Bennelongia Environmental Consultants

Roy Hill Iron Ore Project

Managed Aquifer Recharge and Stage 2 Borefield

Subterranean Fauna Desktop Assessment

Prepared for:

Roy Hill

July 2018

Final Report

Short-Range Endemics | Subterranean Fauna

Waterbirds | Wetlands

Roy Hill Iron Ore Project
Managed Aquifer Recharge and Stage 2 Borefield
Subterranean Fauna Desktop Assessment

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Report Number: 323

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			Method	Date
Draft	Anton Mittra		Email	16-04-2018
Draft V2	Anton Mittra	Stuart Halse	Email	10-05-2018
Final	Anton Mittra	Stuart Halse		4 -07-2018

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EXECUTIVE SUMMARY

The Roy Hill Iron Ore Project ('the Project') in the Pilbara region of Western Australia is located approximately 115 km north of Newman on the northern edge of the Fortescue Marsh. A Managed Aquifer Recharge (MAR) system including reinjection and recharge basins is proposed as part of a strategy to dispose of excess water. Altered groundwater levels and water quality resulting from MAR have the potential to affect habitat for subterranean fauna. This desktop assessment evaluates the potential impacts of MAR on subterranean fauna species.

The MAR system comprises injection bores located in the South West Injection Borefield (SWIB), Stage 1 Borefield, Stage 2 Borefield and Stage 2 MAR Area, as well as recharge basins located in the SWIB. Injection of disposal water will occur at depth. Information on the MAR system used in this assessment is provided by a hydrogeological assessment of the SWIB and Stage 1 Borefield and a Phase 1 Feasability Study for the Stage 2 Borefield and Stage 2 MAR Area.

Prospective habitats for stygofauna in proposed MAR areas are Alluvials (potentially highly prospective depending on local transmissivity, salinity suitable for stygofauna); Detritals (including calcrete and potentially highly prospective depending on local transmissivity, salinity variable); Hardcap and Semi Hardcap in the Nammuldi Member of the MMF (well-developed vughs and cavities in parts, salinity variable); and weathered and karstic dolomite of the Wittenoom Formation (Stage 2 Borefield/MAR Area). Other units may host reduced suites of stygofauna. The same units, if above the water table, may be prospective for troglofauna. Potential troglofauna habitat in the SWIB and Stage 2 Borefield/MAR Area is limited to Alluvials and calcrete (moderately prospective), while the remaining units occur below the water table. In the Stage 1 Borefield Alluvials, Detritals and MMF provide potential troglofauna habitat, with upper layers of the MMF considered the most prospective.

To further clarify the likelihood of subterranean fauna being present, previous records in a 100 km x 100 km search area surrounding the Project (defined by 22.0742°S, 119.4786°E and 22.9943°S and 120.4691°E) were reviewed. At least 119 stygofauna species have been collected in the search area. A moderate number of stygofauna species have previously been recorded in Roy Hill tenements including several species in proposed MAR areas. At least 66 species of troglofauna have also been recorded in the search area. Two troglofauna species, a cockroach and an isopod, have been recorded in stygofauna samples in Roy Hill tenements. To the east-northeast, 14 species have been recorded from mineralised iron formations including the MMF, while 29 troglofauna species have been recorded from Christmas Creek. It is unlikely that previous survey has recorded all subterranean fauna species that occur in the Project area.

The proposed MAR system has the potential to affect the existing groundwater environment increasing groundwater levels and, possibly, salinity levels. However, injection water is generally less saline than receiving aquifers and Roy Hill predict that vertical mixing of groundwater will not occur in the SWIB and Stage 1 Borefield. Therefore, increased salinity is not expected to occur in stygofauna habitat in these areas. The potential for salinisation in the Stage 2 Borefield and Stage 2 MAR Area has not been modelled, although feasibility studies are ongoing. If aquifer mixing does occur, salinisation of fresh and brackish habitats could lead to alteration of existing stygofauna communities proportional to the magnitude of increases in salinity. Receiving surficial aquifers in the vicinity of proposed recharge basins are less saline than disposal water that will be infiltrated at the surface and it is expected that water quality beneath, and surrounding, the recharge basins will increase from 3,000 mg/L to 5,000 mg/L..

The predicted salinity increase associated with the recharge basins is within natural variation occurring across the surficial aquifer in the surrounding area. Species-specific salinity tolerances are likely to reflect this variation. Therefore, based on the MAR hydrogeological information provided by Roy Hill, salinisation as a result of MAR is not considered a significant threat to stygofauna and there is no threat of stygofauna habitat removal through groundwater level modifications, as the water table in the zone of influence is likely to increase relative to background conditions following MAR.

The primary threat to troglofauna from the MAR system is the potential for loss of habitat via flooding. If reinjection exceeds groundwater drawdown, some troglofauna habitat will be removed in MAR areas. The net effect of reinjection and drawdown is yet to be determined. While the values of troglofauna assemblages in MAR areas remain to be definitively quantified, all geological units within borefield areas cover larger areas than the likely zones of influence and suggest that species in these habitats may have ranges larger than potential impacts. Species in BIF units (e.g. MMF in the Stage 1 Borefield) may have tighter distributions than species in alluvial and detrital habitats.

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1. INTRODUCTION

The Roy Hill Iron Ore Project ('the Project') is an iron ore mining, rail and port operation in the Pilbara region of Western Australia, approximately 115 km north of the town of Newman and on the northern edge of the Fortescue Marsh (Figure 1). The Project will require dewatering to allow dry mining and to provide processing water and this will lower groundwater levels. Conversely, during periods of excess extracted groundwater, a Managed Aquifer Recharge (MAR) system including reinjection and recharge basins will be implemented as part of the excess water disposal strategy. Reinjection has the benefit of storing water in a manner that allows future recovery.

Key aspects of Project groundwater management include:

- Submission of an s45C application for a short-term (two year) Managed Aquifer Recharge programme of reinjection into the South West Injection Borefield (SWIB) and Stage 1 Borefield;
- Submission of a s38C referral document including the Life of Mine (LOM) Water Management Strategy, which is likely to include dewatering of mine pits and reinjection/infiltration of surplus water into the SWIB, Stage 1 Borefield and Stage 2 Borefield/MAR Area. Note that the Stage 1 Borefield is in a future mine pit area and the Stage 2 Borefield will continue to be used for water supply as per previous regulatory approvals; and
- Southward extension of the proposed Stage 2 Borefield.

The alteration of groundwater levels through MAR has the potential to affect habitat for subterranean fauna – aquatic stygofauna and air-breathing troglofauna – occurring within the area in which groundwater change occurs. Accordingly, this desktop assessment aims to determine the potential impacts of MAR on subterranean fauna species.

The specific aims of the assessment are to:

- Collate and evaluate previous records of subterranean fauna species in the vicinity of the Project;
- Identify prospective habitat for subterranean fauna in the Project area;
- Determine the likelihood that subterranean fauna occur in the vicinity of the SWIB, Stage 1 Borefield, Stage 2 Borefield and Stage 2 MAR Area;
- Determine the likelihood of reinjection/infiltration having conservation-significant impacts on any stygofauna or troglofauna species present.
- Comment on the requirement for additional field survey of subterranean fauna if required.

2. PROJECT BACKGROUND

The Roy Hill Iron Ore Project consists of a conventional open pit, bulk mining operation from multiple production benches; a wet processing plant; a 344 km single line, heavy haul railway; and a purpose built, dedicated two berth iron ore port facility at Port Hedland. The proposed MAR system (Figure 2) has a capacity of 55 GL/a and comprises the following components:

- Conveyance pipework;
- Injection bores located in the SWIB, Stage 1 Borefield, and Stage 2 Borefield/Stage 2 MAR Area;
- Disposal water to be injected at depth into aquifers in the Marra Mamba Formation (MMF) in the SWIB and Stage 1 Borefield and weathered dolomite formation in the Stage 2 Borefield/MAR Area;
- Recharge basins located in the SWIB and co-located in future mining locations; and
- Groundwater monitoring bores.

Information on the MAR system proposed for the SWIB and Stage 1 Borefield used in this assessment is provided by Roy Hill (2018). Information for the MAR system proposed for the Stage 2 Borefield/Stage 2 MAR Area is provided in Managed Recharge (2018).

Legend

The Project

0 40 80
kilometres

Bennelongia Environmental Consultants

GDA MGA94 (Zone 50)
Author: A. Mittra
Date: 06-04-2018

Figure 1. Location of the Roy Hill Iron Ore Project.

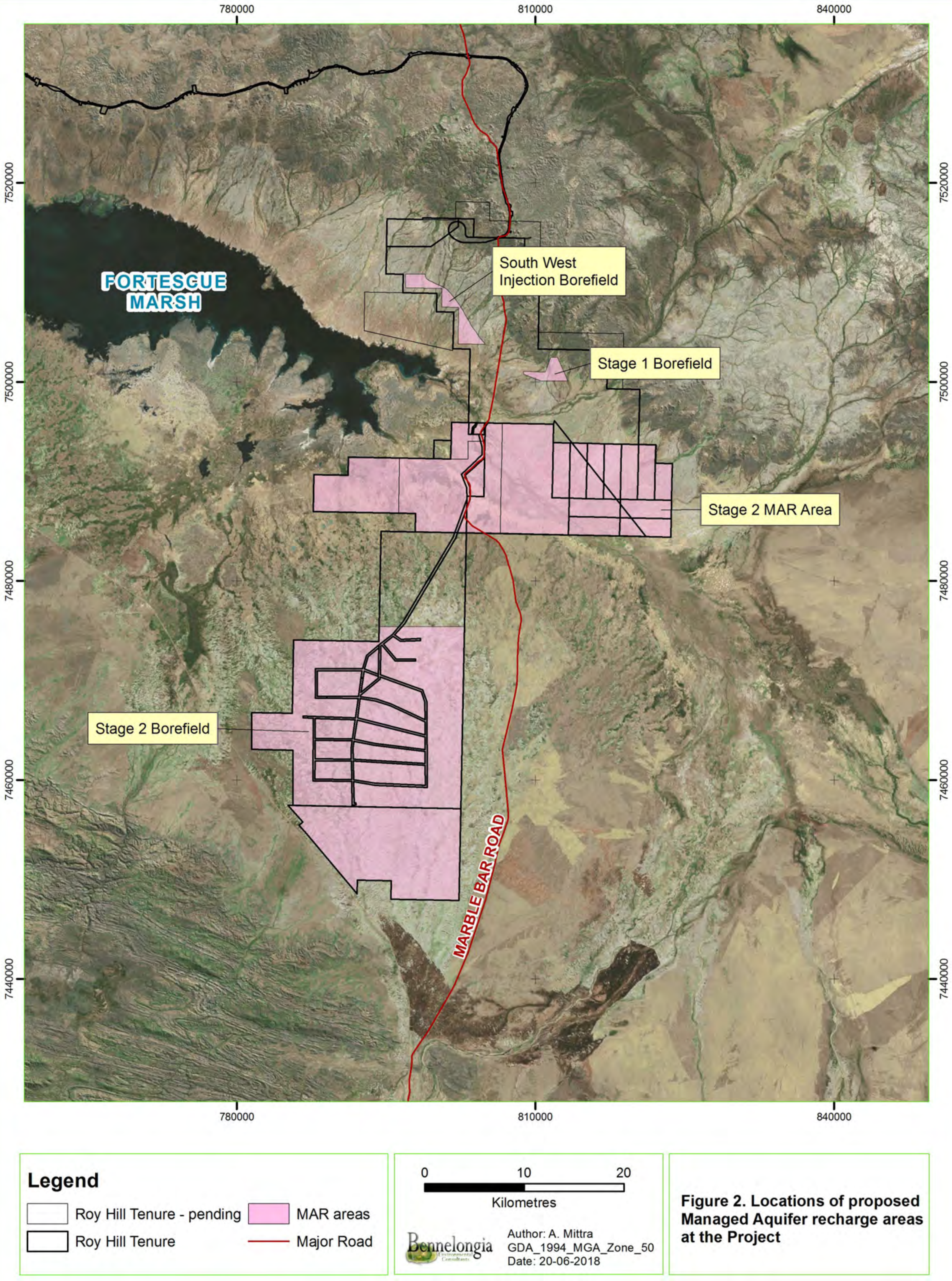

Figure 2. Locations of proposed Managed Aquifer recharge areas at the Project

3. HABITAT ASSESSMENT

The assessment of habitat prospectivity takes into account regional and local geological and hydrogeological information to assess the prospectivity of subterranean fauna habitat for stygofauna and troglofauna in the vicinity of the Project.

3.1. Geology and Hydrogeology

The Project occurs on the southern slopes of the Chichester Range that level out in a south-westerly direction into the Fortescue Valley. This area is in the north-west margin of the Hamersley Basin, a depositional basin of Archean to Lower Proterozoic volcanic and sedimentary rocks, overlying older Archean granite and greenstone basement rocks.

Surficial geology of the Project area is mapped in Figure 3. The stratigraphy of the Project area (Figure 4) generally comprises a sequence of alluvial, detrital, Marra Mamba Formation (MMF) and Jeerinah Formation and these units are characterised in Table 1. The alluvial and detrital deposits occur on the lower slopes of the Chichester Range and increase in thickness towards the Fortescue Valley. Within much of the Chichester Range the MMF overlies the shale, chert, basalt and dolomite of the Jeerinah Formation. The uppermost unit of the Jeerinah Formation, the Roy Hill Shale, is locally pyritic and dolomitic. In creeks and riverbeds the sequence generally comprises unconsolidated silt, sand and gravel, while in adjacent floodplains, finer-grained clays predominate. Detritals comprising silty and clayey playa deposits overlie calcrete of the Oakover Formation.

