Bennelongia Environmental Consultants

Mt Morgans Gold Project: Subterranean Fauna Assessment

Prepared for:

Dacian Gold Ltd

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Final Version

Short-Range Endemics | Subterranean Fauna

Waterbirds | Wetlands

Mt Morgans Gold Project: Subterranean Fauna Assessment

Bennelongia Pty Ltd
5 Bishop Street
Jolimont WA 6913

P: (08) 9285 8722
F: (08) 9285 8811
E: info@bennelongia.com.au

ACN: 124 110 167

Report Number: 273

Report Version	Prepared by	Reviewed by	Submitted to Client	
			Method	Date
Draft 1	Renee Young	Stuart Halse	Email	20 July 2016
Draft 2	Anton Mittra	Stuart Halse	Email	20 December 2016
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Executive Summary

Dacian Gold Limited (Dacian) plans to develop the Mt Morgans Gold Project (the Project) in the northern Goldfields of Western Australia, approximately 35 km southwest of Laverton. The Project encompasses three historic operational areas, namely Westralia, Jupiter and the Mt Morgan/Jupiter borefields (the production borefield). The production borefield is associated with a calcrete aquifer that comprises a Priority 1 Priority Ecological Community (PEC) for subterranean fauna. This study assesses the likelihood of operations at the Project impacting the conservation values of subterranean fauna.

Specific objectives of the assessment were to: collate information on subterranean fauna that may occur within the Project and its vicinity; characterise habitats according to suitability for subterranean fauna; and conduct a field survey to determine diversity and distribution of stygofauna at the Project.

Eleven troglofauna species were identified in the desktop assessment within the search area, which is considered to reflect a depauperate community. Pit excavation at Jupiter is the only proposed Project activity that will potentially degrade troglofauna habitat. Proposed pits cover 80 ha, compared to the ranges of Yilgarn troglofauna, which typically exceed 100 ha. Given consolidated geology at Jupiter, occurrence of significant troglofauna communities is considered unlikely. It is concluded that development of the Project is unlikely to significantly impact troglofauna.

In contrast, a rich community of stygofauna occurs in the region surrounding the Project. Desktop assessment showed that at least 48 stygofauna species occur within the search area. Conclusions drawn from the desktop study regarding potential for subterranean habitat within the three operational areas are summarised in Table ES1.

Table ES1. Conclusions of desktop assessment.

Area	Likelihood of supporting significant fauna		Study Outcome
Westralia	stygofauna	Low – moderate	Further assessment of subterranean fauna not required.
	troglofauna	Low – moderate	
Jupiter	stygofauna	Low	Further assessment of subterranean fauna is not required.
	troglofauna	Low	
Production Borefield	stygofauna	High	Field assessment of borefield required to document composition of the stygal community within the calcrete aquifer. Further assessment of troglofauna not required.
	troglofauna	Low – moderate	

A three-phase stygofauna field survey of the borefield was completed in accordance with EPA Guidance Statement 54a and Environmental Assessment Guideline 12. A total of 66 stygofauna samples were collected across 23 reference sites and 16 impact sites. Sites were delineated based on their occurrence outside (reference) or inside (impact) a predicted 2 m drawdown contour (modelling by Red Creek Water Solutions Pty Ltd). Modelling shows that ≥70 % of aquifer habitat will persist outside the 2 m contour. All specimens were identified to species level where possible.

In total, 2,179 stygofauna specimens belonging to at least 45 species of stygofauna were recorded. Crustaceans were by far the most diverse group with 31 species in six orders: harpacticoid copepods (10 species), cyclopoid copepods (7), isopods (6), ostracods (2), syncarids (4) and calanoid copepods

(1). Forty of these species are known to occur outside the predicted area of groundwater drawdown. Two flatworm species were only recorded within the 2 m drawdown are but are not currently assessed in EIA. Three species are known only from the 2 m drawdown area: the worms Tubificidae sp. and Echytraeidae sp. and the isopod *Andricophiloscia* sp. B02. While it is difficult to determine the ranges of species identified only to family level, both worm species are considered likely to be widespread at the Project scale and not threatened by drawdown. The isopod *Andricophiloscia* sp. B02 is likely to be restricted to the Mt Morgan calcrete. However, it is likely to extend beyond the area of groundwater drawdown because of high habitat connectedness across the calcrete, as shown by the wider distribution of the biological surrogate Haloniscus sp. B09. Accordingly, *Andricophiloscia* sp. B02 is unlikely to be threatened by Project-related groundwater drawdown.

Further confidence that drawdown will not significantly affect the stygofauna community in the Project area is provided by analysis of stygofauna communities inside and outside the area affected by previous pumping of up to 1 GL annually. Both mean abundance and species richness per bore are similar between sites inside and outside the previous drawdown, suggesting that stygofauna were not impacted by historic pumping of the borefield.

