts may be short-term, if trees can respond and grow roots further into the soil profile to access water deeper in the soil profile. Trees closer to creek and river lines may be less affected than trees which are further away.

Given that there is uncertainty on potential impacts on tree condition, we recommend that a monitoring program is established. Following the risk matrix (Serov et al. 2012), the following management actions are recommended for high value/moderate risk proposal sites:

Short term

- Protection measures, ideally for aquifer and GDEs, but also targeted at hotspots;
- Baseline risk monitoring. Mitigation action.

Mid term

- Protection measures, ideally for aquifer and GDEs, but also targeted at hotspots;
- Monitoring and periodic assessment of mitigation.

Long term

- Adaptive management. Continue monitoring.

Monitoring should include monitoring of water table levels, water table quality and tree condition. Tree condition monitoring should occur in patches of living River Red Gum, Ghost Gum, Bean Tree, Desert Bloodwood and Coolabah, in areas where the groundwater is predicted to drop following borefield pumping. In addition, monitoring points should be established at control sites that are not expected to be affected by groundwater drawdown.

This report is subject to, and must be read in conjunction with, the limitations set out in sections 1.1, 1.2 and 1.3 and the assumptions and qualifications contained throughout the Report.

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Appendix A – Types of GDEs

1. Introduction

GHD has been engaged by Arafura Resources Limited (Arafura) to complete an assessment of the potential impacts of the proposed Nolans Rare Earths mine in central Australia, on Groundwater Dependent Ecosystems (GDEs). This has been assessed based on data from flora, fauna and groundwater studies of the area (GHD 2016a, GHD 2016b, GHD 2016c), and mapping of vegetation types to determine the area of individual vegetation types potentially impacted under different groundwater drawdown scenarios (Desert Wildlife Services 2016), following groundwater extraction at the site. Groundwater extraction is proposed to occur from the Nolans Mine Site for pit dewatering (within the Ti-Tree Water Control District) and within the Southern Basins (borefield) for process and potable water.

1.1 Purpose of this report

This report has not been prepared as a stand-alone document. The purpose of this document is to provide content to be included within an EIS supplement for the Nolans project.

This report presents a risk assessment, undertaken to determine the potential impacts of groundwater changes to GDEs of the Nolans Project area following the risk assessment guidelines for groundwater dependent ecosystems developed by NSW Office of Water (Serov et al. 2012). The NSW Office of Water risk assessment guidelines for groundwater dependent ecosystems was chosen as this was seen as the most comprehensive, systematic, current and relevant method to assess the effects of changes to groundwater on GDEs.

This assessment uses the existing hydrogeological (groundwater) study for the Nolans Project Environmental Impact Statement (EIS) (GHD 2016a), and specifically, makes use of the groundwater drawdown models. This report covers the Nolans mine site, processing site and borefield with the major emphasis on assessment the impacts of groundwater extraction from the borefield during operation, but also incorporating the cumulative effects of extraction of groundwater from the mine site both during operation and beyond closure.

1.2 Limitations Statement

This report: has been prepared by GHD for Arafura Resources Limited (Arafura) and may only be used and relied on by Arafura for the purpose agreed between GHD and Arafura as set out in section 1.3 and within this report.

GHD otherwise disclaims responsibility to any person other than Arafura arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

1.3 Data limitations

The Nolans Project is located within the Burt Plains bioregion, a data-limited region with regard to data availability related to GDEs. The majority of the datasets available are broad scale, and therefore the information provides a baseline assessment only. It must be recognised that the limitations of the data affect the level of certainty of the presence or absence of GDEs, and conclusions should be reassessed if further data becomes available.

The desktop assessment for the study area uses data from the Atlas of Groundwater Dependent Ecosystems managed by the Australian Government Bureau of Meteorology.

1.4 Definitions

For the purposes of this assessment, the following definitions are employed:

Study site – refers to the mine site, processing site, accommodation village, access roads, potable water pipeline, water supply pipeline, and borefields area as shown in Figure 1.1.

Study area – the area within a 20 km radius of the Study Site.

1.5 Location

The Nolans Project Study Site is located approximately 135 km north-west of Alice Springs, Northern Territory (NT), approximately 10 km west of the Stuart Highway and 65 km from the Darwin-Adelaide railway. The predominant land use in the area is cattle grazing on pastoral tenure, with stocking rates tending to vary according to rainfall patterns.

1.6 The study site

The Study site is situated in central Northern Territory within the Burt Plain bioregion. It is located on the Aileron and Napperby pastoral stations. These stations have been used for grazing since the early 1880's. The Study area contains a wide variety of landforms including rocky outcrops consisting of granitic orthogneiss and granite, alluvial plains and fans and drainage channels (watercourses). The outcrops extend up to 150 m from the surrounding plain.

The proposed borefield area consists of gently undulating sandplains with limited surface drainage. Dominant vegetation types within the Study area include Acacia shrublands, hummock grasslands, and grassy eucalypt woodlands.

Groundwater extraction is proposed to occur from the Nolans Mine Site for pit dewatering and within the Southern Basins borefield for process and potable water. In addition to active pit dewatering during mining, passive dewatering during groundwater rebound (the period following pumping) and ongoing dewatering via evaporation were considered.

An assessment of groundwater (GHD 2016a) as part of the projects EIS made a limited consideration of environmental users of water (not necessarily groundwater) in the study area including 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 below the reach of most vegetation (i.e. greater than 15m) (GHD 2016a).

Riparian vegetation

Riparian vegetation is dominated by River Red Gums (*Eucalyptus camaldulensis* subsp. *arida*) and Bean Trees (*Erythrina vespertilio*), which line the larger creeks and rivers in the study area. These larger creeks and rivers with river red gums dominated riparian vegetation include, but may not be limited to, Napperby Creek, Day Creek and Woodforde River (Figure 1). It is conceivable that such riparian vegetation could tap groundwater (potentially even at depths greater than 15 m (GHD 2016a)) and therefore these areas are potential groundwater dependant ecosystems (GDEs), and are considered in this impact assessment. River red gums, for example, tap surface water and either the main water table or elevated and perched groundwater associated with the creek and river channels flowing through the sub-surface.

Floodout vegetation and open woodlands

In addition to riparian vegetation, groundwater may be important for vegetation in floodout areas at the toe of hills and ranges where runoff is highest, and potentially also to some trees in areas of open woodland which dominate much of the broader study area. Bloodwood (*Corymbia opaca*), Coolabah (*Eucalyptus coolabah* subsp. *arida*) and Bean Trees (*Erythrina vespertilio*), are known facultative phreatophytic species (O' grady, et al., 2009; O' grady, et al., 2006; Loomes, 2010), trees which are deep rooted plant species that tap into groundwater, via the capillary fringe, to satisfy at least some portion of their environmental water requirement, but will also inhabit areas where their water requirements can be met by soil moisture reserves alone (Pritchard, et al., 2010). That is, the species will be groundwater dependent in some environments, but not in others

Groundwater extraction

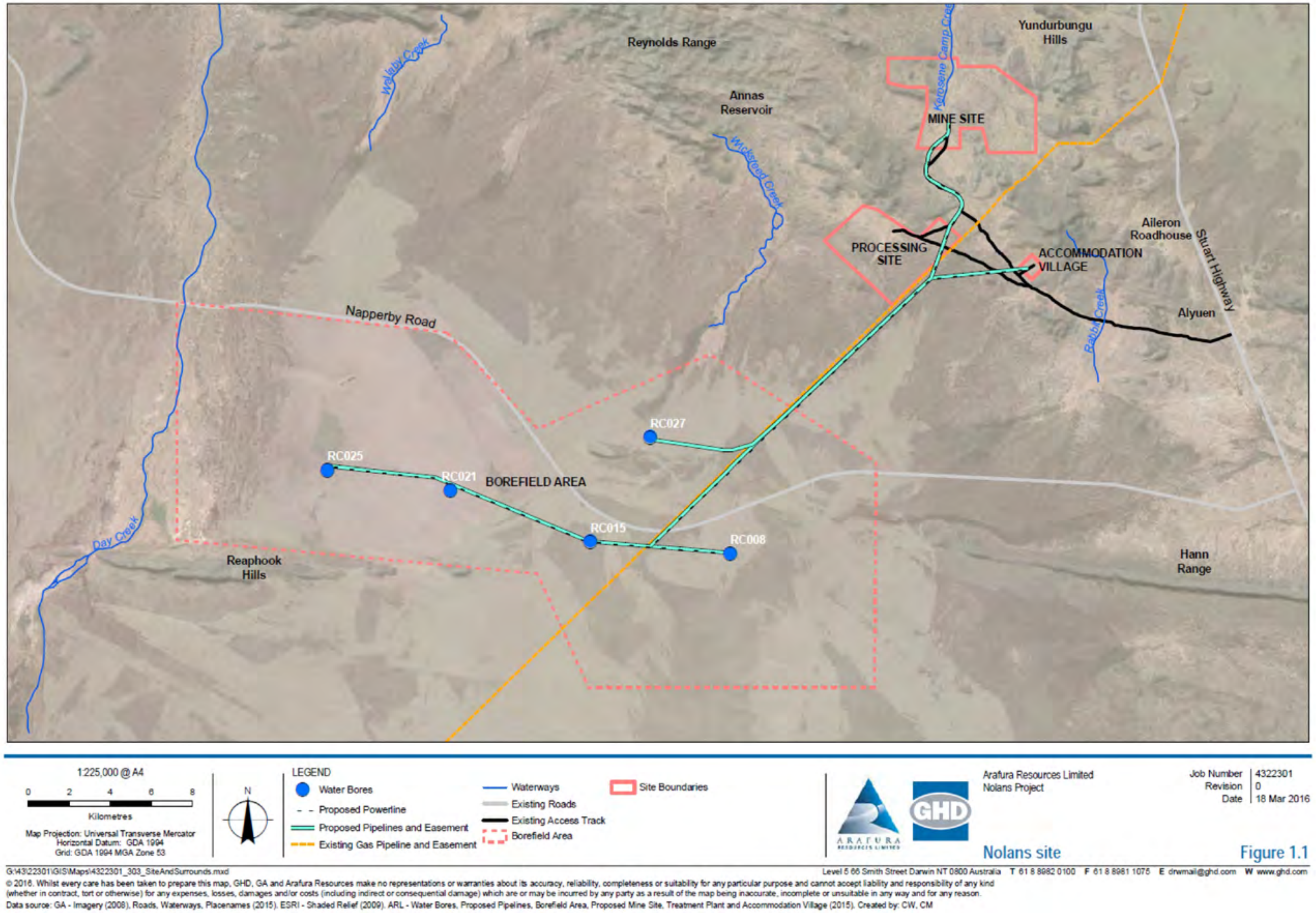
Groundwater is extracted from the Ti-Tree Basin for irrigation, stock and domestic purposes. Elsewhere in the study area, localised small-scale groundwater extraction occurs for stock and domestic purposes. An additional groundwater extraction of 4.5 GL/year for a 43-year period is proposed for the Nolans Project. The impact of this extraction is the focus of the remainder of this study.