Geological cross-sections of the SWIB, Stage 1 Borefield and Stage 2 Borefield are shown in Figures 5, 6 and 7 respectively.

Table 1. Characteristics of major geological units in the Project area.

Lithological unit	Description
Alluvials	Varies from a moderately-consolidated conglomerate of mixed ore, BIF and shale clasts to loose gravel and silt. Clasts are mostly sub angular, with softer shale clasts being sub-rounded and range in size from fine gravel to cobbles up to 80mm diameter.
Detritals	Includes gravelly siltstone, lacustrine clay, calcrete and hematite conglomerate subunits: • Gravelly siltstone – generally a moderately consolidated and matrix dominated by sub-rounded hematite with some sub-angular BIF gravels. • Lacustrine clay – non-carbonaceous and contains/is overprinted by calcrete resulting in increased hardness. Clay unit thickens towards south-west. • Calcrete – pale, massive unit, sometimes interbedded by calcrete clay. • Hematite conglomerate – mineralised detrital units including Channel iron and Detrital iron deposits; highly cemented, with sub-angular clasts in a silty matrix.
Wittenoon Formation	Underlies surficial detritals in the Stage 2 Borefield area, above the MMF and below the water table. Absent from the SWIB and Stage 1 Borefield areas. Comprises dolomite, chert and shale; weathered and karstic in parts.
MMF (Nammuldi Member)	Multiple horizons defined based on textural, mineralogical and geochemical characters: • Hardcap – well-developed vughy to cavernous texture often infilled by Cainozoic clays. • Semi-Hardcap – transitional zone comprising combinations of bedded and Hardcap zones. Vughs contain less infill material. • Bedded Mineralised Nammuldi – variable porosity and hardness. Fractures and cavities associated with high levels of clay and siliceous linings and fill. • Mineralised Shaley Nammuldi – bedded ore interbedded with shales/mineralised shaley ore. Highly porous. • Unminedralised Nammuldi – banded iron, shales and cherts.
Jeerinah Formation	Uppermost member of the Fortescue Group and generally conformably underlies the MMF. Kaolinitic and carbonaceous shales of the uppermost Roy Hill Shale Member and subordinately by the interbedded shale-chert and dolomite sequence of the Warrie Member.

3.1.1. Groundwater Quality

Groundwater salinity is variable but generally increases with depth and with proximity to the Fortescue Marsh (Roy Hill 2018). At the broad scale, this reflects the existence of a wedge-shaped transitional zone between overlying fresh groundwater and the deeper hypersaline groundwater that underlies the Marsh and extends laterally outside it. Table 2 characterises groundwater units in the Project and indicative MAR areas.

Table 2. Summary of groundwater salinity in alluvial, detrital, MMF and Jeerinah Formation aquifers in the Project area.

Lithological unit	Indicative Salinity Range	Comments
Alluvials	Generally 500 to 3,000 µS/cm	Salinity increases up to 30,000 µS/cm in the southwestern portion of the SWIB. Stage 1 Borefield hosts fresh groundwater. Stage 2 Borefield/ MAR area host fresh-to-saline groundwater depending on depth.
Detritals (including calcrete)	500–100,000 µS/cm	Variable in SWIB, salinity increasing towards Marsh, sometimes hypersaline. Stage 1 Borefield < 3,000 µS/cm. Stage 2 Borefield/MAR Area host fresh-to-saline groundwater depending on depth.
Wittenoom Formation	2,000–40,000 µS/cm	Somewhat variable with depth, although generally, salinities in the Stage 2 Borefield/MAR areas are more or less constant or increase only slightly with depth.
MMF (Nammuldi Member)	30,000 to 100,000 µS/cm in SWIB; Generally < 3,000 µS/cm in Stage 1 Borefield;	Salinity increases with depth. SWIB data indicate potential proximity of saline wedge. Stage 1 Borefield fresh with salinity increasing westward.
Jeerinah Formation	Generally > 100,000 although may be fresh in Stage 1 Borefield area	Data indicate the hypersaline body extends at least 5 km north of the Fortescue River. Closest datum to Stage 1 Borefield (~1.2 km east-northeast) indicates fresh water.

3.2. Assessment of Habitat Prospectivity

Geology influences the presence, richness and distribution of subterranean fauna species by providing different types of habitat (Eberhard *et al.* 2005; Hose *et al.* 2015). Geologies with larger internal spaces such as vughs and cavities tend to support richer assemblages of subterranean fauna, both in terms of abundance and diversity, than more consolidated geologies. Stygofauna communities tend to be richest in alluvial and calcrete aquifers (Humphreys 2001), while troglofauna have been found to occur widely in mineralised iron formations (especially BIF), calcretes and alluvial-detrital deposits. The abundance and richness of subterranean fauna communities is also limited by depth as a result of reduced energy inputs from the surface. Prospectivity for stygofauna is greatest in fresh to brackish aquifers, although a reduced suite of fauna may occupy more saline aquifers. A guide to the levels of habiat prospectivity considered in this assessment is provided in Table 3.

Table 3. Levels of habitat prospectivity considered in this assessment.

Prospectivity	Description
Low	Unlikely to host subterranean fauna based on tight, consolidated or fine-grained geology; great depth below the surface; and/or limiting physicochemical conditions, e.g. high salinity or acidity. May host a low number of species in some situations.
Moderate	Likely to host some subterranean species, although at least one environmental factor (e.g. depth, water chemistry) points to a limited assemblage in terms of richness and/or abundance.
High	Highly likely to host a considerable number of subterranean species based on abundant underground spaces/high transmissivity; suitable physicochemical conditions (fresh-to-brackish groundwater, circumneutral pH); and the potential for surficial energy inflow due to shallow depth or transmissive overlying strata. Additionaly, similar geologies elsewhere are known to host subterranean assemblages. Includes calcretes, banded ironstone formations and alluvial deposits.

3.2.1. Stygofauna

Within the Project area, including proposed MAR areas in the SWIB, Stage 1 Borefield and Stage 2 Borefield/MAR Area, the most prospective hydrogeological units for stygofauna are:

- **Alluvials** – potentially highly prospective depending on local transmissivity. Salinity levels are suitable for stygofauna throughout this unit.
- **Detritals** – potentially highly prospective depending on local transmissivity and groundwater salinity. Calcrete deposits in this unit may may provide highly prospective habitat.
- **Hardcap and Semi-Hardcap (Nammuldi Member)** in the MMF – especially areas with well-developed vughs and cavities but also, depending on groundwater salinities and depth, deeper, more saline MMF units may provide habitat for a reduced suite of stygofauna.
- **Weathered Wittenoom** – a widespread, relatively transmissive brackish aquifer comprising weathered and karstic dolomite over depths of 10–35 m potentially provides highly prospective habitat in the Stage 2 Borefield and Stage 2 MAR Area.

3.2.2. Troglofauna

The units listed above are also potentially prospective for troglofauna depending on the occurrence of these geologies above the water table. Depth to groundwater is spatially variable and generally decreases towards the Marsh, so that prospectivity for troglofauna decreases with proximity to the Marsh. In proposed MAR areas, it is considered that:

- Depth to groundwater across the SWIB ranges approximately 5–20 metres below ground level from the south-west to the north-east, with the unsaturated zone (and therefore potential habitat for troglofauna) occurring in the alluvial unit (Roy Hill 2018). Prospectivity of SWIB alluvials is considered moderate and will depend on local transmissivity and size of interstitial spaces.
- Depths to groundwater in the Stage 1 Borefield injection zone are approximately 45–50 m, with alluvial, detrital and some MMF units all occurring above the water table. All three units provide potentially prospective habitat for troglofauna in the Stage 1 Borefield area, with the MMF (Hardcap Semi-Hardcap and Mineralised Nammuldi) considered the most prospective due to well-developed vughs, fractures and cavities (Table 1). Again, the prospectivity of each unit will depend on local transmissivity.
- In the Stage 2 Borefield, the water table is variable and sits at approximately 11–30 mbgl. Weathered and karstic dolomite of the Weathered Wittenoom Formation occurs below this level and is therefore not prospective for troglofauna. Calcrete and surficial alluvium provide moderately prospective habitat for troglofauna above the water table in the Stage 2 Borefield and Stage 2 MAR Area.

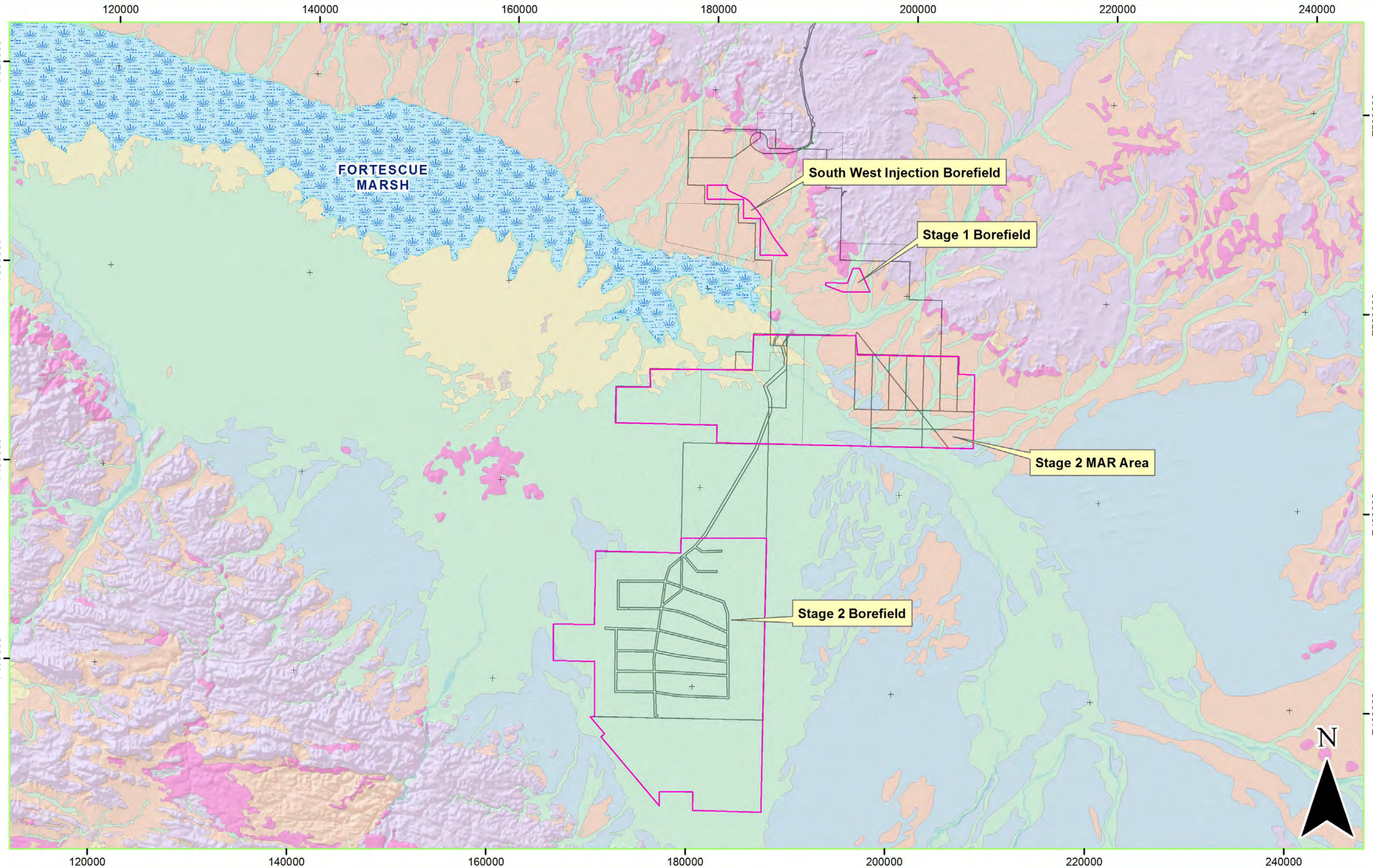

Figure 3. Surficial geologies in and around the Project.