Based on drawdown modelling, the predicted loss of calcrete aquifer habitat as a result of groundwater abstraction associated with the Project is not likely to exceed 30 %. A layer of saturated calcrete of 1.5–2 m thick will persist throughout the area, including the most heavily impacted zones surrounding the production borefield. The saturated layer of underlying sand will not be affected by pumping and may provide refuge/additional habitat for stygofauna.

In order to protect the habitat and species richness within the Mt Morgans PEC, Bennelongia recommends the following management framework should be adopted by Dacian:

- Ecological monitoring bores to be established within 500 m of production bores.
- Standing Water Level (SWL) measurements to be taken on a quarterly basis when bores are being pumped.
- Where SWLs measured in ecological monitoring bores indicate a trending decline in aquifer saturated thickness, monitoring of SWL to increase to a monthly frequency.
- Where monthly SWL monitoring suggests an ongoing reduction in saturated thickness, pumping rates of the production bore(s) to be reduced to maintain the groundwater levels predicted in the hydrogeological studies associated with this assessment.

Additionally, the potential impacts of groundwater abstraction at the Project on spatial and temporal patterns in salinity are unknown. Four of five bores historically pumped showed increases in electrical conductance (EC) of between 1.51 mS cm^{-1} and 8.44 mS cm^{-1}. Therefore, changes to EC in the dewatering impact zone and ecological monitoring bores should be monitored during and after groundwater abstraction, with follow up stygofauna monitoring if excessive changes in EC are observed.

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1. INTRODUCTION

Dacian Gold Limited (Dacian) plans to develop the Mt Morgans Gold Project (the Project) in the northern goldfields of Western Australia, located approximately 35 km south west of Laverton (Figure 1).

The Environmental Protection Authority (EPA) usually requires that the risks to subterranean fauna are considered when assessing proposed mine developments because subterranean fauna have very limited ranges. There are two kinds of subterranean fauna: stygofauna and troglofauna. Stygofauna occur in groundwater, whereas troglofauna are air-breathing and occur in the various unsaturated layers of the vadose zone (Gibert and Deharveng 2002). Species with restricted ranges, such as stygofauna and troglofaunal, are vulnerable to extinction through habitat loss and other environmental changes (Fontaine *et al.* 2007; Ponder and Colgan 2002), and are therefore a focus for conservation and environmental impact assessments (EIAs).

Dacian proposes to commence mining and processing at the Project in 2017. As the proposed activities have the potential to impact subterranean fauna, Bennelongia Environmental Consultants was engaged to complete a subterranean fauna assessment of the Project.

This report provides the results of:

- A desktop assessment of the likelihood of stygofauna and troglofauna in the Project area.
- A comprehensive field assessment for stygofauna undertaken within the production borefield area in accordance with the Environmental Assessment Guideline 12 (EPA 2013).

The aims of the desktop assessment were to:

- Undertake a review of existing project and regional data to determine the likelihood of occurrence of subterranean fauna in the vicinity of the Project;
- Complete an assessment of the suitability of habitat within the area for subterranean fauna and its geological extension to the wider local area;
- Document the known occurrences of any listed subterranean species or communities in the vicinity of the Project (*Wildlife Conservation Act 1950* or *Environment Protection and Biodiversity Conservation Act 1999*); and
- Determine the likelihood of the Project having significant conservation impacts in the areas for which approval is being sought.

From the desktop assessment it was determined that a field survey of the production borefield (and associated calcrete aquifer) was required. Bores in reference areas and areas of predicted groundwater drawdown were sampled to:

- Provide information about the subterranean fauna community within the Project impact area; and
- Improve confidence in the conclusions reached in the desktop assessment about the likely level of threat to subterranean fauna from the proposed Project.