Palaeochannels

Palaeovalley alluvial sediments - Palaeovalley alluvials and palaeochannels represent remnants of river channels that are associated with prehistoric drainage basins. They are typically composed of unconsolidated material including fine to course grains sediments. Palaeovalley aquifers are limited by their shallow depth (typically < 50m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of a palaeovalley (from Serov et al 2012).

The previous groundwater study (GHD 2016a) identified a significant palaeochannel (the Reaphook Palaeochannel), across which much of the southern borefield is located (Figure 1 in GHD 2016a). Palaeochannel (also known as a palaaeovalley) alluvial aquifers represent remnants of river channels that are associated with prehistoric drainage basins. Although surface water no longer flows in most palaeochannels, the sediment which has filled these old river channels still retain recharge and storage capacity. These aquifers are capable of storing significant quantities of groundwater which can support a variety of GDEs. Palaeochannel aquifers are typically limited by their shallow depth (mostly <50m) and narrow width, but can extend for great distances longitudinally down-valley (typically tens to hundreds of kilometres), with good aquifer connectivity along the length of the palaeochannel. However the Reaphook Palaeochannel of the Nolans Project study area was found to be highly irregular and up to hundreds of meters deep below the current surface level (GHD 2016a).

Figure 1 Map of Nolans Project study site.



1.7 Groundwater Dependent Ecosystems (GDEs)

Groundwater Dependent Ecosystems (GDEs), also known as Groundwater Sensitive Ecosystems (GSE) are ecosystems that require access to groundwater to meet all or some of their water requirements so as to maintain the communities of plants and animals, ecological processes they support, and ecosystem services they provide (Richardson, et al., 2011). Groundwater supply to ecosystems in particularly important in arid and semi –arid regions due to low precipitation rates, high evaporation rates resulting in scarce supplies of surface water (Eamus, et al., 2006).

GDEs can be divided in three distinct classes (Eamus, et al., 2006; Richardson, et al., 2011):

Type 1: Aquifer and cave ecosystems- "These ecosystems typically include karst aquifer systems fractured rock and saturated (consolidated and unconsolidated) sedimentary environments. The hyporheic zones of rivers, floodplains and coastal environments are also included in Type 1. The deep subsurface groundwater environment provides relatively stable, lightless environmental conditions with restricted inputs of energy and low productivity which allows a particular suite of subsurface ecosystems to prosper. The ecological diversity is created from variable geology, oxygen, carbon and nutrient gradients (linked to the dynamics of water flow) and physico-chemical conditions. Subsurface ecosystems provide an important supporting service of bioremediation of contaminated groundwater, and provide an important role in carbon and nutrient cycling" (Richardson, et al., 2011).

Type 2: Ecosystems dependent on the surface expression of groundwater- These "include wetlands, lakes, seeps, springs, river baseflow, coastal areas and estuaries that constitute brackish water and marine ecosystems. In these cases, the groundwater extends above the earth surface, as a visible expression. Examples include the mound springs of the Great Artesian Basin), and wetlands in the south-eastern part of South Australia. In these situations, groundwater provides water to support aquatic biodiversity by providing access to habitat (especially when surface runoff is low) and regulation of water chemistry and temperature' (Richardson, et al., 2011).

Type 3: Ecosystems dependent on subsurface presence of groundwater- (via the capillary fringe) include terrestrial vegetation that depends on groundwater fully or on a seasonal or episodic basis in order to prevent water stress and generally avoid adverse impacts to their condition. In these cases, and unlike the situation with Type 2 systems, groundwater is not visible from the earth surface. These types of ecosystem can exist wherever the watertable is within the root zone of the plants, either permanently or episodically.

A sub-class of Type 3 GDEs includes **facultative GDEs**, which require groundwater in some locations but not in others, particularly where an alternative source of water can be accessed to maintain ecological function (Clifton et al, 2007; O'Grady et al, 2007). Dependence on groundwater for facultative GDEs can range from opportunistic to being highly dependent. Ecosystems with a proportional dependence on groundwater do not generally exhibit the threshold type response of the more dependent ecosystems. As a change occurs in a groundwater attribute; e.g. level, a proportional response generally occurs within the ecosystem, (Hatton and Evans, 1998). Opportunistic dependency occurs when ecosystems use groundwater as required. For example, this may occur when surface water / soil moisture is unavailable, such as at the end of a dry period. Minor changes to the groundwater regime may not have any adverse impacts but these ecosystems can die if a lack of access to groundwater is prolonged. It is however difficult to distinguish between proportional and opportunistic dependency.

1.8 Potential impacts of groundwater changes to Groundwater Dependent Ecosystems (GDEs)

It is a basic tenet of ecology that ecosystems will generally use resources in proportion to their availability. It is therefore assumed that if groundwater can be accessed, ecosystems will generally develop some degree of dependence and that dependence will likely increase with increasing aridity (Hatton and Evans, 1998).

For many communities, depth to groundwater is an important parameter controlling the availability of groundwater to a plant (Hatton and Evans 1998; Eamus et al, 2006; Froend and Loomes, 2006). Groundwater dependent communities require that groundwater levels be episodically or periodically within their root zone for use when soil water availability is low so as to satisfy demands for water and nutrients (Hattermann et al, 2008; Groom et al, 2000). Information on root depth and morphology can therefore be used to determine dependency. However, little is known about the rooting depths of plants and reliance on groundwater when surface water is unavailable.

The groundwater dependence of many ecosystems can be inferred from their position in the landscape, their response to altered water regimes and the occurrence of vegetation or species associated with shallow groundwater (Froend et al, 2004). The groundwater dependency of many ecosystems is self-evident; e.g. cave and aquifer ecosystems, base flow dependent ecosystem. Groundwater dependency of wetlands and terrestrial vegetation can be inferred through the impact of altered water regimes on the distribution and composition of species. The importance of groundwater on more xeric or opportunistic species, such as the semi-arid areas of this study area, may be more difficult to infer.

Before undertaking a risk assessment, it is important to consider the impact of existing disturbances on the ecosystems being assessed. For example, in assessing the risk of extraction from new licences, it is important to consider the impact of current licences, if any. This was included in the groundwater study (GHD 2016a), which considered groundwater extraction for a number of communities, station homesteads, livestock water points and agricultural irrigation projects.

To determine the significance of a change, the existing values and disturbance tolerances of the ecosystem being affected must be understood. This includes the dispersal capabilities and opportunities of the associated biota. The level of anticipated impact is a comparison of the degree of change relative to the ecological values being affected. In ecosystems that are totally dependent on groundwater and which have limited dispersal capabilities are disturbance intolerant and more sensitive to change.

In ecosystems that only rely on groundwater during extreme climatic conditions (i.e. droughts) such as terrestrial vegetation communities, there may have to be a large change to warrant a response or the response may have a significant time lag from the disturbance event. Different elements of an ecosystem will have different reaction times and responses to a particular impact.

The reliance of central Australian vegetation on groundwater is poorly known. Vegetation that may be most likely to be reliant on groundwater are River Red Gum, Coolabah, Bloodwood and Bean Tree (O'Grady et al. 2009; Santini et al. 2016). Ghost gums may also possibly access groundwater resources, but this has not been examined in central Australia. Tree height and tree basal area are considered good indicators of available water resources for tree growth (Zolfhager 2013).

1.9 Proposed lowering of water table

A hydrological assessment that has been completed for the Project considers the impacts of the proposed groundwater extraction (GHD 2016a). Groundwater extraction is proposed to occur from the Nolans Mine Site for pit dewatering (within the Ti-Tree Water Control District) and within the Southern Basins (borefield) for process and potable water.

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 of pit water. Drawdowns are expected to be very large at the pit site, reflective of pit levels during operation (i.e. as deep as 390 mAHD which equates to approximately 260 m of drawdown at the completion of mining), and then reflective of the pit lake levels (modelled levels at 575 mAHD which equates to approximately 80 m of drawdown) during closure as the water rebounds to a level where groundwater flow equates to evaporation.

1.10 Operational impacts

The Nolans Project involves the clearing of vegetation, which has been considered in the EIS, with a focus on impacts to flora and fauna values. The operational impact considered here is from the taking of groundwater. Groundwater within the study site is typically greater than 15 m below the ground surface, considered to be below the reach of most vegetation, although groundwater levels are known to be shallow in isolated areas across the study area (GHD 2016a).

The propose borefield is expected to source about 12.87 ML/day of groundwater (GHD 2016a) from the Southern Basins aquifer. Modelling of the groundwater drawdown associated with mine and borefield groundwater extraction were completed for five key times:

- Commencement of mining 1/1/2020 (Figure 2 (Figure 30 in GHD 2016a));
- Approximately mid-way through mining 1/1/2040 (Figure 3 (Figure 31 in GHD 2016a));
- End of mining 1/1/2060 (Figure 4 (Figure 32 in GHD 2016a));
- 100 years of closure 1/1/2160 (Figure 5 (Figure 33 in GHD 2016a)); and
- 1,000-years of closure 1/1/3060 (Figure 6 (Figure 34 in GHD 2016a)).