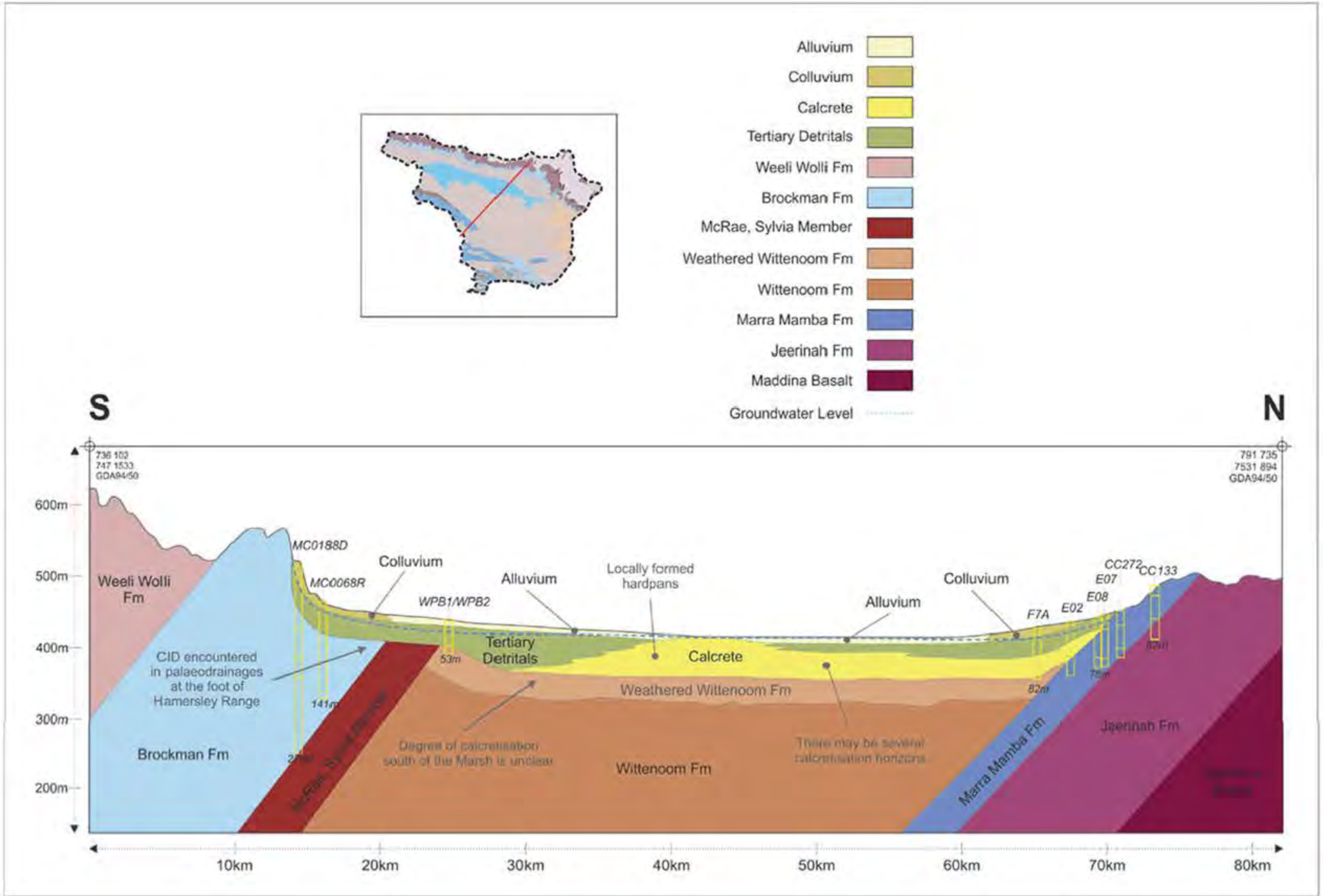

Figure 4. Generalised cross-section of the geology of the Project area.

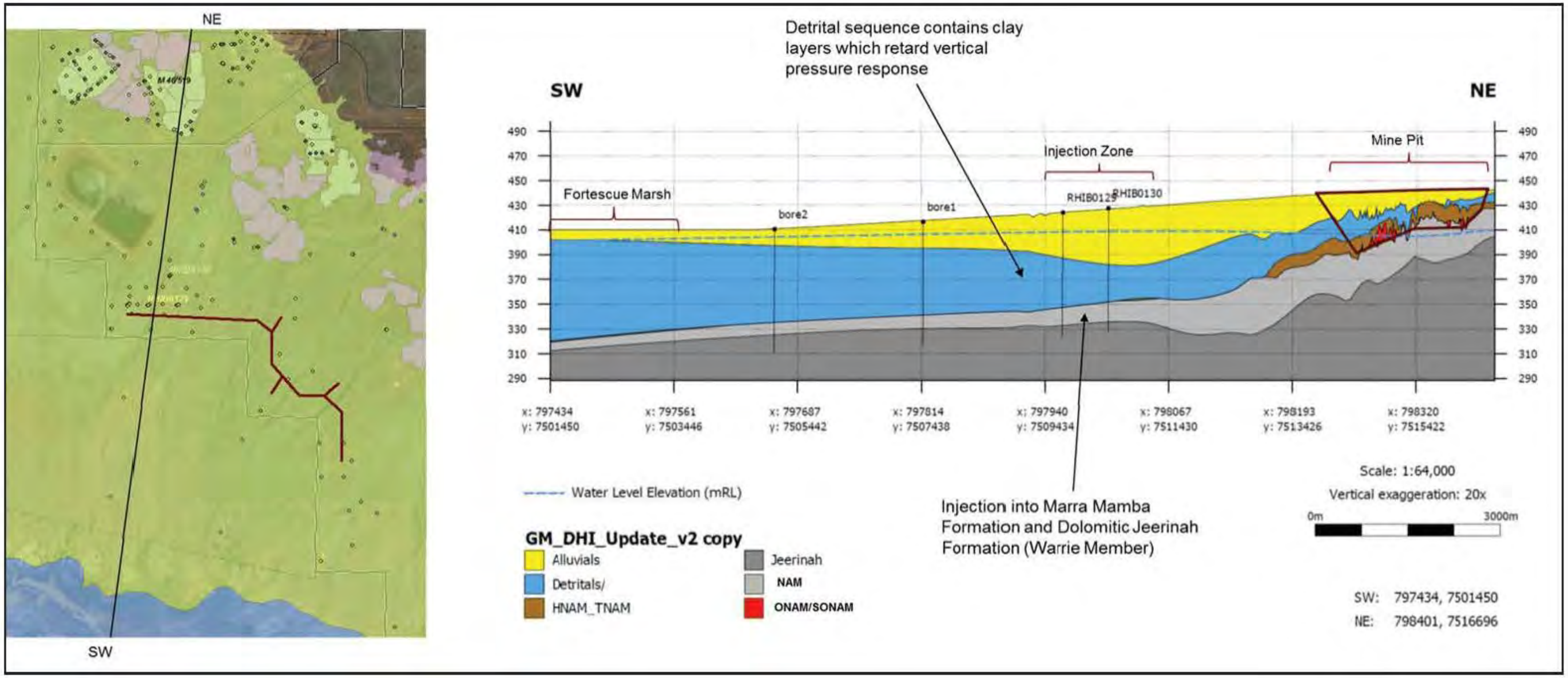

Figure 5. Cross-section of the SWIB (Roy Hill 2018).

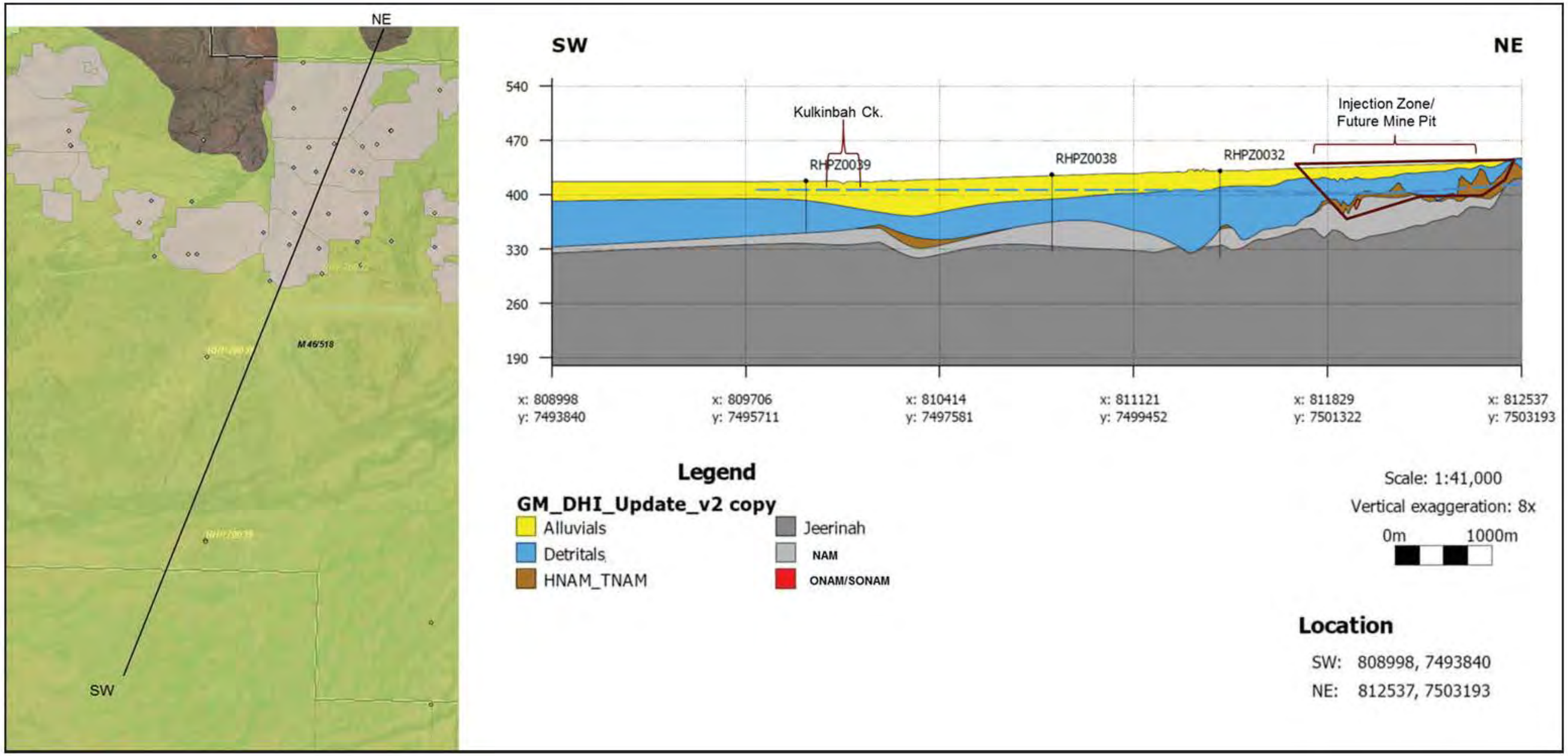

Figure 6. Cross-section of the Stage 1 Borefield (Roy Hill 2018).

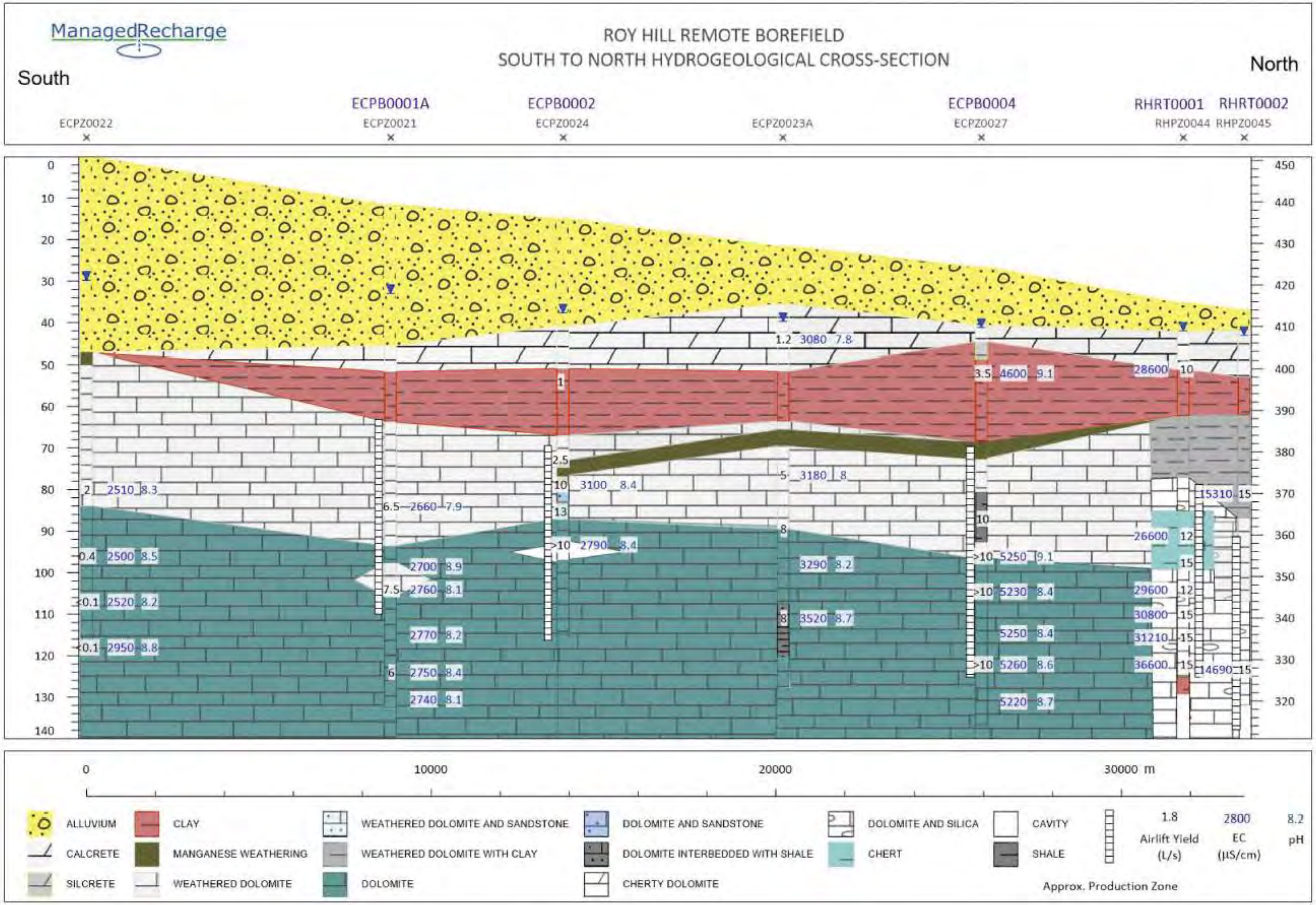

Figure 7. Cross-section of the Stage 2 Borefield (Managed Recharge 2018).

4. PREVIOUS RECORDS OF SUBTERRANEAN FAUNA

Previous records of subterranean fauna species in the vicinity of the Project were collated and evaluated to further clarify the likelihood of subterranean fauna species occurring in and around the Project, specifically the proposed MAR areas. Records were obtained from Western Australian Museum (WAM) and Bennelongia databases within a search area of approximately 100 km x 100 km encompassing the Project (defined by 22.0742°S, 119.4786°E and 22.9943°S and 120.4691°E). The search included many areas that are geologically and hydrologically analogous to or, in some cases such as the Chichester Hub, contiguous with the Project.

4.1. Stygofauna

The desktop review yielded records of 119 species of stygofauna that have been collected in the search area surrounding the Project (Appendix 1), including hydrozoans, platyhelminth flatworms, rotifers, snails, oligochaete and polychaete annelids, nematode roundworms, mites, amphipods, isopods, syncarids, copepods, ostracods and a species of Spelaeogriphacea. Collection locations are mapped in Figure 8.

Records come from a number of projects and studies, with the most relevant to the current assessment being from Roy Hill tenement areas (Bennelongia 2009; SMEC 2009) and further west-northwest throughout Fortescue's Christmas Creek Project (Bennelongia 2007, 2008, 2010, 2012, 2017). Approximately 370 bores have been sampled for stygofauna in the search area (Figure 9). A more detailed view of historical stygofauna sampling effort for Roy Hill assessments is shown in Appendix 3.

Two surveys for stygofauna have previously been undertaken within Roy Hill tenements. Bennelongia (2009) sampled 47 bores in Roy Hill tenements, primarily in and around the Stage 2 Borefield, but also including three bores in or adjacent to the SWIB and the Stage 1 Borefield, and two bores in the Stage 2 MAR Area. A total of 22 species of stygofauna were recorded, with all recorded species known to occur outside the then proposed Stage 2 Borefield impact area and the current Project area. Species recorded in or adjacent to the proposed MAR areas included rotifers, nematodes, oligochaetes, copepods, amphipods, ostracods and syncarids (Stage 2 Borefield); a copepod and an amphipod (Stage 2 MAR Area); and nematodes, oligochaetes, copepods, amphipods, ostracods, an isopod and *Mangkurtu mityula*, a crustacean of the order Spelaeogriphacea (SWIB and Stage 1 Borefield). A subsequent survey for subterranean fauna by SMEC (2009) sampled 49 bores predominantly located in and around LOM pit areas to the northeast of the SWIB. While that report did not provide a list of recorded species *per se*, a total of 124 specimens of stygofauna were collected across 10 bore holes, including oligochaetes, amphipods, copepods, isopods, ostracods and syncarids.

Sampling effort for stygofauna across Fortescue's Christmas Creek Project area, the entirety of which occurs within the search area for the current desktop assessment, has been substantial (Bennelongia 2007, 2008, 2010, 2012, 2017) and has yielded a diverse suite of species. In total, at least 68 species of stygofauna have been recorded across Christmas Creek including Rotifera (3 species), Gastropoda, Polychaeta, Aphanoneura (each with 1 species), Oligochaeta (9 species), Acariformes (1 species), Ostracoda (12 species), Copepoda (22 species), Spelaeogriphacea (1 species) Syncarida (3 species), Amphipoda (11 species), Isopoda (2 species) and Nematoda (treated as 1 species but probably more). Considering that geological units providing stygofauna habitat are contiguous between Christmas Creek and Roy Hill, sampling results at Christmas Creek are considered indicative of the potential suite of stygofauna in the north of the Project area. The geological units identified as the most prospective for stygofauna based on sampling results at Christmas Creek are Tertiary detritals (including alluvium), especially pebble cemented and loose gravel layers; and aquifers in BIF, especially Hardcap and where vughs and pisolitic structures occur in upper MMF strata (Bennelongia 2017).

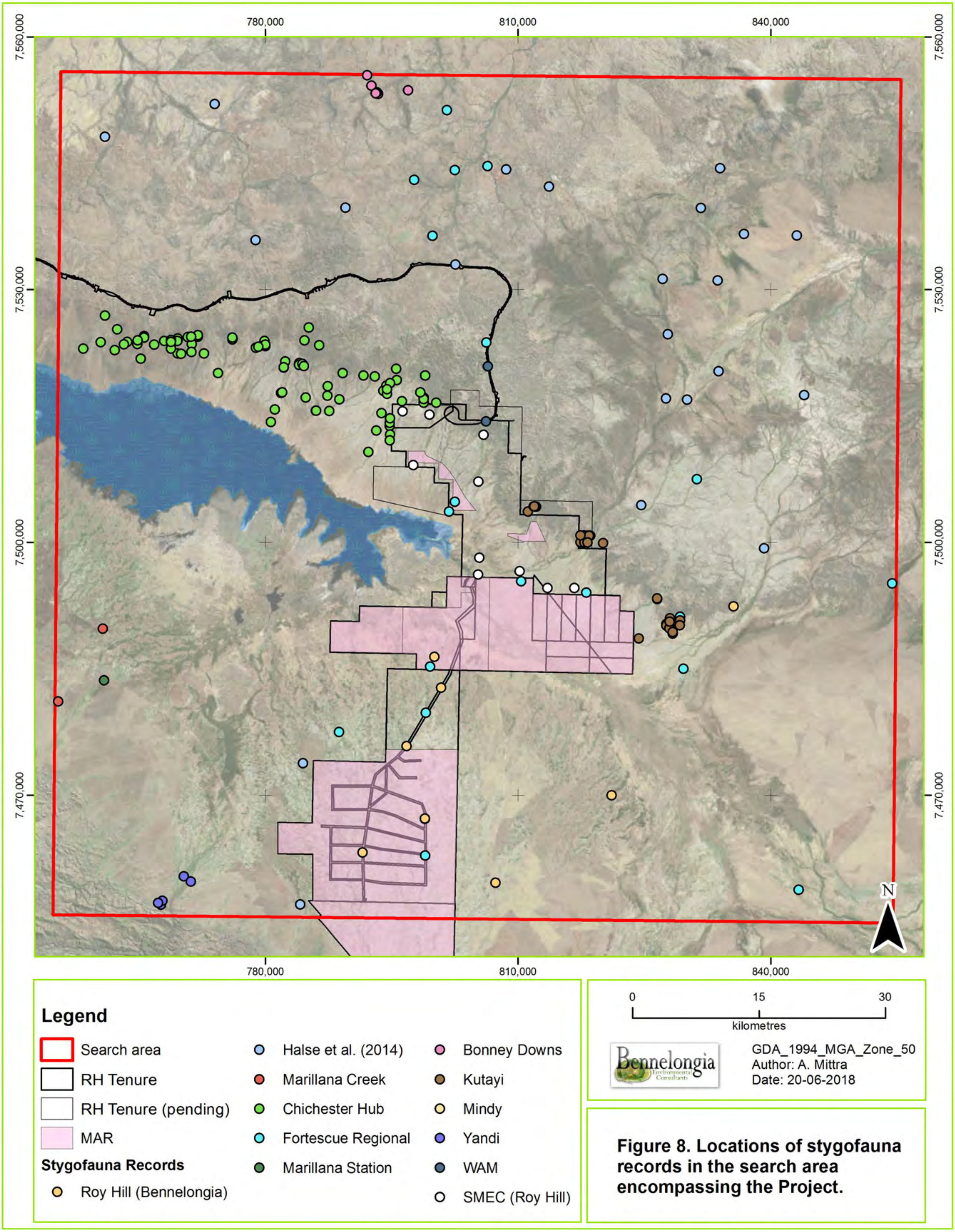

Figure 8. Locations of stygofauna records in the search area encompassing the Project.

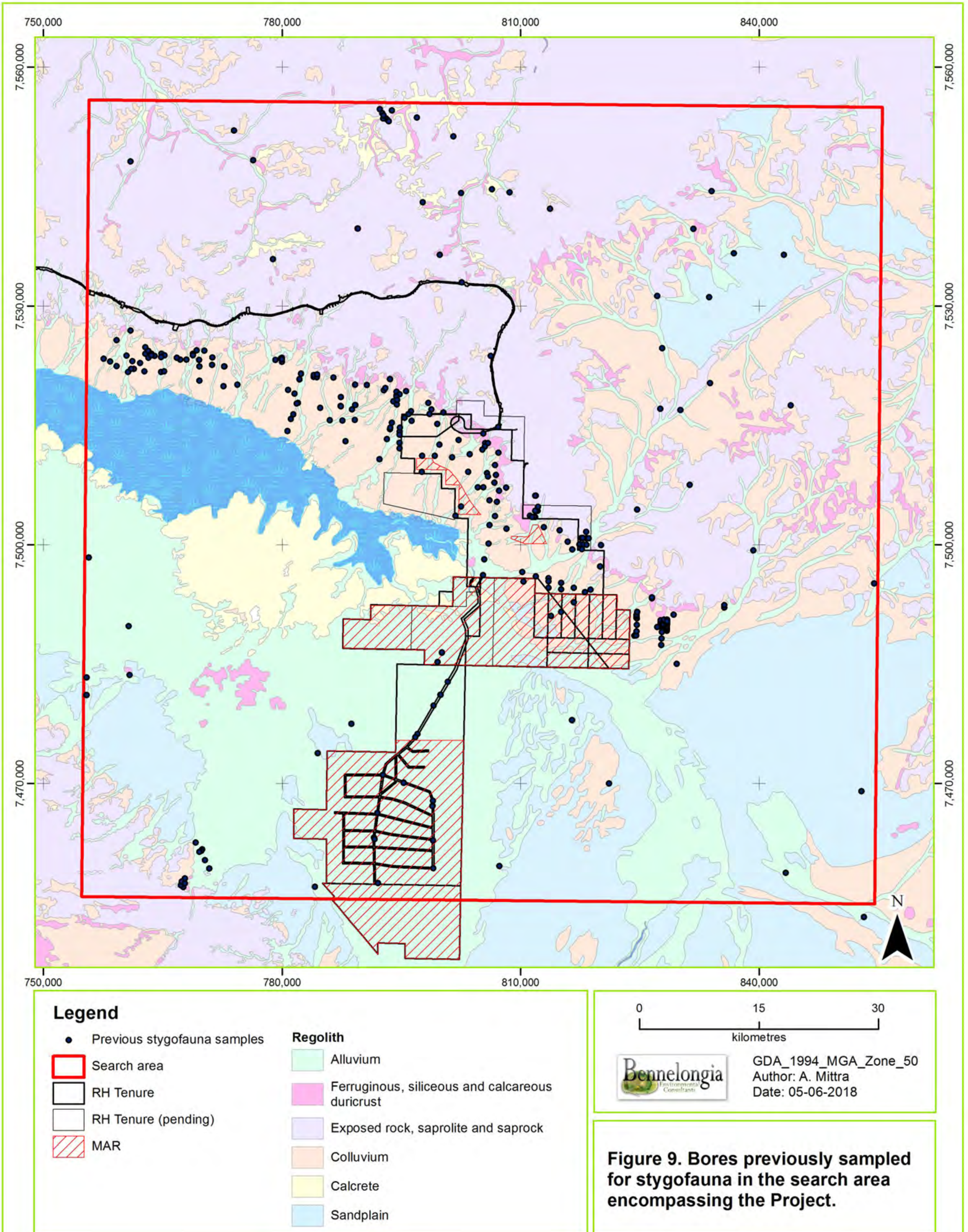

Figure 9. Bores previously sampled for stygofauna in the search area encompassing the Project.

4.2. Troglofauna

At least 66 species of troglofauna have been recorded in the search area surrounding the Project including spiders, palpigrades, pseudoscorpions, schizomids, isopods, diplurans, cockroaches, beetles, true flies, true bugs, silverfish, centipedes, millipedes, pauropods and symphylans (Appendix 2). Records of troglofauna identified in the desktop search (Figure 10) come from a number of project areas and studies. Approximately 700 holes in the search area have been sampled for troglofauna (Figure 11) and a detailed view of historical troglofauna sampling effort for Roy Hill assessments is shown in Appendix 4.

Two species of troglofauna have been recorded in stygofauna samples within Roy Hill tenements – the cockroach *Nocticola* sp. and the isopod nr *Andicophiloscia* sp. B12. The isopod was recorded in Knuckleduster Bore, approximately 2.1 km south of the Stage 2 MAR Area, while the cockroach was recorded in Collins #1 Bore within the Stage 2 Borefield.

The most relevant of the remaining records come from east-northeast of the Project area and from Christmas Creek to the west-northwest (Figure 10). Fourteen species have been collected to the east-northeast and two of these – the pseudoscorpion *Linnaeolpium* sp. B01 and the isopod *Troglarmadillo* sp. B45 – are considered to have potentially restricted distributions. The mineralised MMF deposits from which these animals are likely to have come extend into the Project area but occur at increasing depth in a southwest direction. Considering local relief it is likely that there is a relatively small volume of prospective ironstone habitat in the Roy Hill Project area. Nevertheless, prospective BIF habitat occurs above the water table in the Stage 1 Borefield area.

Targeted sampling effort for troglofauna throughout the Christmas Creek Project area has been significant and has yielded 13 orders and at least 29 troglofauna species. Several recorded species are considered potentially locally restricted (Bennelongia 2012, 2017). In terms of troglofauna habitat, the Christmas Creek area is essentially contiguous with the Project, with geological strata associated with the lower slopes of the Chichesters and Fortescue Valley comprising upper alluvials, Hardcap and weathered mineralised iron deposits of the MMF (Nammuldi Member).

5. ASSESSMENT OF POTENTIAL THREATS

This section discusses the potential and expected effects of MAR on existing subterranean environments and examines the potential threats posed by these changes to subterranean fauna.

5.1. MAR and the Existing Subterranean Environment

The proposed MAR system has the potential to affect the existing groundwater environment in two ways – increasing the salinity of groundwater and increasing groundwater levels.

5.1.1. Salinity

Increased salinity of existing groundwater aquifers (including potential stygofauna habitat) could occur if reinjected disposal water is more saline than background levels, or if increased vertical pressure causes mixing between upper fresher groundwater and underlying hypersaline layers. The effect of increased salinity would be greatest in the immediate vicinity of reinjection and would attenuate over distance and time due to dilution resulting from the lateral flow of surrounding groundwater. MAR water quality parameters are specified in Table 4.