These models indicate that across the borefield area a maximum groundwater drawdown of 5 to 10 metres will occur at the end of mining (Figure 4), over a very small area of the central borefield, with larger areas experiencing a drawdown of 1 to 5 metres and 0.5 to 1 metres within this same timeframe. The surrounding area is projected to experience a drawdown of less than 0.5 metres, which is unlikely to significantly impact terrestrial GDEs in this area. Modelling of the groundwater drawdown following closure of the mine show groundwater levels rebounding slowly (Figure 5 and Figure 6).

These models also show a long term maximum groundwater drawdown in the area surrounding the mine pit of 10 to 50 metres (and up to 260 metres immediately adjacent to the pit) will occur following closure of the mine Figure 6. Acting as a permanent sink, the pit is predicted to significantly change the groundwater flow regime in this area (GHD 2016a). Groundwater is modelled to draw down by one to five metres up to 15 km from the centre of the mine pit, potentially impacting GDEs across this area.

1.10.1 Southern Basins borefield

Modelled drawdown in the water table from the operation of the Southern Basins borefield peaks at approximately 6 m (Figure 46 in GHD 2016a) in the centre of the borefield. This excludes actual drawdowns within the operating bores which is more likely to be a coupled function of bore efficiency as well as aquifer drawdown. The drawdown-rebound is a typical log-linear response to aquifer pumping and recovery. Further away the response varies (as expected) and results in a far slower response to recovery (i.e. Figure 47 and Figure 48 in GHD 2016a). This is a function of the aquifer size, material properties and the limited modelled recharge applied.

1.10.2 Day Creek

Modelled drawdown from the borefield peaks in the order of 1.5 m in the vicinity of Day Creek (Figure 47 in GHD 2016a) and rebounds rapidly once pumping ceases. If vegetation is currently dependent on the groundwater at these locations, based on watertable level observations (of approximately 28 m below top of collar) in the adjacent bore SB0026 (RC00026 RN19038), tree roots must be capable of extracting water from greater than 20 m deep, which is considered unlikely, even accounting for the river bank and collar heights. Watertable depths greater than 20m are unlikely to support riparian woodland vegetation given tree response to water table depth elsewhere including in the adjacent Ti Tree basin. It seems more likely that trees along Day Creek are utilising water from a perched water supply in recent alluvial material of the creek channel, especially given the lack of tree species known to utilise groundwater away from the creek channel and immediate banks (except near the Reaphook Hills) 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 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.

1.10.3 Napperby Creek

Like Day Creek, there are no planned surface works in the Napperby Creek catchment that are likely to affect the recharge to the area. However unlike Day Creek, the modelled drawdown cone does not extend with significant magnitude to the Napperby Creek area during mining operations, but doubles in magnitude in the approximately 50 years following closure (Figure 48 in GHD 2016a) as the aquifer recovers at the centre and extends laterally. The magnitude is half that predicted at Day Creek but the duration to reach it is twice as long, therefore it is reasonable to assert that even less impact (if any) is expected at Napperby Creek.

1.10.4 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 expected that this impact will be negligible.

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 m3/day (3.5 L/s) and this rebounds to approach steady state at a decrease of approximately 1% or 31 m3/day (0.35 L/s) (GHD 2016a).

1.10.5 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 m3/day (8 L/s) and this rebounds to approach steady state with a decrease of approximately 0.5 % or 103 m3/day (1 L/s) (GHD 2016a).

1.10.6 Rock-holes

There are no conceivable impacts to water bodies in basement rock-holes along drainage lines or in depressions in the outcropping rock mass because they are perched in the bedrock watertable and there is no conceivable change to bedrock permeability associated with the proposed activities (GHD 2016a).

1.10.7 Groundwater flow and quality

The modelled groundwater flow regime displays almost no change (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.

As all storage facilities are designed as zero discharge facilities (i.e. evaporation controlled), they should be designed or managed such that they do not breach or decant either to the surface water bodies or groundwater system. As such, their design and management should ensure that the water balance can demonstrate that they will remain evaporating controlled events far greater than any probable maximum flood. Likewise, their design and management should ensure zero discharge occurs via leakage.

Figure 2 Modelled drawdown at commencement of mining 1/1/2020 (Figure 30 in GHD 2016a)

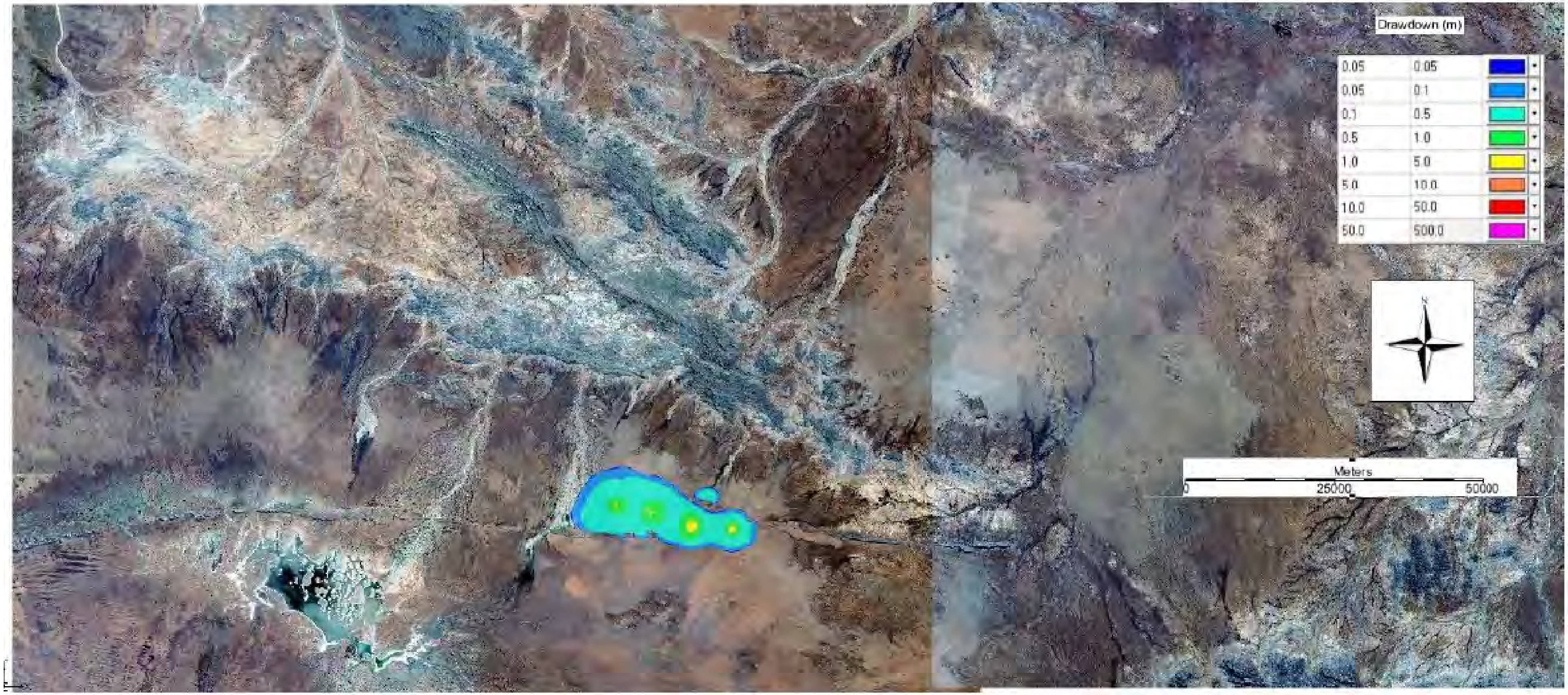


Figure 3 Modelled drawdown at approximately mid-way through mining 1/1/2040 (Figure 31 in GHD 2016a)

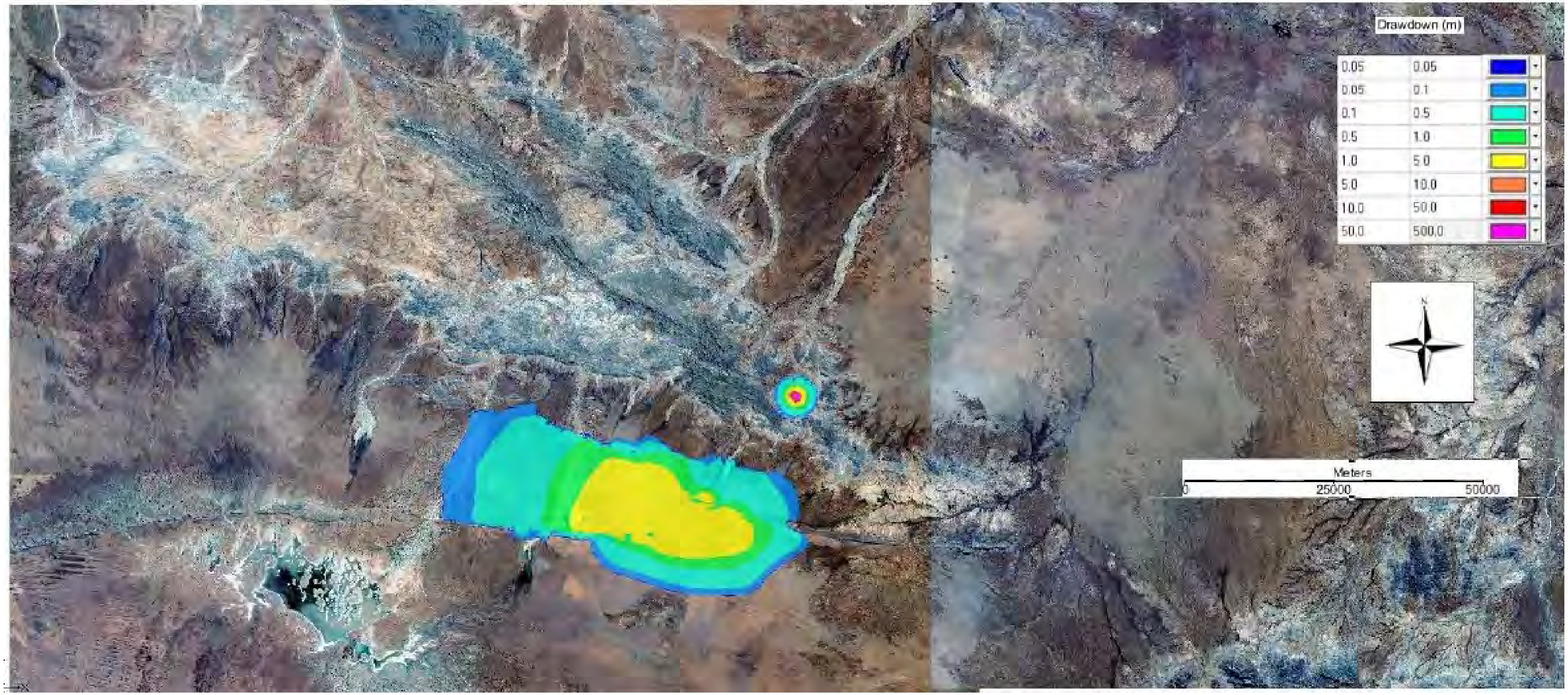


Figure 4 Modelled drawdown at end of mining 1/1/2060 (Figure 32 in GHD 2016a)

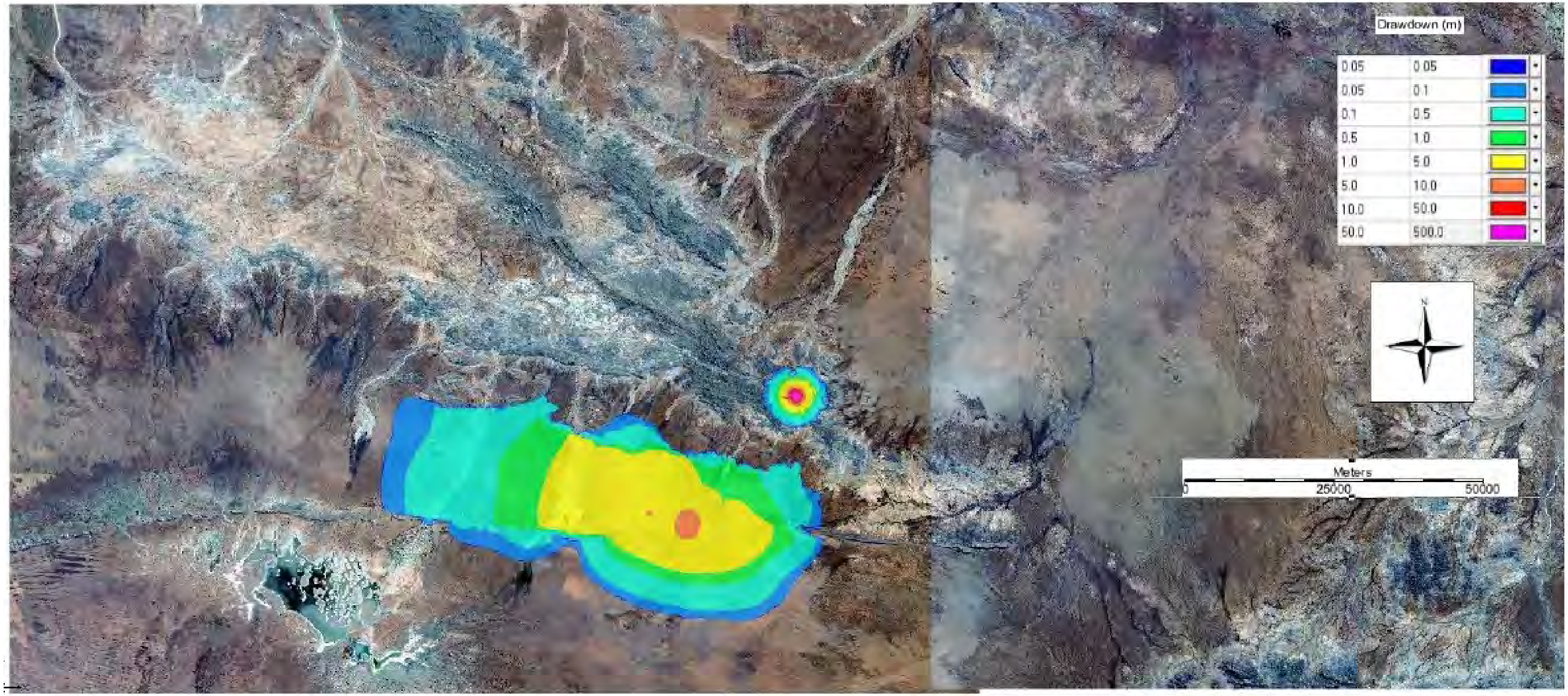


Figure 5 Modelled drawdown at 100 years of closure 1/1/2160 (Figure 33 in GHD 2016a)

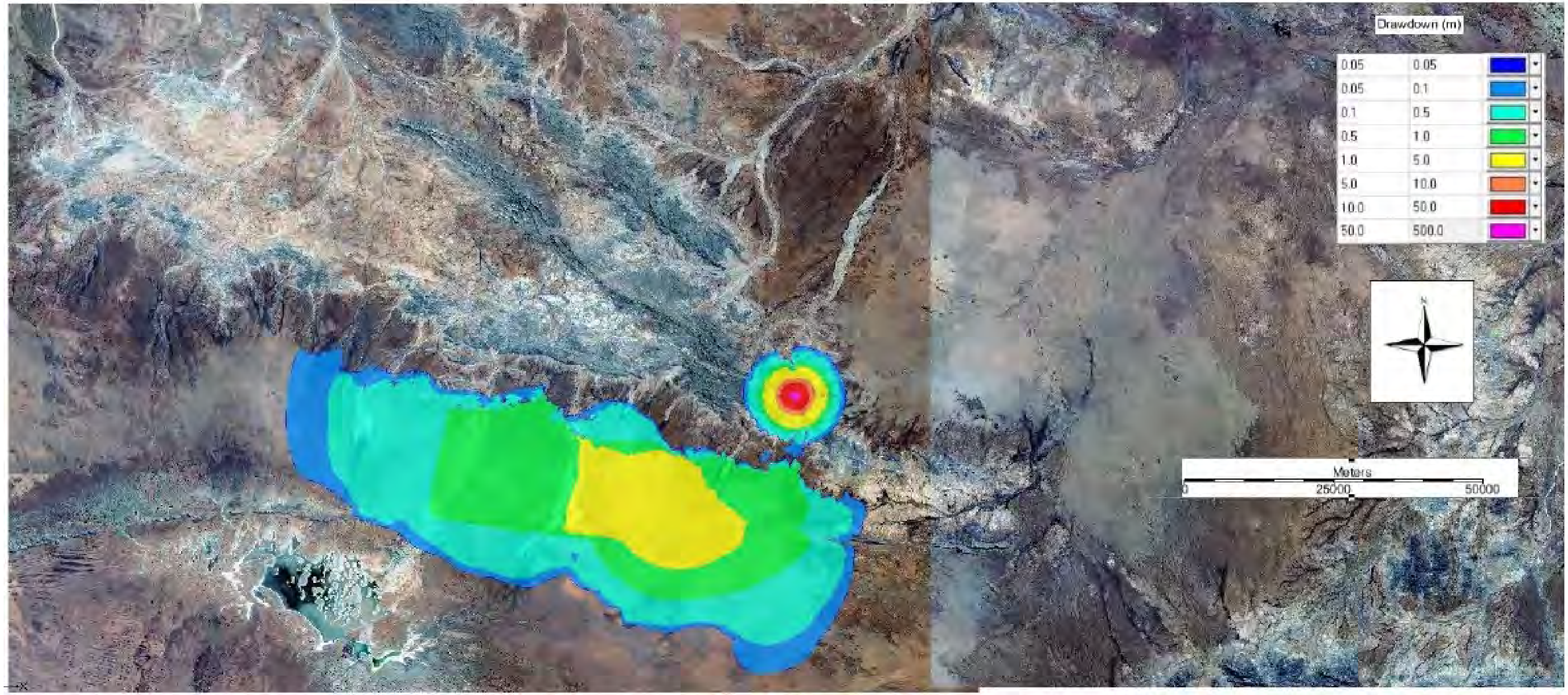
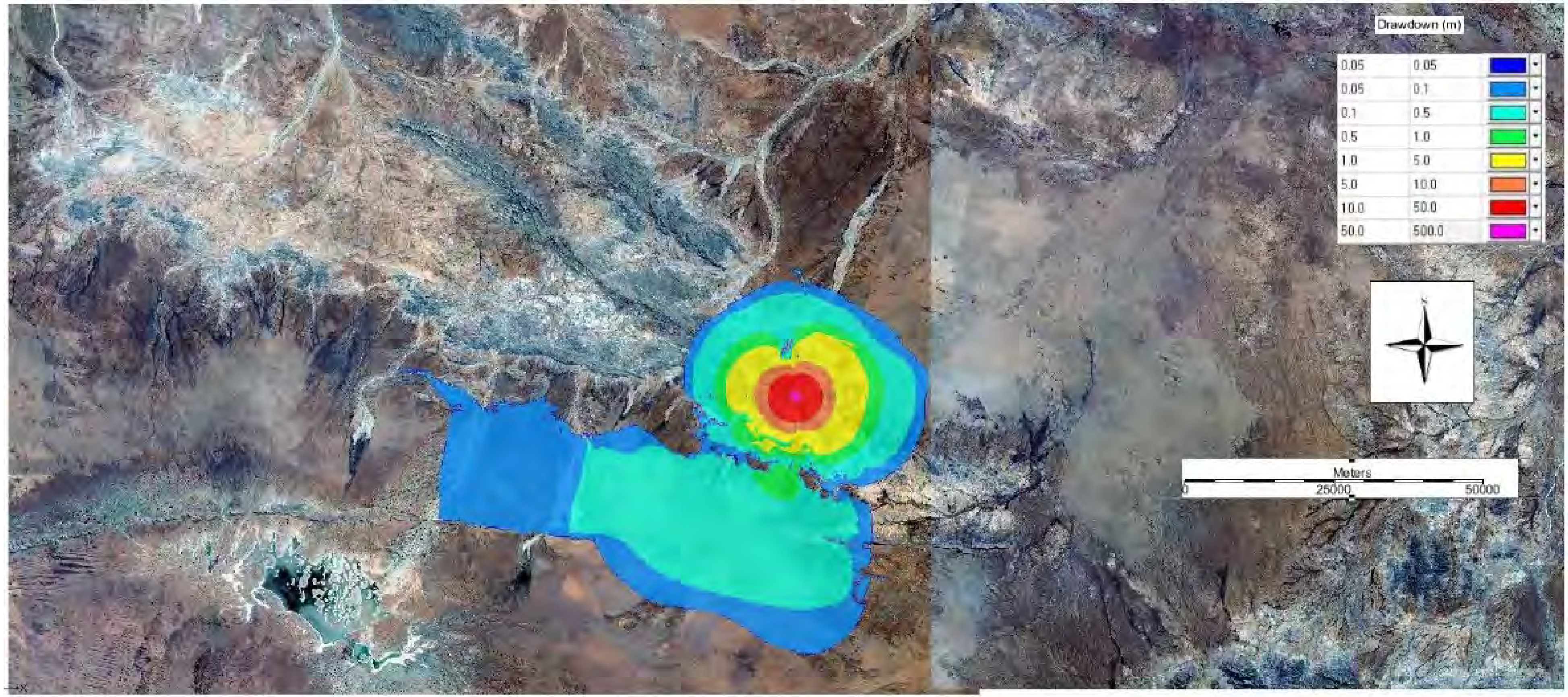