As stated in the hydrogeological assessment for MAR (Roy Hill 2018; Tamisier and Boudouresque 1994), disposal water to be injected into the MMF (see Section 3.1 for hydrogeological context) in the SWIB is less saline than the deep receiving aquifer, which is hypersaline (Table 4). Modelling (Roy Hill 2018) predicts that as the vertical pressure gradient increases injection water will migrate vertically within the zone of reinjection.

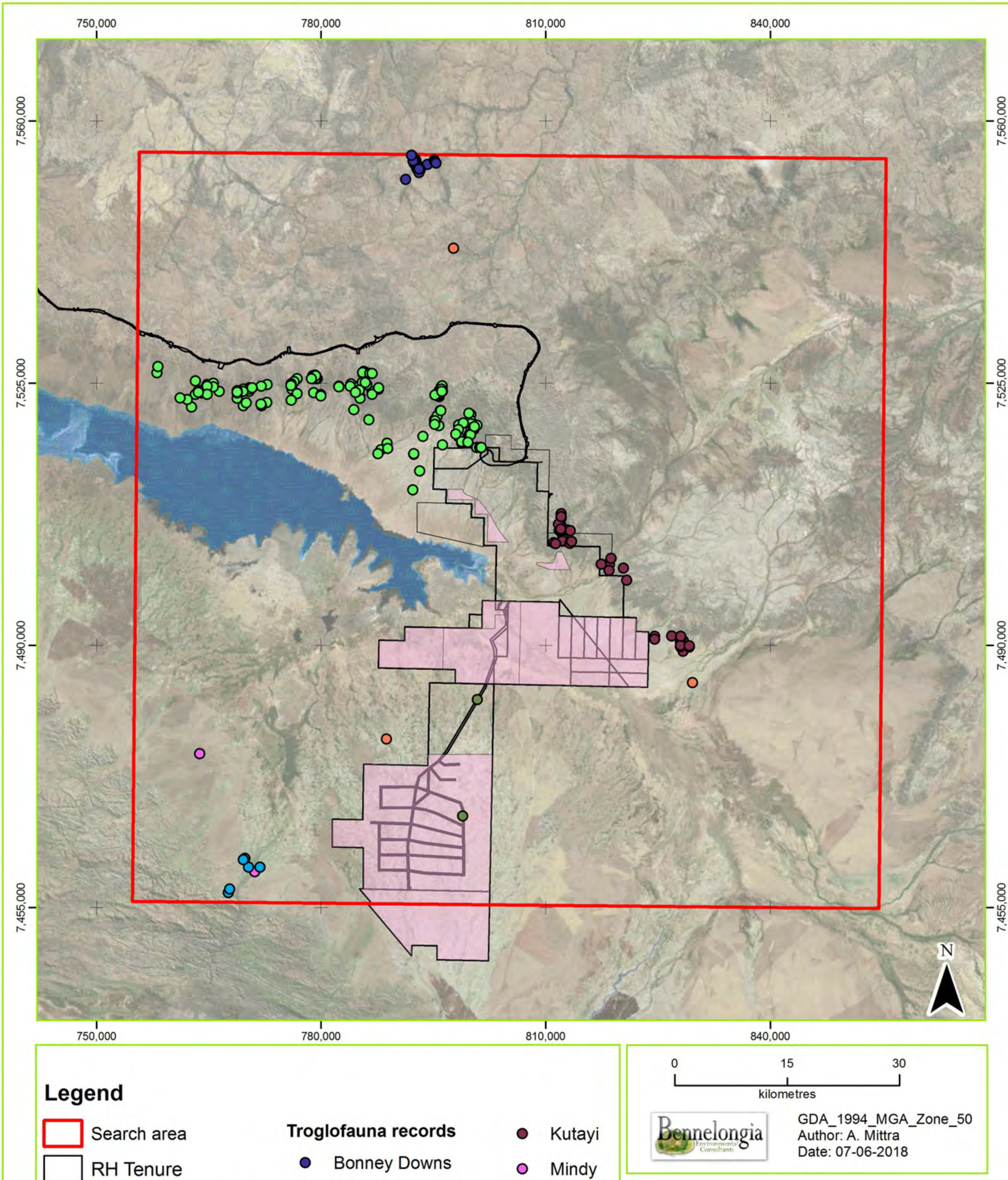

Figure 10. Locations of troglofauna records in the search area encompassing the Project.

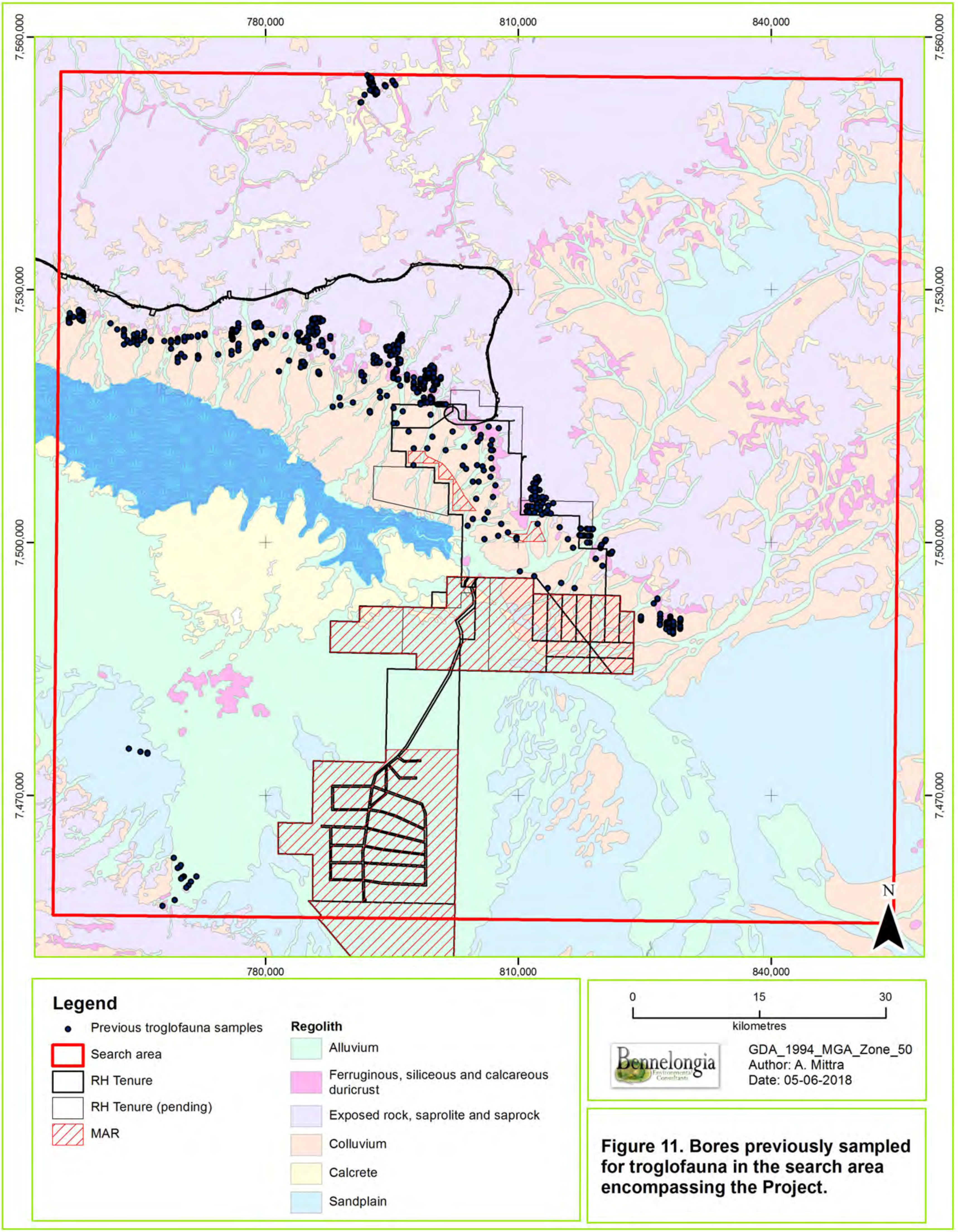

Figure 11. Bores previously sampled for troglofauna in the search area encompassing the Project.

Table 4. Water quality parameters for disposal water in the MAR system and background conditions.

Parameter	SWIB	Stage 1 Borefield	Stage 2 Borefield	Stage 2 MAR Area	Recharge Basins
Total Dissolved Solids (TDS, mg/l)					
Background	>100,000	<3,000	<6,400	960–96,000	<3,000
Disposal water	30,000	5,000	TBC	TBC	5,000
Conductivity (EC, µS/cm)					
Background	>156,00	4,690	<10,000	1,500–150,000	4,690
Disposal water	46,900	7,810	TBC	TBC	7,810

Injection water is not expected to mix vertically through the full stratigraphic column owing to the difference in water density in shallower alluvial aquifers (Roy Hill 2018). Therefore, salinity is not expected to increase in the vicinity of the SWIB as a result of MAR.

Background salinities in the MMF in the Stage 1 Borefield are fresh to brackish and slightly less saline than disposal water (Table 4). Consistent with predictions for the SWIB, injected water is expected to migrate vertically within the zone of influence but is not expected to mix through the full stratigraphic column.

In the vicinity of proposed recharge basins, the receiving alluvial/colluvial aquifers are slightly less saline than disposal water that will be infiltrated at the surface (Table 4). It is expected that water quality beneath and surrounding the recharge basins in the zone of recharge will increase from 3,000 mg/L to 5,000 mg/L.

Background salinities throughout the Stage 2 Borefield are brackish (<10,000 mg/L) and this area has been deemed suitable for brackish reinjection (Managed Recharge 2018). Background salinities in the Stage 2 MAR Area are variable with salinity appearing to increase east-to-west (Managed Recharge 2018). Two bores in the west and northwestern portion of the Stage 2 MAR Area have salinities of 140,000–150,000 µS/cm and the areas around these have been identified as potentially suitable for saline reinjection (Managed Recharge 2018). The likely effects of reinjection on groundwater salinities in the Stage 2 Borefield and Stage 2 MAR Area will be determined in subsequent feasibility studies (Managed Recharge 2018).

5.1.2. Groundwater Levels

Rising groundwater level as a result of reinjection has the potential to remove existing troglofauna habitat via flooding. Conversely, lowering the water table would remove potential habitat for stygofauna, although this is unlikely to occur under MAR conditions.

Based on a prediction of MAR performance in the first two years of operation, the water table will be raised 18 m in the immediate vicinity of the injection borefield and influenced for up to 3 km in a south-to-southwest direction from the injection area of the SWIB. Compared to background water table levels in the vicinity of the SWIB of approximately 20 metres below ground level (mbgl) in the injection borefield and about 6 mbgl close to the Marsh, the water table in the immediate vicinity of injection may rise to 2 mbgl in the last months of the two-year simulation (Roy Hill 2018). Outside the immediate vicinity of the recharge basin and injection area (but within the zone of influence) the water table icreases will be smaller but some mounding will occur at the edge of the Marsh. Predicted changes to the water table around the SWIB are shown in Figure 12.

Based on the same numerical assessment, the water table will be influenced up to around 8 km in a south-to-southwest direction from the injection area of the Stage 1 Borefield and by a magnitude of almost 30 m in the immediate vicinity of the borefield (Figure 13).

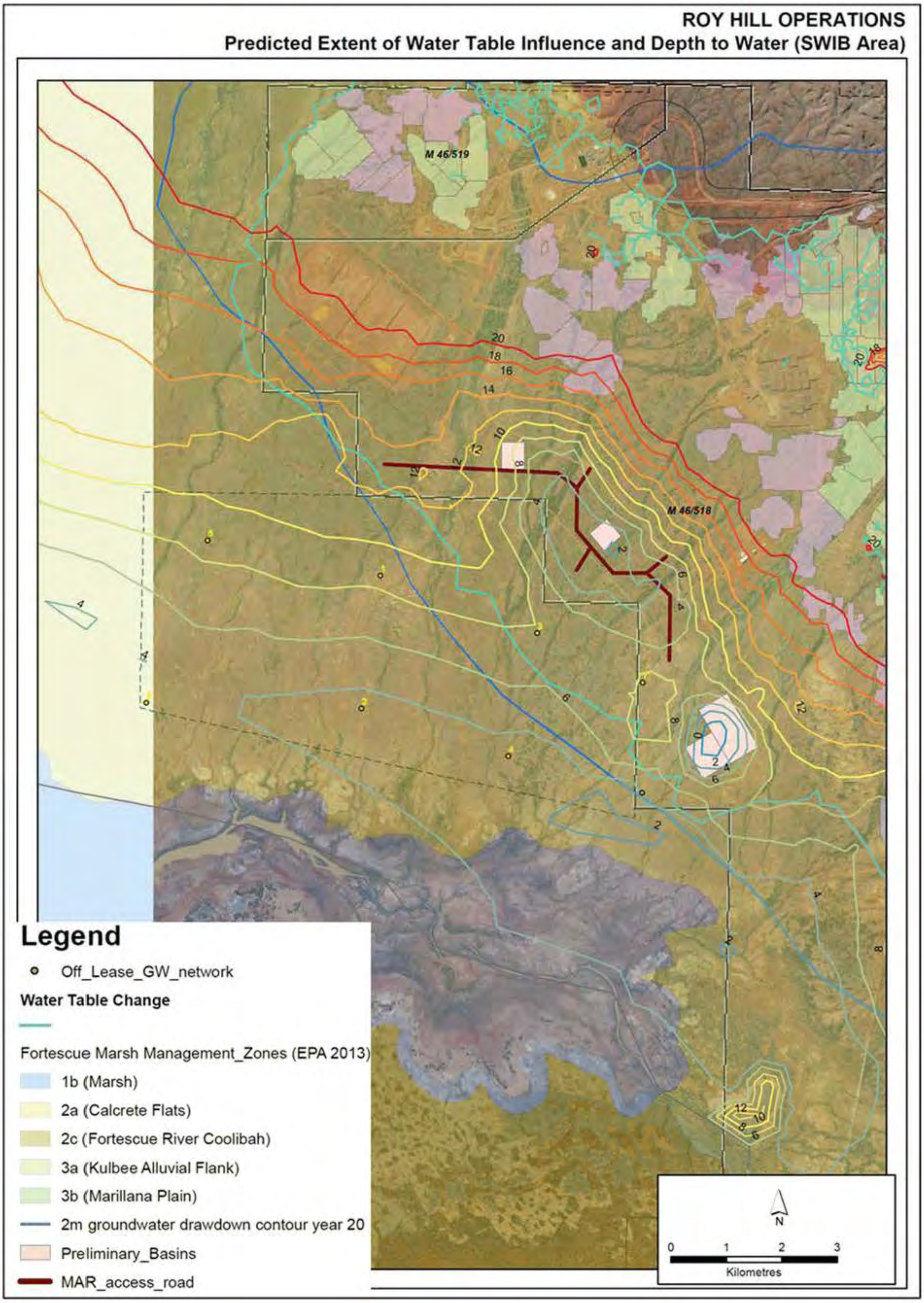

Figure 12. Depth to the watertable after two years of reinjection in the SWIB (Roy Hill 2018). Natural watertable at the injection site is 20 mbgl.