Figure 6 Modelled drawdown at 1,000-years of closure 1/1/3060 (Figure 34 in GHD 2016a)



1.11 Site inspection and ground-truthing

A site inspection to ground-truth and characterise the vegetation types of the Day Creek area was completed on the 18th and 19th of October 2016 by Desert Wildlife Services (DWS 2016). The vegetation of the creek and floodplain was divided into six different units. Two of these, Day Creek channels and banks (RGC) and Corymbia alluvial woodlands (CAW), include a significant component of tree species, namely River Red Gums (*Eucalyptus camaldulensis* subsp. *arida*), Bean Trees (*Erythrina vespertilio*) and Desert Bloodwoods (*Corymbia opaca*) which possibly utilise groundwater resources. Localised flow and run-on areas supporting River Red Gums, *Erythrina* and *Corymbia* spp. occur in small areas on the greater alluvial floodplain at a scale that is not readily mapped. The remainder of the alluvial floodplain was characterised by tree species including whitewood (*Atalaya hemigaluca*), ironwood (*Acacia estrophiolata*) and supplejack (*Ventilago viminalis*), which are not known to be associated with groundwater.

An additional unit (BWS, bloodwood sandplain) located between the Day Creek floodplain and base of the Reaphook Hills was also assessed as indicative of good deep soil water resources on the base of the size and density of bloodwood trees, which could potentially include groundwater.

Besides large high-water use trees, there was a lack of other vegetation indicative of GDEs, such as groundwater dependent sedges (e.g. perennial *Cyperus* spp.), in the Day Creek area.

2. Risk assessment: potential impacts of groundwater changes to GDEs

No formal risk assessment process for GDEs exists for the Northern Territory.

Following previous experience assessing the potential risks and impacts to GDEs, it was decided that the most appropriate method for determining the potential impacts of groundwater changes to GDEs of the Nolans Project area was to follow the risk assessment guidelines for groundwater dependent ecosystems developed by NSW Office of Water (Serov et al. 2012). The NSW Office of Water risk assessment guidelines for groundwater dependent ecosystems was chosen as this was seen as the most comprehensive, systematic, current and relevant method to assess the effects of changes to groundwater on GDEs.

2.1 Approach

A risk assessment was undertaken following the *Risk assessment guidelines for groundwater dependent ecosystems* developed by NSW Office of Water (Serov et al. 2012). The main steps of the ecological valuation and risk assessment process are:

1. Identify the type and location of GDEs;
2. Infer or determine groundwater dependency;
3. Identify High ecological Value Assets of aquifer (Table 1);
4. Determine ecological value of GDEs and the associated aquifer;
5. Determine the impact of an activity to identified GDEs;
6. Determine the magnitude of the risk to identified GDEs;
7. Apply the GDE Risk Matrix; and
8. Determine appropriate management actions.

2.2 Type, location and groundwater dependency of GDEs

Table 2 lists the GDE[1] vegetation communities that have been identified as occurring within the Nolans Project study area. These communities are in particular associated with a number of ephemeral and episodic waterways across the broader study area (including the Woodforde River, Napperby Creek, Day Creek, Kerosene Camp Creek, Sandy Creek, Rabbit Creek, Wickstead Creek and Wallaby Creek), as well as broad back channels and run-on areas of alluvial floodplain.

The Atlas of Groundwater Dependent Ecosystems identifies the borefield and surrounding area as containing a number of the waterways as containing potential GDEs (reliant on surface and/or subsurface expression of groundwater) and inflow dependent ecosystem (i.e. vegetation reliant on water in addition to rainfall) (GDE types are presented in Appendix A), though these are mapped as having a low potential for subsurface groundwater interaction. The Atlas also identifies these waterways as variously having low, moderate and high likelihood of Inflow Dependent Ecosystems (IDEs).

Woodland containing River Red Gum (*Eucalyptus camaldulensis* subsp. *arida*), Ghost Gum (*Corymbia aparrerinja*), Bean Tree (*Erythrina vespertilio*), Desert Bloodwood *(Corymbia opaca*) and Coolabah (*Eucalyptus coolabah* subsp *arida*) occur within the study site and within areas where groundwater drawdown is predicted to occur as a result of proposed groundwater pumping. These species are all known to use groundwater as one of their sources of water, particularly in the absence of overland flooding and/or rainfall (Roberts and Marston 2011). River Red Gum, Ghost Gum and Coolabah in particular are considered GDEs because they are highly likely to source some of their water from groundwater. They are considered facultative GDEs:

"A GDE that is not entirely dependent on groundwater, and may rely on groundwater on a seasonal basis or only during extended drought periods. At other times, water requirements may be met by soil or surface water."

Current data on water table levels across the study area show that groundwater is known to be shallow in isolated areas, but over the vast majority of the area are generally well below the reach of most vegetation (i.e. greater than 15 m), and is typically around 28 m below ground surface (GHD 2016a). Therefore, it is highly likely that trees such as River Red Gum, Ghost Gum, Bean Tree, Desert Bloodwood and Coolabah are using soil stored moisture from within or above the phreatic zone (zone above the water table).

River Red Gum water requirements typically exceed those provided by rainfall alone, and are regularly met by the trees accessing groundwater (Feikema et al., 2010; Doody et al., 2009; 2014a). As an adaptation to arid and semi-arid environments, it is opportunistic in its water use, sourcing water according to osmotic and matric water potential (Thorburn et al., 1993; Mensforth et al., 1994; Holland et al., 2006; Doody et al., 2009). Water sources include fresh to moderately saline groundwater, lateral bank recharge and overbank flooding which replenishes floodplain groundwater (Thorburn et al., 1993; Mensforth et al., 1994; Holland et al., 2006; Doody et al., 2009; 2014b; Holland et al., 2009; Feikema et al., 2010). In areas with low rainfall and infrequent flooding, groundwater may provide the most temporally stable water resource (Mensforth et al. 1994; Burges, et al. 2001). A conceptual drawing of River Red Gum roots and soil profile is shown in Figure 7.

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[1] **Groundwater dependent ecosystem or GDE**
Is a broad, overarching term encompassing all ecosystems that use groundwater either permanently or occasionally to survive. In this context the term covers a vast majority of terrestrial and aquatic ecosystems.

2.2.1 Ecological value

GDEs may be regarded as **high value** if they are considered to meet criterion a), b) or c) of the NSW Risk assessment guidelines for groundwater dependent ecosystems, as listed below and assessed in Table 1:

a) *"Any Groundwater dependent communities where a slight to moderate change in groundwater discharge or water tables would result in a substantial change in their distribution, species composition and/or health. This includes all ecosystems that are identified and acknowledged as being entirely (or obligate) dependent on groundwater for their survival. These ecosystems included all Karst, springs, mound springs, subterranean aquifer ecosystems and some wetlands including hanging swamps."*

b) *"Those ecosystems that have already been identified as important by other environmental agencies or within existing legislation or international agreements; ie. those GDEs that are partly or wholly located within a State or Federal Reserve System; eg. National Park/ Reserve; or are a recognised high conservation area, such as a sub-catchment identified as high conservation value; eg. stressed rivers; high value vegetation etc."*

c) *"Any natural groundwater dependent system that is habitat for any endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under state legislation* {here the Territory Parks and Wildlife Conservation Act 2000} *or the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 or identified by an acknowledged expert taxonomist / ecologist."* (Serov et al. 2012)

Assessment of endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities

Flora

No flora species listed under the EPBC Act have been recorded or are predicted to occur within 20 km of the Study area, and it is highly unlikely that any of these species would occur within the Study area due to the lack of suitable habitat (GHD 2016b). There were no communities of national significance known or predicted to occur within 100 km of the Study area. The DLRM herbarium database search identified 412 plant taxa known to occur within 20 km of the Study area. Under the TPWC Act, 390 are of 'least concern' (i.e. widespread and abundant taxa), eight are 'not evaluated', eight are 'data deficient' and six are listed as 'near threatened' (Holtz 2015).

Most of the vegetation types present within the Study area are well represented within the Burt Plain bioregion, however less than 1% of the Burt Plain bioregion is conserved within reserves; and thus vegetation communities within the Study area are poorly represented in the National estate (e.g. hummock grassland 0.01%, Acacia woodland 0.05%, Eucalyptus low Woodland with Tussock Grass Understorey 0.01% (NRETAS 2005)).

Mixed woodlands dominated by bean trees (*Erythrina vespertilio*) are in decline in the southern Northern Territory (Neave 2006). This may be as a result of grazing pressure and inappropriate fire regimes (P. Latz pers comm. 2010). *E. vespertilio* was a co-dominant canopy species in two of the vegetation communities in the Study area; riparian woodland and mixed woodlands on alluvial plains (Vegetation Types 1 and 3). This species was locally abundant on alluvial plains adjacent riparian zones and at the foot of rocky outcrops (associated with groundwater springs). The size structure of the population indicates that these stands have adequate levels of regeneration.

Neave et al (2006) provides an overview of important vegetation types within the Burt Plain bioregion. These include a number of wetlands and mesic areas, sites of botanical significance and flora and fauna hotspots. The Study area does not contain any of these identified sites. There is however, a small wooded Coolibah swamp adjacent to the Nolans site (but outside the proposal site) that is considered an important vegetation type (Neave et al 2006).

Fauna

Forty-nine fauna species are listed under one or more category of threat (i.e. vulnerable, extinct, near threatened) under the EPBC Act and/or the TPWC Act. More than half (25) are mammals, and of those, 11 species are listed as extinct in the Northern Territory or across Australia. The other threatened species are made up of birds (20 species) and reptiles (4 species) (GHD 2016c). On the basis of habitat requirements and geographic distribution, the Study area potentially provides at least some habitat for 27 of the 38 extant listed species.

Eleven threatened or Near Threatened fauna species were assessed as warranting further detailed assessment due to their detection during the surveys (nine species), or as they were considered likely to occur within the study area (GHD 2016c).

None of the threatened fauna species that are considered as present, or likely to be present within the Study Area are considered to rely on a natural groundwater dependent system as habitat.

Table 1 General aquifer ecological valuation (from Serov et al 2012)

	Yes	No
Does the aquifer or portion of it occur within a state reserve or support any GDEs within a sub-catchment identified as High Conservation Value; eg. Stressed Rivers; high value vegetation, SEPP wetlands, DIWA wetland etc?		No
Does the aquifer support obligate/entirely dependent GDEs including: karsts, springs, mound springs, subterranean aquifer ecosystems and some wetlands such as hanging swamps.		No
Any natural groundwater dependent system that is habitat for any endemic, relictual, rare, or endangered biota (fauna or flora) populations or communities as listed under state legislation {here the Territory Parks and Wildlife Conservation Act 2000} or the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 or identified by an acknowledged expert taxonomist / ecologist?		No

Table 2 Summary of types and ecological values of GDEs at Nolans Project

Vegetation Type or community	Vegetation type (from Nolans Project 2010/11 and 2015 mapping)	GDE type	General aquifer ecological valuation
Eucalyptus camaldulensis subsp. *arida* (river red gum), *Corymbia aparrerinja* (Ghost Gum) and *Erythrina vespertilio* (Bean Tree) as part of 'Riparian woodland along water courses and drainage channels'	1	Phreatophytes – groundwater dependent terrestrial vegetation, and Facultative phreatophytes – may access some portion of water requirement from groundwater	Considered low value as does not meet any of the above criteria.
Corymbia opaca (Desert Bloodwood) and *Erythrina vespertilio* (Bean Tree) as part of 'Mixed woodland on alluvial plains'	3	Facultative phreatophytes – may access some portion of water requirement from groundwater	Considered low value as does not meet any of the above criteria.
Corymbia opaca (Desert Bloodwood) as part of '*Triodia schinzii* hummock grassland on red clayey sands'	4	Facultative phreatophytes – may access some portion of water requirement from groundwater	Considered low value as does not meet any of the above criteria.
Corymbia opaca (Desert Bloodwood) as part of '*Hakea/Senna* shrubland on calcareous alluvial plains and low rises'	5	Facultative phreatophytes – may access some portion of water requirement from groundwater	Considered low value as does not meet any of the above criteria.
Corymbia opaca (Desert Bloodwood) as part of Acacia kempeana and/or mulga shrubland on gravel	9	Facultative phreatophytes – may access some portion of water requirement from groundwater	Considered low value as does not meet any of the above criteria.
Eucalyptus coolabah subsp *arida* (Coolabah) as part of 'Coolabah swamp associated with claypans'	14	Facultative phreatophytes – may access some portion of water requirement from groundwater	Considered low value as does not meet any of the above criteria.

2.2.2 Known water requirements of River Red Gum

Table 3 summarises known tolerances of River Red Gum to periods of inundation and dry conditions. Lawrie *et al* (2012) reports that in the absence of a surface water resource (during drought conditions and/or due to regulation) access to groundwater may be principally responsible for supporting vegetation. While it is difficult to completely rule out other water sources, a degree of groundwater reliance may be likely when woody vegetation maintains relatively constant condition in the absence of surface water.

Eamus *et al.* (2006) reports that the greater the depth to groundwater, the lower the requirement for groundwater and the more tolerant the vegetation to water-table decline, owing to the corresponding increase in alternative water sources. These alternative sources are primarily the larger volume of unsaturated zone (with increasing depth) exploitable by the plant's root system. Currently, quantitative information suggests reduced importance of groundwater to vegetation where depths to groundwater exceed 10 m Zolfhager (2013). However, it is assumed that at depths of 10–20 m there is a possibility of vegetation groundwater use, although it is thought to be negligible in terms of total plant water use, and that at depths of over 20 m the probability of groundwater use is low (Froend and Zencich 2001).

Table 3 Comparison of water requirements to maintain adults and encourage recruitment of River Red-Gum

Hydrological component	River Red-Gum	River Red-Gum Recruitments
Ideal flood frequency to maintain adults	1 in 1-3 years	Flooding important for recruitment, however, immersion of seedlings <25 cm height for several months is lethal.
Maximum inter-flood dry period	36-48 months	Unknown, but probably related to life-span of adult trees
Requirements for recruitment of young plants	N/A	Large flood in late spring or winter, followed by wet winter-spring or even shallow summer flooding. Floods in subsequent years may maximise seedling survival

Source: Green *et. al* (1998), Roberts and Marston (2011), MDBC (2006), Rogers and Ralph (2011)

2.2.3 Known water requirements of *Corymbia opaca* (Desert Bloodwood) and *Eucalyptus coolabah* (Coolabah)

Both *Corymbia opaca* (Desert Bloodwood) and *Eucalyptus coolabah* (Coolabah) are known facultative phreatophytic species (O' grady, et al., 2009; O' grady, et al., 2006; Loomes, 2010), trees which are deep rooted plant species that tap into groundwater, via the capillary fringe, to satisfy at least some portion of their environmental water requirement, but will also inhabit areas where their water requirements can be met by soil moisture reserves alone (Pritchard, et al., 2010). That is, the species will be groundwater dependent in some environments, but not in others. Size and particularly the basal area of trees are often a good indicator of ground-water access (Zolfhager 2013), and stands of larger trees at higher densities may indicate localised use of groundwater. Conversely, scattered isolated small trees such as bloodwoods may occur on the wider sandplain area suggests minimal or no access to groundwater.

A study conducted by Loomes (2010) in the Pilbara found *Eucalyptus coolabah* growing in areas where the water table was as low as 7 m from the ground. *Corymbia opaca* is reported to draw water from as far as 20 m below ground level (Department of Natural Resources, Environment, the Arts and Sport, 2009). Groundwater depths reported in the groundwater studies are generally beyond the range for both of these species (GHD 2016a).

2.3 Impact of groundwater pumping on the GDE

A checklist of impacts on the GDEs is provided in Table 4, indicating likely and unlikely changes to groundwater from the proposal (in accordance with Serov et al. 2012). The main predicted changes are:

- **Water quantity impacts:**
  - Alteration to the watertable levels (dropping water tables);
- **Water quality impacts**
  - An alteration to the natural groundwater chemistry and / or chemical gradients – possibly may occur as a result of changes to water levels.

2.3.1 Impacts on trees

Potential impacts of drawdown of groundwater on trees (facultative phreatophytes; such as River Red Gum, Ghost Gum, Bean Tree, Desert Bloodwood and Coolabah) may include:

- The disconnection of roots from its aquifer by a rapid drop in the water table can cause severe stress and partial or complete mortality in large trees which cannot grow their root systems rapidly enough to maintain adequate water supplies to their extensive canopies, Le Maitre *et al,* 1999;
- A prolonged period of drawdown can result in the disconnection of the root zone from the water table, resulting in the subsequent drying out of the ecosystem over time. The loss of species and changes in the vegetation community structure may have time lags of years to decades before becoming evident as different species of plants within a community have varying groundwater dependency and stress thresholds, Froend and Sommer (2010) and Le Maitre *et al,* (1999);
- The impact of a rapid or an extended drawdown can be exacerbated if it occurs during periods of environmental stress such as drought.