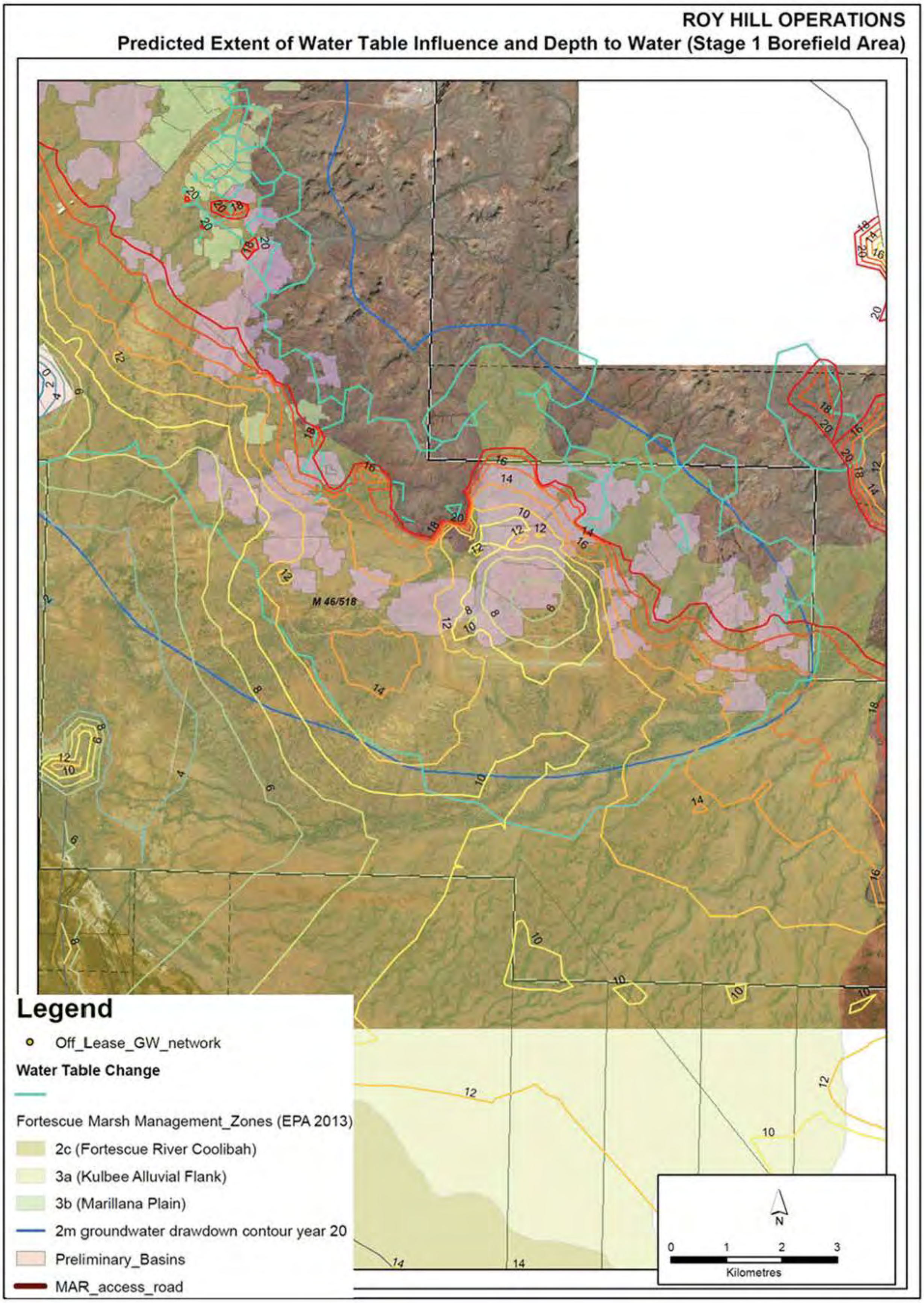

Figure 13. Depth to the watertable after two years of reinjection in the Stage 1 Borefield (Roy Hill 2018).
Natural watertable at the injection site is 35 mbgl.

Compared to background water table levels in the vicinity of the Stage 1 Borefield of approximately 35 mbgl, the water table in the immediate vicinity of injection is predicted to be 6 mbgl in the immediate vicinity of the borefield, although it will be more than 10 mbgl across most of the area affected by reinjection.

The effects of reinjection and groundwater production on groundwater levels in the Stage 2 Borefield and Stage 2 MAR Area have yet to be determined.

5.2. Potential Impacts on Subterranean Fauna

Previous records confirm that subterranean fauna occur in the wider Project area (although it is considered that hitherto sampling effort is unlikely to have captured the complete suite of species present) and MAR therefore has the potential to impact subterranean species and communities.

The potential impacts of mining and related operations on subterranean fauna can be broadly divided into primary impacts, namely, possible extinction or threat to the persistence of local populations through the direct removal of habitat; and secondary impacts, including habitat degradation and reduced population densities through various environmental factors, such as pollutants and altered water chemistry. Assessing the threat of potential secondary impacts generally requires detailed physicochemical information related to the environmental changes expected to occur. Some further information on sencondary impacts is given in Appendix 5.

The potential threats to subterranean fauna as a result of MAR comprise a mixture of primary and secondary impacts and are summarised in Table 5 and discussed further in subsequent sections. It is noted that this assessment of potential threats to subterranean fauna is based on hydrogeological modelling of water level changes in the first two years of operation of MAR in the SWIB and Stage 1 Borefield (Roy Hill 2018), as well as the Phase 1 Feasability Study for the Stage 2 Borefield and Stage 2 MAR Area (Managed Recharge 2018). Modelling of the cumulative effects of MAR and dewatering drawdown for the life of mine (LOM) is yet to be completed. A definitive assessment of the potential threats on subterranean species and communities in the Project area as a result of aquifer management will need to consider the combined effect on groundwater levels of both aquifer recharge via reinjection (MAR) and drawdown via pit dewatering and water production. The assessment will need to consider both groundwater levels and salinity levels following the LOM period compared to background conditions.

Table 5. Summary of potential threats to subterranean fauna as a result of aquifer management at the Project.

Fauna	Threat	Primary/secondary	Comments
Stygofauna	Salinisation	Both, depending on severity	Moderate increases (slightly outside natural limits) may cause reductions in stygofauna fitness and population densities. More severe rises could effectively remove suitable habitat leading to loss of species and communities.
	Modified groundwater levels	Primary	Increased groundwater levels (recharge) will not threaten stygofauna. Drawdown (dewatering, water production) could lower the water table and directly remove stygofauna habitat resulting in species and community loss. The actual effect on water levels will depend on both MAR and drawdown.
Troglofauna	Modified groundwater levels	Primary	Increased groundwater levels via recharge may act to flood troglofauna habitat that currently sits above the water table, causing direct habitat removal for troglofauna. This effect may be counteracted by drawdown.

5.2.1. Stygofauna

Based on the modelled outcomes of reinjection alone, there is no threat of the removal of stygofauna habitat through modified water levels, as the water table in the zone of influence is predicted to increase relative to background conditions.

Assuming the predictions of the MAR assessment (Roy Hill 2018) are correct, reinjection of disposal water via the SWIB and Stage 1 Borefield will not cause significant groundwater mixing. Deeper saline water will rise due to increasing water pressure as a result of reinjection, but will continue to underlie fresh and brackish surficial aquifers following injection due to differences in water density at different salinities. Under this assumption, there is no threat of stygofauna habitat loss via increased salinity following reinjection in either the SWIB or the Stage 1 Borefield.

If aquifer mixing does occur, salinisation of fresh and brackish habitats in alluvial and detrital geologies (and possibly, to a lesser extent, in the MMF) could lead to alteration of existing stygofauna communities proportional to the magnitude of salinisation.

It is likely that the surficial aquifer in the vicinity of proposed recharge basins will experience salinity increase from approximately 3,000 mg/L up to approximately 5,000 mg/L (Roy Hill 2018). While the spatial extent of this potential effect is uncertain, rates of horizontal groundwater flow in the Fortescue Valley are low (Skrzypek *et al.* 2013). Low horizontal flow rates mean that attenuation effect of flow is limited. However, the increase of in salinity of 3,000 mg/L to 5,000 mg/L lies within the natural variation of groundwater salinity in the surficial aquifer around recharge sites and the impact on stygofauna is likely to be low. While the salinity tolerance thresholds for individual species of stygofauna are unknown, they are likely to reflect the natural environmental conditions of local habitats, with widespread species usually likely to tolerate a wider range of salinities than more restricted ones.

Overall, under the modelled outcomes of the MAR system for the SWIB and Stage 1 Borefield, habitat loss through either groundwater levels or salinisation is not considered a significant threat to stygofauna species that may occur in and around the Project. It is reiterated that this assessment may change depending on the net effect of reinjection and drawdown, which is yet to be determined. If drawdown exceeds aquifer recharge, decreased groundwater levels would cause the direct removal of stygofauna habitat.

The potential threat to stygofauna species in and around the Stage 2 Borefield and Stage 2 MAR Area will depend on the effects of aquifer management on existing aquifers as predicted by modelling, which is yet to be undertaken.

5.2.2. Troglofauna

The primary threat to troglofauna from the MAR system is the potential for habitat loss via flooding as the water table rises following reinjection at depth and an increase vertical pressure. This will only occur if reinjection exceeds drawdown, although this net effect is yet to be determined.

Prospectivity for troglofauna in the SWIB is considered to be moderate, with potential habitat for troglofauna occurring entirely in upper alluvials, the prospectivity of which will depend on the characteristics of the alluvium. Remaining strata (detritals, MMF) occur below the water table. Considering the extent and connectivity of alluvial habitat throughout the Fortescue Valley, species occuring in alluvials at the Project could reasonably be expected to have moderately large distributions relative to the extent of proposed impacts. However, a net increase in groundwater levels will result in some loss of potential troglofauna habitat in the vicinity of the SWIB and may possibly affect some troglofauna species.

Geologies in the Stage 1 Borefield are considered more prospective for troglofauna than the SWIB, with additional geologies available above the water table including detritals and upper strata of the MMF (see Section 3 and Figure 7). Again, the values of troglofauna assemblages that may occur in this vicinity remain unquantified. Compared to the current water table that sits at approximately 35 mbgl, it is predicted that the water table in the Stage 1 Borefield area will rise to 6 mbg in the immediate vicinity of injection, suggesting a greater volume of potential troglofauna habitat may be lost in the Stage 1 Borefield than in the SWIB. While the ranges of species in BIF geologies are likely to be somewhat tighter than species inhabitating less consolidated geologies such as alluvials, all the geological units considered prospective for troglofauna in the Stage 1 Borefield extend beyond any influence of reinjection and species may have larger ranges than the areas withgroundwater increase.

The potential threat to troglofauna species in and around the Stage 2 Borefield and Stage 2 MAR Area will depend on the effects of MAR on the surficial aquifer as predicted by numerical modelling, particularly in relation to changes in background watertable levels. These potential changes have yet to be determined by Roy Hill. Prospective habitats for troglofauna in these areas predominantly comprise alluvials and calcrete above the water table. Mapped surficial geology suggests that these units are moderately extensive and there is the potential for habitat connectivity (Figure 3). If so, the effect of fluctuating groundwater levels on troglofauna species in the Stage 2 Borefield and Stage 2 MAR Area may be mitigated by the spatial extent of habitat and associated species ranges.

6. CONCLUSIONS

This desktop assessment identified potentially prospective habitat for both stygofauna and troglofauna within the Project, including areas proposed for managed aquifer recharge in the South West Injection Borefield, Stage 1 Borefield, Stage 2 Borefield and Stage 2 MAR Area.

Previous records of both stygofauna and troglofauna species in both Roy Hill tenements and neighbouring areas with similar or contiguous geology also point to the likely presence of both stygofauna and troglofauna in the MAR areas. The conservation values of the potential assemblages in these areas remain to be quantified through field survey, although a small number of species have previously been recorded in the SWIB, Stage 2 Borefield and Stage 2 MAR Area from limited sampling effort.

Disposal water is generally less saline than receiving aquifers and it is predicted that vertical mixing of aquifers in the reinjection areas will not occur. This means increases in salinity of the surficial aquifer is not predicted to occur in the vicinity of the SWIB or the Stage 1 Borefield. The predicted effects on salinity of aquifer management in the Stage 2 Borefield and Stage 2 MAR Area remain to be determined,

It is expected that water quality beneath and surrounding the recharge basins in the zone of influence will increase from 3,000 mg/L to 5,000 mg/L. This increase is within natural variation that occurs in surficial aquifers surrounding the recharge basins.

Species-specific salinity tolerances for stygofuana are unknown but are likely to reflect natural environmental conditions. Based on modelled changes, changes to salinity as a result of MAR in the SWIB and Stage 1 Borefield is not considered a significant threat to stygofauna. This is also likely to be the case in the Stage 2 Borefield and MAR Areas, assuming that the aquifers selected are of suitable salinities to receive disposal water.

While the net effect of reinjection and dewatering drawdown are yet to be modelled for the Project area, if aquifer recharge following reinjection exceeds drawdown as a result of mine dewatering, some degree of troglofauna habitat loss is likely to occur in MAR areas (volumes lost when the effects of reinjection alone are considered are large). While the values of troglofauna assemblages in these areas remain to be quantified, all geological units within borefields cover larger areas than the likely extent of groundwater mounding and, accordingly, troglofauna species in these areas are likely to have larger ranges than the extent of predicted impacts. Species in BIF units, such as the MMF in the Stage 1 Borefield, may have tighter distributions than species in alluvial and detrital habitats.

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8. APPENDICES

Appendix 1. Stygofauna species recorded in a search area of approximately 100 km x 100 km encompassing the Project.

The search area is defined by 22.0742°S, 119.4786°E and 22.9943°S and 120.4691°E.

Higher Classification	Lowest Identification	No. of Sites
Cnidaria		
Hydrozoa		
Olindiidae	Olindiidae sp.	1
Platyhelminthes		
Turbellaria	Turbellaria sp.	1
Mollusca		
Gastropoda		
Hypsogastropoda		
Hydrobiidae	Hydrobiidae sp. B04	2
Annelida		
Aeolosomatidae	*Aeolosoma* sp. 1 (PSS)	4
Enchytraeidae	*Enchytraeus* AP PSS1 sp.	7
	Enchytraeus AP PSS2 sp.	6
	Enchytraeus sp. Ench4	2
	Enchytraeus sp. Ench5	1
	Enchytraeus sp. Ench7	1
	Enchytraeus sp. Ench8	1
Naididae	*Pristina longiseta*	6
Phreodrilidae	*Insulodrilus lacustris* s.l. Pilbara type 2/3 (PSS)	2
	Phreodrilus peniculus	3
Phreodrilidae	Phreodrilidae AP DVC spp.	16
	Phreodrilidae AP SVC spp.	8
Tubificidae	*Monopylephorus* sp. nov. WA29 (ex *Pristina* WA3) (PSS)	1
	Tubificidae sp. stygo morphotype 2 (PSS)	1
	Tubificidae sp. stygo type 4	1
Naididae	Tubificoid Naididae AP 5 sp.	3
Polychaeta		
Nereididae	*Namanereis pilbarensis*	2
Rotifera		
Eurotatoria		
Bdelloidea		
Philodinidae	*Dissotrocha* sp.	2
	Bdelloidea sp. 2:2	7
Monogononta		
Flosculariacea		
Filiniidae	*Filinia australiensis*	1
	Filinia longiseta	1
Nematoda	Nematoda sp. 01 (PSS)	1
	Nematoda sp. 19 (PSS)	1
Arthropoda		
Chelicerata		
Arachnida		
Trombidiformes		
Anisitsiellidae	*Rutacarus* sp.	1
Halacaridae	Halacaridae sp. 1 (PSS)	1
Mideopsidae	*Guineaxonopsis* sp.	1
Crustacea		
Malacostraca		
Amphipoda		
Bogidiellidae	*Bogidiella* sp. B03	2
	Bogidiella sp. B04	2
	Bogidiellidae sp. 1 (PSS)	1
Melitidae	Melitidae sp. B01 (sp. 1 group)	1
Paramelitidae	*Chydaekata* sp. B02	3
	Chydaekata sp. B03	2
	Maarrka etheli	4
	Molina cf. *pleobranchos* (PSS)	1

Higher Classification	Lowest Identification	No. of Sites
	nr *Pilbarus* sp. B06	2
	Paramelitidae cf. sp. 2 (PSS)	2
	Paramelitidae Genus 2 sp. B01	1
	Paramelitidae Genus 2 sp. B10	2
	Paramelitidae Genus 2 sp. B11	5
	Paramelitidae sp. 2 (PSS)	4
	Paramelitidae sp. 6 (PSS)	2
	Paramelitidae sp. 7 (PSS)	3
	Paramelitidae sp. B12	20
	Paramelitidae sp. B15	7
	Paramelitidae sp. B29	6
	Paramelitidae sp. Coondiner	7
Isopoda		
Microcerberidae	Microcerberidae sp. B01	4
	Microcerberidae sp. B08	2
Tainisopidae	*Pygolabis* sp. B08	2
	Pygolabis weeliwolli	2
Spelaeogriphidae	*Mangkurtu kutjarra*	12
Syncarida		
Bathynellidae	*Bathynella* sp. B02 (Christmas Creek)	5
	Bathynellidae sp. MC	1
Parabathynellidae	*Atopobathynella* sp. B05	1
	Chilibathynella sp.	1
	Notobathynella sp.	2
	Parabathynellidae sp. MC	3
	Bathynellaceae sp.	1
Maxillopoda		
Calanoida	Calanoida sp.	2
Cyclopoida		
Cyclopidae	*Anzcyclops* sp. CCk	1
	Australocyclops sp.	1
	Diacyclops cockingi	1
	Diacyclops einslei	1
	Diacyclops humphreysi humphreysi	27
	Diacyclops humphreysi unispinosus	20
	Diacyclops sobeprolatus	7
	Dussartcyclops (Dussartcyclops) mortoni	2
	Ectocyclops phaleratus	1
	Goniocyclops sp.	2
	Mesocyclops brooksi	5
	Mesocyclops darwini	1
	Mesocyclops notius	1
	Metacyclops 3443 sp. B03	2
	Metacyclops sp. B01 nr *pilbaricus*	2
	Microcyclops varicans	19
	Orbuscyclops sp.	1
	Pilbaracyclops frustratio	2
	Pilbaracyclops sp. B03 (nr *frustratio*)	2
	Thermocyclops aberrans	2
Harpacticoida		
Ameiridae	*Archinitocrella newmanensis*	1
	Megastygonitocrella bispinosa	3
	Megastygonitocrella trispinosa	1
	Megastygonitocrella unispinosa	8
Canthocamptidae	*Australocamptus* sp. B07	1
	Canthocamptidae sp. B02	8
	Elaphoidella humphreysi	8
	Elaphoidella sp. B01 (PIL)	1
Ectinosomatidae	*Pseudectinosoma galassiae*	2
Parastenocarididae	*Parastenocaris jane*	17
	Parastenocaris sp. nov. B02	1
	Harpacticoida sp. B03	1

Higher Classification	Lowest Identification	No. of Sites
Ostracoda		
Candonidae	?Candoninae sp.	1
	?*Candonopsis tenuis*	1
	Areacandona sp.	2
	Candonopsis `tuccamunna` (PSS)	1
	Candonopsis cf. *tenuis* (PSS)	1
	Candonopsis dedeckkeri	1
	Candonopsis tenuis	3
	Humphreyscandona akaina	1
	Kencandona harleyi	1
	Meridiescandona facies	2
	Meridiescandona lucerna	1
	Notacandona whitecliff	2
	nr *Areacandona* sp. BOS315	2
	Origocandona sp.	1
	Pilbaracandona colonia	1
	Pilbaracandona rhabdote	12
Cyprididae	*Cypretta seurati*	1
	Cyprididae sp. A	2
	Cyprinopsinae sp.	1
	Riocypris fitzroyi	1
	Sarscypridopsis ochracea	3
	Stenocypris bolieki	3
	Strandesia kimberleyi	1
Darwinulidae	Darwinulidae sp.	1
Limnocytheridae	*Limnocythere stationis*	2

Higher Order Classifications

Higher Classification	Lower Identification	No. of Sites
Rotifera		
Eurotatoria		
Bdelloidea		
Philodinidae	Bdelloidea sp.	7
Annelida		
Enchytraeidae	Enchytraeidae sp.	19
	Enchytraeus sp.	18
Phreodrilidae	*Insulodrilus* sp.	1
Tubificidae	Tubificidae sp.	1
	Oligochaeta sp.	22
Nematoda	Nematoda sp.	64
Arachnida		
Trombidiformes		
Halacaridae	Halacaridae sp.	1
Crustacea		
Malacostraca		
Amphipoda		
Bogidiellidae	Bogidiellidae sp.	1
Paramelitidae	*Chydaekata* sp.	3
	Paramelitidae sp.	11
	Amphipoda sp.	15
Isopoda		
Microcerberidae	Microcerberidae sp.	12
Tainisopidae	*Pygolabis* sp.	2
Syncarida		
Parabathynellidae	*Atopobathynella* sp.	3
Maxillopoda		
Cyclopoida		
Cyclopidae	*Diacyclops* sp.	7
	Mesocyclops sp.	2
	Metacyclops sp.	1
	Thermocyclops sp.	1

Higher Classification	Lower Identification	No. of Sites
	Cyclopoida sp.	5
Harpacticoida		
Ameiridae	Ameiridae sp.	2
Canthocamptidae	*Elaphoidella* sp.	1
Parastenocarididae	Parastenocarididae sp.	1
	Parastenocaris sp.	21
	Harpacticoida sp.	3
Ostracoda	Ostracoda sp. unident.	23

Appendix 2. Troglofauna species recorded in a search area of approximately 100 km x 100 km encompassing the Project.

The search area is defined by 22.0742°S, 119.4786°E and 22.9943°S and 120.4691°E.

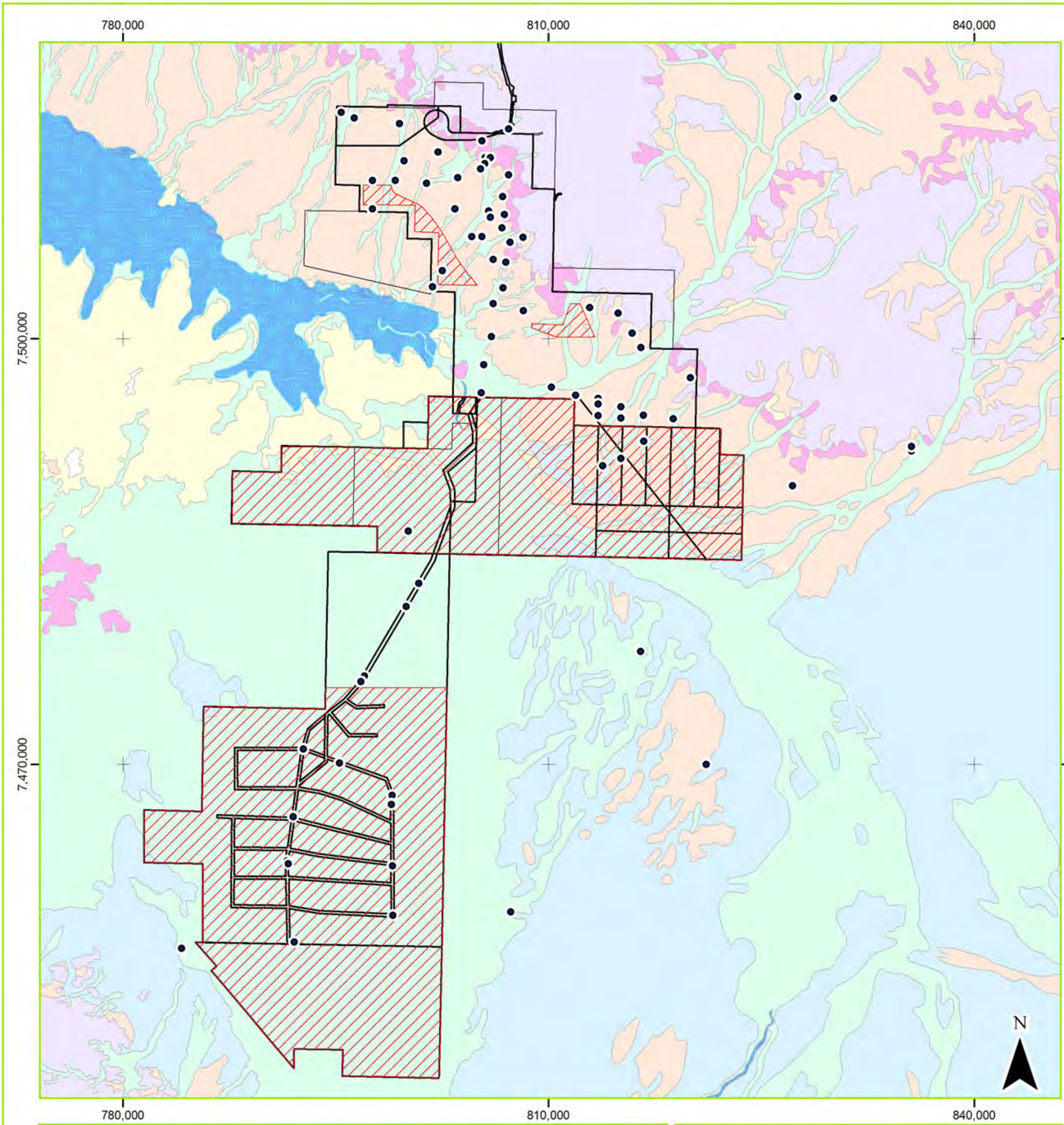
Higher Classification	Lowest Identification	No. of Sites
Arthropoda		
Chelicerata		
Arachnida		
Araneae		
Gnaphosidae	nr *Encoptarthria* sp. B05	3
	nr *Encoptarthria* sp. B07	1
Oonopidae	Oonopidae sp. MC	1
	Prethopalpus sp.	3
Symphytognathidae	*Anapistula* sp. MC	1
	Araneomorphae sp. B03	1
Palpigradi	Palpigradi sp. B12	2
	Palpigradi sp. MC	3
Pseudoscorpiones		
Chthoniidae	Chthoniidae sp.	1
	Tyrannochthonius `PSE054`	1
Hyidae	*Indohya* sp. B07	6
Olpiidae	*Indolpium* `PSE099`	1
	Linnaeolpium sp. B01	1
	Olpiidae sp. MC	1
Schizomida		
Hubbardiidae	*Draculoides* `SCH019`	4
	Draculoides `SCH104-DNA`	2
	Draculoides sp. B33	1
Crustacea		
Malacostraca		
Isopoda		
Armadillidae	Armadillidae sp. B09	2
	Gen. nov. 2 (nr *Buddelundia*) sp. B01	2
	Troglarmadillo sp. B30	4
	Troglarmadillo sp. B31	11
	Troglarmadillo sp. B40	2
	Troglarmadillo sp. B45	1
Philosciidae	*Andricophiloscia* sp.	1
	nr *Andricophiloscia* sp. B12	1
	nr *Andricophiloscia* sp. B20	1
	Philosciidae `ISO017`	1
Stenoniscidae	Stenoniscidae gen. nov. sp. B03	2
Hexapoda		
Entognatha		
Diplura		
Anajapygidae	Anajapygidae sp. B02	4
Japygidae	Japygidae sp. B22	3
	Japygidae sp. B29	1
	Japygidae sp. B35	4
Parajapygidae	Parajapygidae `DPL019`	1
	Parajapygidae `DPL031`	7
	Parajapygidae sp. B24	1
Projapygidae	Projapygidae sp. B12	2
	Projapygidae sp. B21	1
Insecta		
Blattodea		
Blattidae	Blattidae sp. S02	2
Nocticolidae	*Nocticola* `BLA003`	3
	Nocticola currani	8
	Nocticola sp. B04	5
	Nocticola sp. B04/B05 (imm or female)	12
	Nocticola sp. B20	8