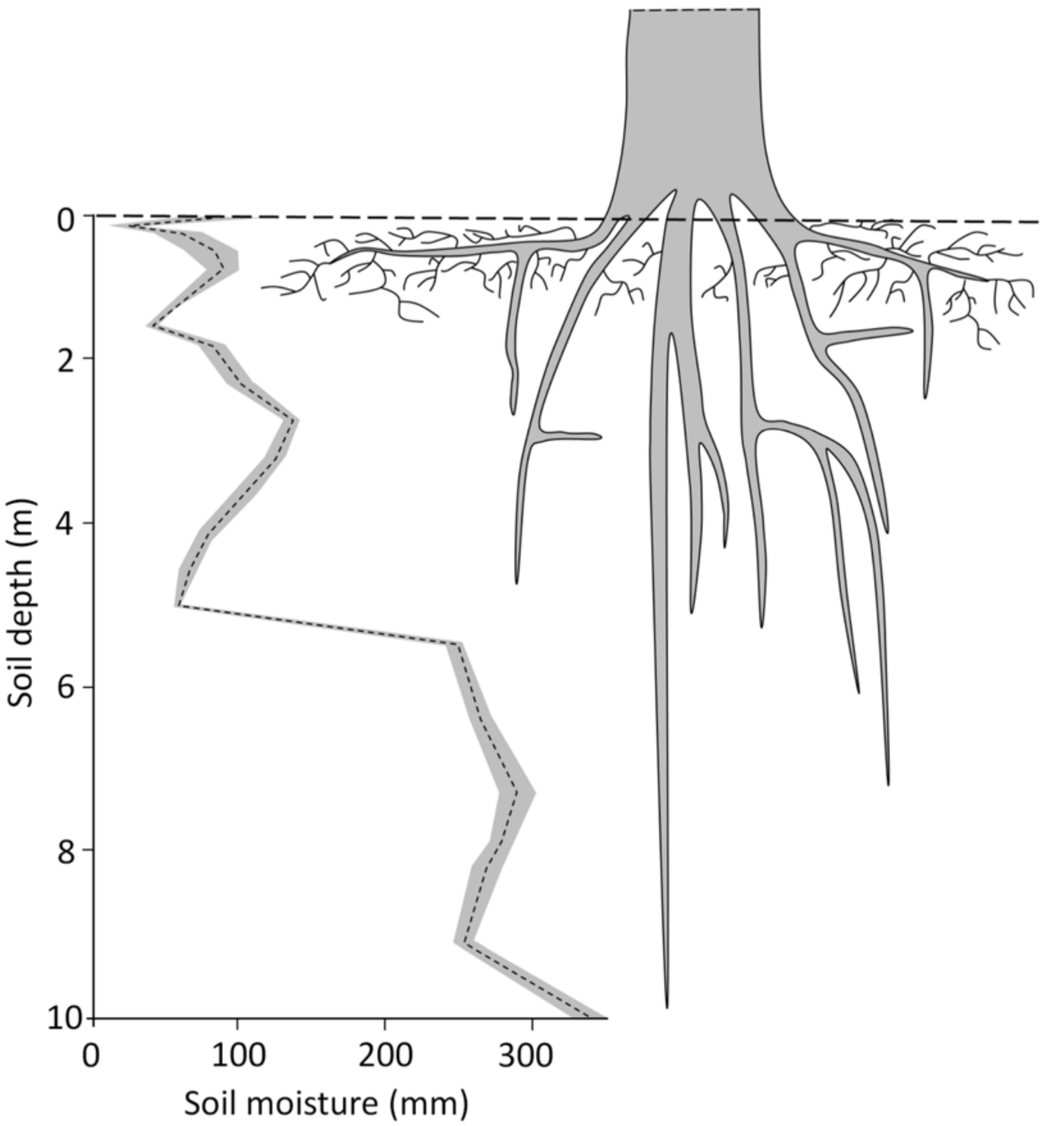

Figure 7 Conceptualisation of root structure within the soil profile (to 10 m) of River Red Gum (from Doody et al. 2015)

Figure 7 presents a conceptualisation of the root structure within the soil profile (soil surface to 10 m soil depth). During times of water deficit, *E. camaldulensis* is known to rely on water stored deep in the soil profile. During times of increased water availability due to high rainfall or flooding, *E. camaldulensis* allocate resources to produce dense but fine roots in the upper soil layer to maximise water uptake. The dashed line indicates mean soil moisture with range highlighted in grey over two years of readings at Yanga National Park (Doody et al. 2015).

2.4 Application of the GDE risk matrix

The Risk matrix (Figure 5 from Serov et al. 2012) is a method of outlining the most appropriate management response for a given environmental value under a particular activity. The risk is a combination of the likelihood that an altered groundwater regime or water quality will impact adversely on the ability of the asset to access sufficient groundwater or sufficient quality to meet its requirements and the degree of threat posed to the groundwater by the proposed or current activity. The matrix consists of two axes, one plots the level of ecological value and the other the level of risk of an activity does or may impose on the aquifer and its associated GDEs. The risk matrix identifies both the level of management action required and the time frame in which this action needs to be implemented (action priority).

As there would be an alteration to the water table level (in this case dropping of water table), a risk assessment has been prepared (in accordance with Table 5 of Serov et al. 2012; Water quantity impacts). The borefield would not be permanent, but would be operated continually for up to about forty years, then permanently decommissioned.

Table 6 presents the risk assessment for the GDEs (Table 7 from Serov et al. 2012). The impacts are considered moderate to high because reduction in "*groundwater level(s) would be beyond seasonal variation, resulting in temporary (or permanent loss) or alteration of a defined habitat type.*"

The risk assessment result is: **Moderate Value / Moderate to High Risk.** Further information (and monitoring) is required to confirm the risk level.

Following the risk matrix (Serov et al. 2012), the following management actions are recommended for moderate value/moderate risk proposals:

Short term

- Protection measures, ideally for aquifer and GDEs, but also targeted at hotspots;
- Baseline risk monitoring. Mitigation action.

Mid term

- Protection measures, ideally for aquifer and GDEs, but also targeted at hotspots;
- Monitoring and periodic assessment of mitigation.

Long term

- Adaptive management. Continue monitoring.

Monitoring should include monitoring of water table levels, quality and tree condition.

Table 4 GDE checklist for a proposed activity (Table 5 from Serov et al. 2012)

GDE impact assessment checklist	Likely	Unlikely	Insufficient data
Water quantity impacts			
Will there be an alteration to the watertable levels (rising or dropping water tables)?	X		
Will there be any alteration to the aquifer flow paths?			X
Will there be any alteration of aquifer discharge volume to off site GDEs?		X	
Will there be an alteration of the frequency/timing of water table level fluctuations?		X	
Will there be any alteration of river base flow in the karst / cave?		X	
Will there be an alteration of surface river base flow?	X		
Will there a reduction in artesian/spring water pressure?		X	
Water quality impacts			
Will there be an alteration to the natural groundwater chemistry and / or chemical gradients?			X
Will acid sulfate soils be exposed, resulting in the acidification of aquifer and acid runoff?		X	
Will there be an alteration in nutrient loads?		X	
Will there be an alteration in sediment loads?		X	
Will there be an alteration in groundwater salinity levels?			X
Will there be an alteration in groundwater temperatures?		X	
Will there be any bioaccumulation of heavy metals?		X	
Aquifer Integrity impacts			
Will there be any substrate alteration compaction; eg. aquifer, river gravel bed compaction by heavy machinery or over extraction of water?		X	
Will there be any cracking or fracturing of the bedrock?		X	
Biological integrity impacts			
Will there be an alteration to the number of native species within the groundwater dependent communities (fauna and flora)?			X
Will there be an alteration to the species composition of the groundwater dependent communities (fauna and flora)?			X
Will exotic flora or fauna be introduced?		X	
Will there be any removal or alteration of a GDE type / subtype habitat; eg. quarrying of limestone around karsts, tramping of cave habitats, sand and gravel extraction?		X	
Total Impact	**2**	**13**	**5**

Table 5 Determining magnitude of potential risk - description of proposed activity (Table 6 from Serov et al 2012)

Information requirements	Results
List of GDE subtype / habitats.	River Red Gum, Ghost Gum, Bean Tree, Desert Bloodwood and Coolabah in open woodlands: • Phreatophytes – groundwater dependent terrestrial vegetation; and • Facultative phreatophytes – may access some portion of water requirement from groundwater
Area of GDE subtype.	Insufficient information to cover whole borefield area to be impacted. Hard to quantify area of river red gum as narrow corridors. • River Red Gum Woodland - ha • Desert Bloodwood in open woodlands - ha • Coolabah in open woodlands - ha
Area and current condition of all habitat and / or GDE subtype listed above.	River Red Gum, Ghost Gum and Bean Tree Woodland: • Good to moderate condition Desert Bloodwood in open woodlands: • Good to moderate condition Coolabah in open woodlands: • Good to moderate condition
Habitat groundwater dependency.	Phreatophytes – groundwater dependent terrestrial vegetation • River Red Gum and Coolabah trees are likely to use groundwater as one of their sources of water (in addition to rainfall and overland flooding), particularly during drought periods (and absence of overland floods and low rainfall). Facultative phreatophytes – may access some portion of water requirement from groundwater • Desert Bloodwood, Ghost Gum and Bean Tree may use groundwater as one of their sources of water (in addition to rainfall and overland flooding), particularly during drought periods (and absence of overland floods and low rainfall).
Natural water table level fluctuations.	Insufficient information, but likely to be small.
Water level requirements for each identified habitat type.	River Red Gum and Coolabah Woodland • Opportunistic use of groundwater, particularly in low rainfall and/or lack of overland flooding. Roots may extend 10 m into soil profile and thus access groundwater or soil moisture within this zone. Changes in water table level and soil moisture in the phreatic zone could impact tree condition, depending on root depth. Desert Bloodwood, Ghost Gum and Bean Tree Woodland • Not as well-known but opportunistic use of groundwater, particularly in low rainfall and/or lack of overland flooding.
Groundwater table level (average).	Generally greater than 15 m

Groundwater depth (thickness).	Layer 1 - 2 m thick Layer 2 - 16 m Napperby Formation Aquifer
Current species list of native species within the groundwater dependent communities (Fauna and Flora). Include list of threatened, rare, endangered or vulnerable species.	No Territory or Nationally threatened species recorded or predicted to occur, which are likely to be dependent on these GDE communities or species.
List of exotic species.	Refer to GHD (2016b) and GHD (2016c).

Table 6 GDE Risk Assessment Nolans Project area (Table 7 from Serov et al. 2012)

Risk factors				
	High	Moderate	Low	Insufficient information
Water quantity asset				
What will be the risk of a change in groundwater levels/pressure on GDEs?	Reduction in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in permanent loss or alteration of defined habitat type.	Reduction in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in temporary loss or alteration of defined habitat type.	No change to aquifer water levels or pressure.	There is currently insufficient data to determine if impacts are likely to be temporary or permanent.
What will be the risk of a change in the timing or magnitude of groundwater level fluctuations on GDEs?	Fluctuation in groundwater level(s) or piezometric pressure beyond established seasonal variation, resulting in permanent loss or alteration of defined habitat type.	Fluctuation in groundwater level(s) or piezometric pressure beyond seasonal variation, resulting in temporary loss or alteration of defined habitat type.	No change in timing of water level fluctuations.	There is currently insufficient data to determine if impacts are likely to be temporary or permanent.
Water quality asset				
What is the risk of changing the chemical conditions of the aquifer?	Permanent change; e.g. in pH, DO, nutrients, temperature and / or turbidity.	Temporary change; e.g. in pH, DO, nutrients, temperature and / or turbidity.	Negligible change (<5%).	
What is the risk on the aquifer by a change in the freshwater/salt water interface?	Permanent change in location or gradient of salt / freshwater interface.	Temporary change in location or gradient of salt / freshwater interface.	No change or not applicable	Insufficient information
What is the likelihood of a change in beneficial use (BU) of the aquifer?	Reduction in water quality beyond designated BU category (for identified trigger parameters).	Reduction in water quality within designated BU category (for identified trigger parameters).	Negligible change for identified triggers (<5%).	Insufficient information
Aquifer integrity asset				
Biological integrity asset				
What is the risk of alterations to the number of native species within the groundwater dependent communities (fauna and flora)?	> 10% reduction in No. of species.	10 to 5% reduction in No. of species.	No reduction in No. of species.	
What is the risk of alterations to the species composition of the	> 10% change in species composition.	10 to 5% change in species composition.	No change in species composition.	

Risk factors				
	High	**Moderate**	**Low**	**Insufficient information**
groundwater dependent communities (fauna and flora)?				
What is the risk of increasing the presence of exotic flora or fauna?	Large populations of one or more species.	Species in small numbers.	None exist.	
Risk valuation	**Moderate**			
Risk	**Water quantity** **Biological integrity**			

Note: cells highlighted green indicate responses to the questions.

3. Mitigation Measures

3.1 Mitigation of impacts

A Construction Environmental Management Plan (CEMP) outlines the environmental goals during construction of a project, the mitigation measures to be implemented, the timing of implementation, responsibilities for implementation and management, and a review process to determine the effectiveness of the strategies. A CEMP should be prepared, implemented and monitored and updated during construction of the proposed borefield and associated pipeline.

The following measures are recommended to minimise impacts to native vegetation, threatened flora community and fauna present within the Study Site:

- Pre-construction management of noxious and environmental weeds to reduce the risk of the spread of weed propagules during clearing and other construction activities. It is recommended that weeds are treated as soon as practicable before construction to reduce the biomass of weeds and weed propagules on site when construction commences.
- Rehabilitation of the disturbance footprint to its pre-disturbance state will ensure the recovery of potential habitat for ground dwelling fauna.

3.1.1 Groundwater dependent ecosystem management

The risk assessment result is: **Moderate Value / Moderate to High Risk**. Further information and monitoring) is required to confirm the risk level.

Given that there is uncertainty on potential impacts on tree condition, we recommend that a monitoring program is established. Following the risk matrix (Serov et al. 2012), the following management actions are recommended for high value/moderate risk proposal sites:

Short term

- Protection measures, ideally for aquifer and GDEs, but also targeted at hotspots;
- Baseline risk monitoring. Mitigation action.

Mid term

- Protection measures, ideally for aquifer and GDEs, but also targeted at hotspots;
- Monitoring and periodic assessment of mitigation.

Long term

- Adaptive management. Continue monitoring.

Monitoring should include monitoring of water table levels, water table quality and tree condition. Tree condition monitoring should occur in patches of living River Red Gum, Ghost Gum, Bean Tree, Desert Bloodwood and Coolabah, in areas where the groundwater is predicted to drop following borefield pumping. In addition, monitoring points should be established at control sites that are not expected to be affected by groundwater drawdown.

4. Conclusions

The Study Site is situated in central Northern Territory within the Burt Plain bioregion. It is located on the Aileron and Napperby pastoral stations. The Study area contains a wide variety of landforms including rocky outcrops, alluvial plains and fans and drainage channels (watercourses). The proposed borefield area consists of gently undulating sandplains with limited surface drainage. Dominant vegetation types within the Study area include Acacia shrublands, hummock grasslands, and grassy eucalypt woodlands.

Groundwater extraction is proposed to occur from the Nolans Mine Site for mine pit dewatering and within the Southern Basins borefield for process and potable water. In addition to active pit dewatering during mining, passive dewatering during groundwater rebound (the period following pumping) and ongoing dewatering via evaporation were considered.

An assessment of groundwater (GHD 2016a) as part of the projects EIS made a limited consideration of environmental users of water (not necessarily groundwater) in the study area including 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 below the reach of most vegetation (i.e. greater than 15 m).

The proposed groundwater extraction would draw down groundwater and this has the potential to impact on GDEs. The GDEs to be impacted include vegetation communities containing River Red Gum, Ghost Gum, Bean Tree, Desert Bloodwood and Coolabah. The proposed area to be impacted by the changes to groundwater would impact a small proportion of these communities which cover extensive areas in the broader region.

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 of pit water. Drawdowns are expected to be very large at the pit site, reflective of pit levels during operation (i.e. as deep as 390 mAHD which equates to approximately 260 m of drawdown at the completion of mining), and then reflective of the pit lake levels (modelled levels at 575 mAHD which equates to approximately 80 m of drawdown) during closure as the water rebounds to a level where groundwater flow equates to evaporation.

Lowering of the water table has the potential to result in a decline in availability of water to ecosystems including riparian vegetation resulting in loss of habitat for species relying on riparian habitat. Riparian vegetation (dominated by *Eucalyptus camaldulensis* (River Red Gums) line the larger creeks and rivers in the study area including Napperby Creek, Day Creek and Woodforde River as well as a number of unnamed drainage lines that occur throughout the study area.

Groundwater dependent vegetation in discharge zones and floodout areas would be susceptible to rapid changes in groundwater levels, in particular riparian woodlands, which are likely to be at least partially dependant on groundwater. Lowering of the groundwater level may result in the die back of riparian vegetation and/or changes to species composition within the community, in the River Red Gum, Bean Tree and Ghost Gum growing along creeks and drainage lines in and around the Nolans site, particularly if the drawdown occurs quickly, or the level of drawdown is large. In either of these situations groundwater dependent species are unlikely to be able to adapt to the changing groundwater levels. Impacts are likely to be evident as far away as Day Creek, to the west of the bore fields.

The riparian vegetation immediately adjacent to the mine area (both upstream to the point of the diversion and downstream in Kerosene Camp Creek to the confluence of Nolans Creek) is highly likely to be heavily impacted by the mining operations (i.e. riparian vegetation may die and not recolonise the area), and these conditions will persist beyond mining and into closure. The reason for this includes, but is not limited to:

- the difference in availability of surface water and therefore recharge to groundwater as well as water for direct contact with riparian vegetation (i.e. a section of the creek will longer exist and a section of the creek will be diverted);
- there will be no availability of groundwater within the mine drawdown cone.

It is reasonable to assert the impact will be greatest immediately adjacent to the pit and decrease radially with distance from the pit. A reasonable estimate for the downgradient extent of this based on the both the modelled drawdown cone and where Kerosene Camp Creek receives additional surface water flow from adjacent catchments (which is likely to in part mask this impact) is the confluence with Nolans Creek. This length of Kerosene Camp Creek beyond the mining area is approximately 1 km long. At this point the groundwater model predicts a drawdown of only 2 m during mining but approaches 20 m in the long term closure model (1000 years).

Modelled drawdown from the borefield peaks in the order of 1.5 m in the vicinity of Day Creek and rebounds rapidly once pumping ceases (GHD 2016b). It is considered highly unlikely that vegetation would currently dependent on the groundwater at these locations, based on watertable level observations (of approximately 28 m below top of collar) in the adjacent bore SB0026, 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 drawdown period during mining and it is therefore anticipated that the slow rate of drawdown would give riparian vegetation the opportunity to adapt to the lowering water table over time.

Groundwater modelling shows that no floodout areas within the Ti-Tree Basin will be impacted by groundwater abstraction in the mine area.

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 negligible.

Groundwater drawdown within the borefield area will create a situation in which some vegetation communities are likely to need to adjust to changes in soil moisture availability in the soil profile. It is difficult to predict whether these changes would impact tree condition with the limited data available. Impacts in the short-term may be expected, particularly if pumping occurs in drought years when trees are more heavily reliant on groundwater as their water source, during which time ability of trees to access water may decrease and may result in a decline in tree condition. Such impacts may be short-term, if trees can respond and grow roots further into the soil profile to access water deeper in the soil profile. Trees closer to creek and river lines may be less affected than trees which are further away. Given that there is uncertainty on potential impacts on tree condition, it is recommend that a monitoring program is established.

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Appendices

Appendix A – Types of GDEs

Types of GDEs

The three primary classes for categorising GDEs are (Eamus *et al.*, 2006):

1. **Ecosystems reliant on surface expressions of groundwater** – including baseflow rivers and streams, wetlands, some floodplains and mound springs and associated vegetation (where surface expressions of groundwater may penetrate to the root zone)
2. **Ecosystems reliant on subsurface presence of groundwater** – terrestrial vegetation that does not require surface expressions of groundwater
3. **Aquifer and cave ecosystems.**

Further discussion of these categories has been provided in previous studies (SKM 2011, BOM 2012). Within these three categories, six types of GDEs have been identified as occurring within Australia (Land and Water Australia, 2006). These are described below:

1. **Terrestrial vegetation**: vegetation communities (and dependent fauna) that obtain at least part of their water requirements from groundwater but are not totally reliant on surface waters
2. **Wetlands**: aquatic communities and fringing vegetation in which groundwater provides at least seasonal waterlogging or inundation
3. **River base flow systems**: aquatic and riparian ecosystems that are dependent on groundwater-derived stream flow or bank storage for their baseflow. This category of GDE includes the hyporheic communities associated with river beds and banks
4. **Estuarine and near shore marine systems**: coastal, estuarine and near shore marine plant and animal communities at least partly dependent on groundwater discharge for the supply of nutrients or modification of salinity regimes
5. **Cave and aquifer ecosystems**: such as karstic, fractured rock and alluvial aquifers where aquatic ecosystems occupy caves or aquifers, including stygofauna
6. **Terrestrial fauna**: native animals that directly use groundwater particularly for drinking rather than the provision of habitat.

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Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A	D Eyles	A Holmes		Nicole Conroy		16/02/2017

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