Higher Classification	Lowest Identification	No. of Sites
Coleoptera		
Carabidae	Bembidiinae sp.	2
Curculionidae	Cryptorhynchinae sp.	1
	Curculionidae sp.	1
	Coleoptera sp. B05	1
Diptera		
Sciaridae	Sciaridae sp. B01	1
Hemiptera		
Meenoplidae	Meenoplidae sp.	7
	Phaconeura sp.	20
Reduviidae	Reduviidae sp.	1
Thysanura		
Nicoletiidae	*Dodecastyla* sp. B02 (=?*Atelurodes* sp. S02)	2
	Trinemura sp. B15	3
	Trinemura sp. B18	1
	Trinemura sp. B19	1
	Trinemura sp. MC	1
Myriapoda		
Chilopoda		
Cryptopidae	*Cryptops* sp. B04 (nr *megalophora*)	1
	Cryptops sp. B32	1
	Cryptops sp. B35	1
	nr *Cryptops* sp. B15	1
Scolopendridae	Scolopendra sp.	2
Diplopoda		
Polyxenida		
Lophoproctidae	*Lophoturus madecassus*	38
Polyxenidae	Polyxenidae sp.	6
Pauropoda		
Tetramerocerata		
Pauropodidae	Pauropodidae sp. B04 (*Decapauropus tenuis*?)	1
Symphyla		
Cephalostigmata		
Scutigerellidae	*Hanseniella* sp. B16	12
	Symphyella sp. B11	1

Higher Order Classifications

Higher Classification	Lower Identification	No. of Sites
Arthropoda		
Chelicerata		
Arachnida		
Araneae		
Gnaphosidae	nr *Encoptarthria* sp.	1
Palpigradi	Palpigradi sp.	8
Pseudoscorpiones		
Chthoniidae	*Tyrannochthonius* sp.	1
Hyidae	Hyidae sp.	1
Olpiidae	Olpiidae sp.	1
	Pseudoscorpiones sp.	2
Schizomida		
Hubbardiidae	*Draculoides* sp.	4
	Schizomida sp.	2
Crustacea		
Malacostraca		
Isopoda		
Philosciidae	Philosciidae sp.	2
	Isopoda sp.	1
Hexapoda		
Entognatha		
Diplura		
Japygidae	Japygidae sp.	6

Higher Classification	Lower Identification	No. of Sites
Parajapygidae	Parajapygidae sp.	1
Insecta		
Blattodea		
Blattidae	Blattidae sp.	11
Nocticolidae	*Nocticola* sp.	101
	Nocticolidae sp.	2
	Blattodea sp.	2
Coleoptera	Coleoptera sp.	1
Diptera		
Sciaridae	Sciaridae sp.	4
Thysanura		
Nicoletiidae	Ateluridae sp.	1
	Atelurinae sp.	3
	Nicoletiidae sp.	1
	Nicoletiinae sp.	3
	Trinemura sp.	1
Chilopoda		
Cryptopidae	*Cryptops* sp.	1
Diplopoda		
Polyxenida		
Lophoproctidae	Lophoproctidae sp.	27
Pauropoda		
Tetramerocerata		
Pauropodidae	Pauropoda sp.	3
Symphyla		
Cephalostigmata		
Scutigerellidae	*Hanseniella* sp.	2
	Symphyla sp.	19



Legend

- Previous stygofauna samples
- RH Tenure
- RH Tenure (pending)
- MAR

Regolith

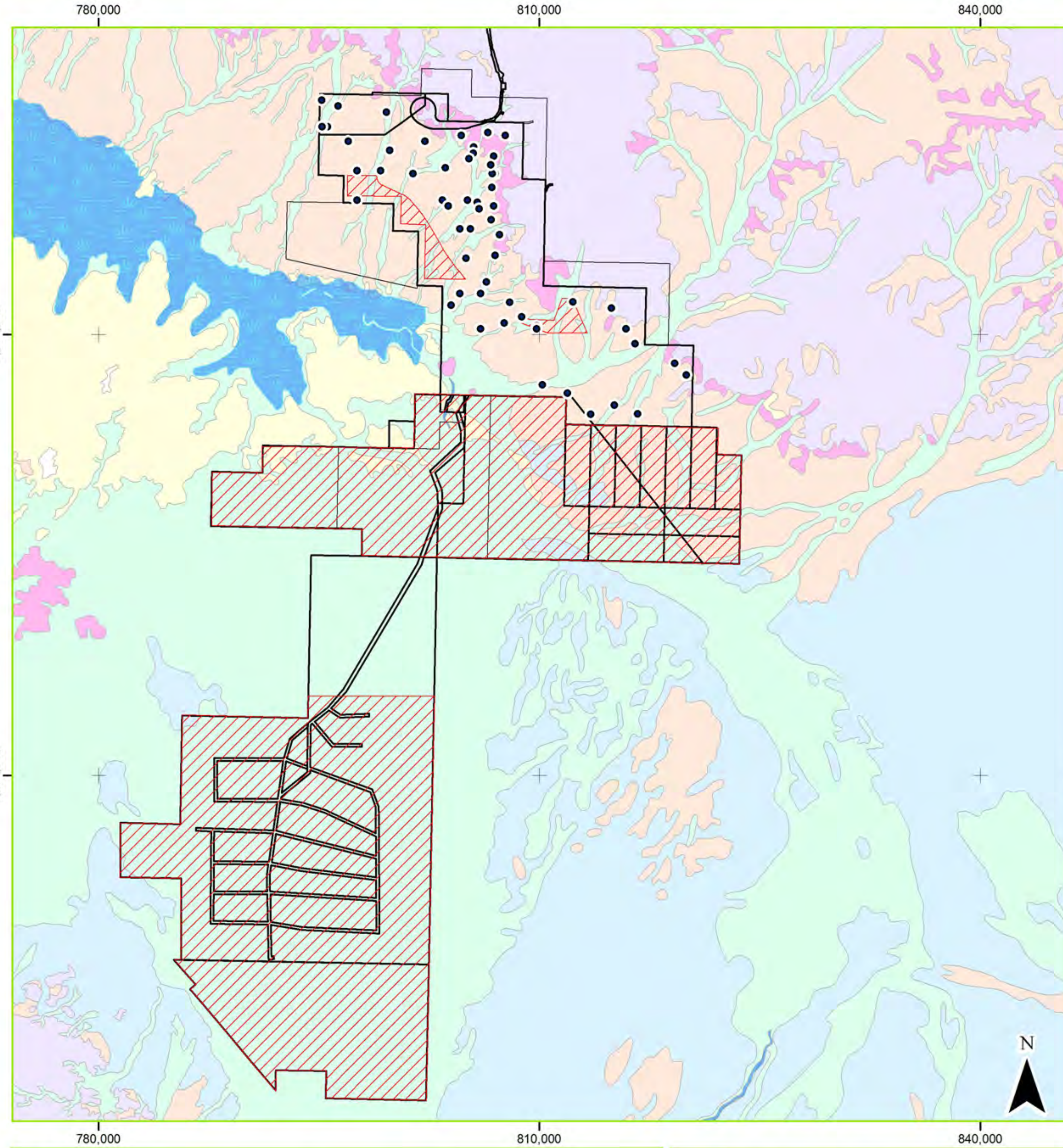
- Alluvium
- Ferruginous, siliceous and calcareous duricrust
- Exposed rock, saprolite and saprock
- Colluvium
- Calcrete
- Sandplain

0 10 20
kilometres

Bennelongia Environmental Consultants

GDA_1994_MGA_Zone_50
Author: A. Mittra
Date: 05-06-2018

Appendix 3. Locations of bores sampled for stygofauna for previous Roy Hill assessments.



Legend

- Previous stygofauna samples
- RH Tenure
- RH Tenure (pending)
- MAR

Regolith

- Alluvium
- Ferruginous, siliceous and calcareous duricrust
- Exposed rock, saprolite and saprock
- Colluvium
- Calcrete
- Sandplain

0 10 20
kilometres

Bennelongia Environmental Consultants

GDA_1994_MGA_Zone_50
Author: A. Mittra
Date: 05-06-2018

Appendix 4. Locations of bores sampled for troglofauna for previous Roy Hill assessments.

Appendix 5. Secondary Impact of Mining on Subterranean Fauna.

Mining activities that may result in secondary impacts to subterranean fauna include:

1. *De-watering below troglofauna habitat*. The impact of a lowered water table on subterranean humidity and, therefore, the quality of troglofauna habitat is poorly studied but it may represent risk to troglofauna species in some cases. The extent to which humidity of the vadose zone is affected by depth to the water table is unclear. Given that pockets of residual water probably remain trapped throughout de-watered areas and keep the overlying substrate saturated with water vapour, de-watering may have minimal impact on the humidity in the unsaturated zone. In addition, troglofauna may be able to avoid undesirable effects of a habitat drying out by moving deeper into the substrate if suitable habitat exists at depth. Overall, de-watering outside the proposed mine pits is not considered to be a significant risk to troglofauna.
2. *Percussion from blasting*. Impacts on both stygofauna and troglofauna may occur through the physical effect of explosions. Blasting may also have indirect detrimental effects through altering underground structure (usually rock fragmentation and collapse of voids) and transient increases in groundwater turbidity. The effects of blasting are often referred to in grey literature but are poorly quantified and have not been related to ecological impacts. Any effects of blasting are likely to dissipate rapidly with distance from the pit and are not considered to be a significant risk to either stygofauna or troglofauna outside the proposed mine pits.
3. *Overburden stockpiles and waste dumps*. These artificial landforms may cause localised reduction in rainfall recharge and associated inflow of dissolved organic matter and nutrients because water runs off stockpiles rather than infiltrating through them and into the underlying ground. The effects of reduced carbon and nutrient input are likely to be expressed over many years and are likely to be greater for troglofauna than stygofauna (because lateral movement of groundwater should bring in carbon and nutrients). The extent of impacts on troglofauna will largely depend on the importance of chemoautotrophy in driving the subterranean system compared with infiltration-transported surface energy and nutrients. Stockpiles are unlikely to cause species extinctions, although population densities of species may decrease under them.
4. *Aquifer recharge with poor quality water*. It has been observed that the quality of recharge water declines during, and after, mining operations as a result of rock break up and soil disturbance. Impacts can be minimised through management of surface water and installing drainage channels, sumps and pump in the pit to prevent of recharge though the pit floor.
5. *Aquifer salinisation*. This may result from aquifer mixing during reinjection or from the disposal of high salinity water into fresher aquifers. Most freshwater invertebrates are not able to maintain body fluid solute concentrations lower than the external aquatic environment, making them vulnerable to dehydration, as salinity increases. Rare species tend to be more sensitive with narrower ranges of salinity tolerance than common species and are therefore more likely to drop out of assemblages following salinisation. Prolonged (chronic) exposure to sub-lethal doses of salinity has been shown to affect a range of ecologically-significant biologically responses in aquatic invertebrates. The level of risk posed by aquifer salinisation to each stygofauna species that is potentially unable to withstand increased salinity will depend on the spatial distribution of that species relative to the spatial extent of elevated salinity.
6. *Contamination of groundwater by hydrocarbons*. This may occur as a result of the drilling process. The spatial extent of contamination around each hole is usually unclear but is likely to depend on the volume of contaminant, its viscosity and toxicity, and aquifer characteristics including transmissivity and rates of lateral movement. Contamination may be minimised by engineering and management practices to ensure the removal or containment of hydrocarbon products.