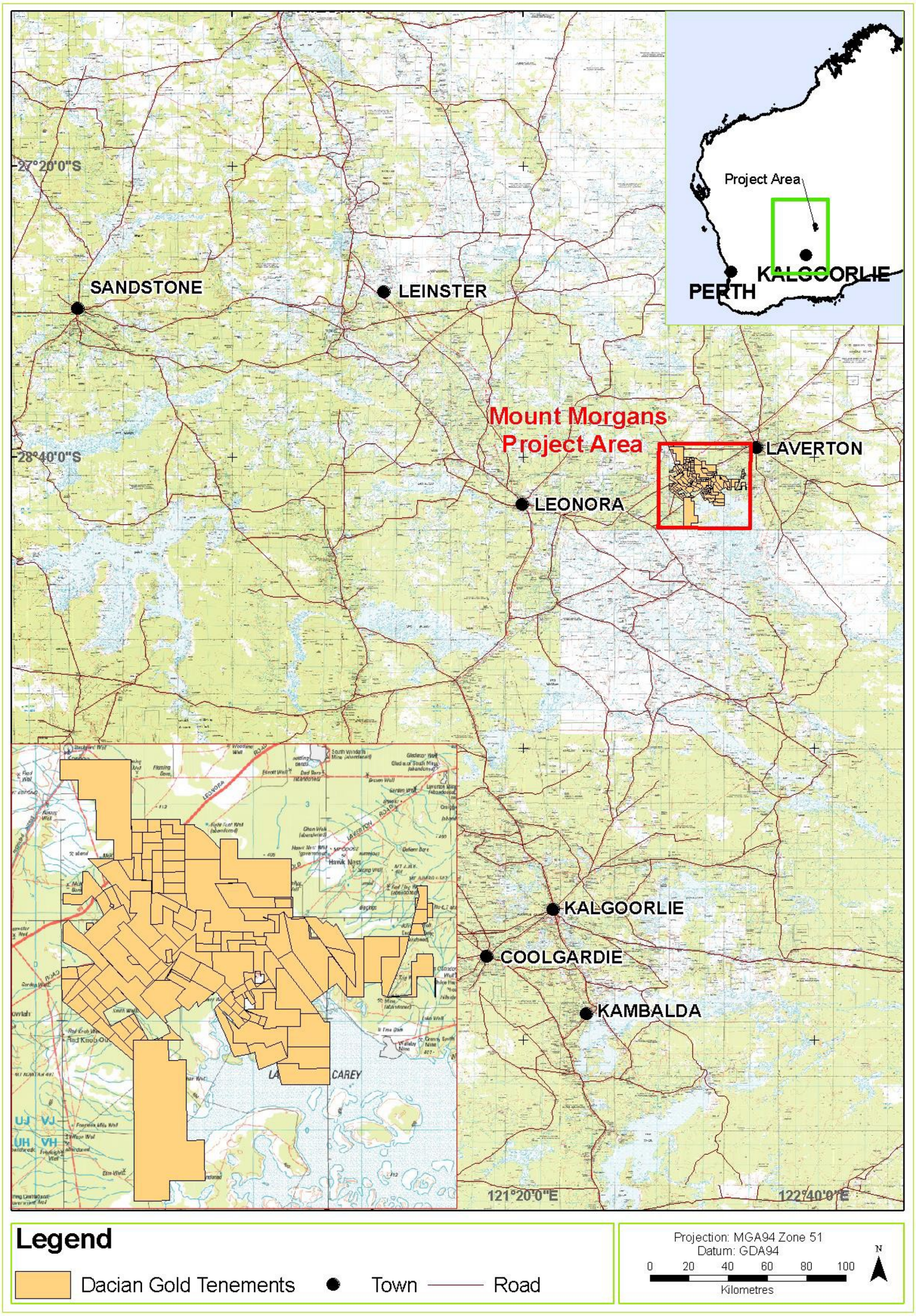


Figure 1. Location of the Mt Morgans Gold Project area.

2. FRAMEWORK

2.1 Project Description

The Project is a brownfields site that encompasses three historic operational areas, comprising:

- Westralia: containing the Westralia and Transvaal pits, other satellite pits and historical processing areas;
- Jupiter: containing the historical Jupiter pit and heap leach area, located approximately 15 km to the east of Westralia; and
- Mt Morgans and Jupiter Borefields (hereafter referred to as the production borefield): containing six production bores situated in a calcrete aquifer.

Dacian is proposing to recommence construction and mining activities at the Project in 2017 (Blueprint 2016). Two mineral resource areas have been identified for development:

1. Jupiter – comprising three pit developments (Heffernans, Doublejay and Ganymede) along a 1.8 km north-south trending strike; and
2. Westralia – comprising development of Beresford underground (UG), Allanson UG, Morgans North pit cutback and Transvaal UG.

Approximately 16 million tonnes of ore and 73.8 million tonnes of waste will be mined over a seven year period. Ore will be transported to a newly constructed carbon-in-leach processing plant, located west of the proposed Jupiter pits. The anticipated throughput of the plant is 2.5 million tonnes per annum. Tailings produced from processing will be discharged to a tailings storage facility (TSF), located at Jupiter.

Mine dewatering will be required to enable mining to occur in a dry working environment. Hydrogeological assessments completed to date have indicated that the aquifers associated with all deposits have relatively low permeability. Groundwater entering open mining voids is therefore likely to be extracted via sump pumps and disposed of into existing pit voids. Excess water will be utilised in dust suppression and processing.

It is proposed that water supply for processing and domestic / potable uses will be sourced from the existing production borefield and a proposed expansion to this borefield, located within a large calcrete unit. Six bores (PB1, 2, 5, 6, 7 and JP60) were pumped between 1985 and 1997 to supply water to the historic processing plant and Jupiter heap leach facility.

An overview of the Project areas is presented in Figure 2.

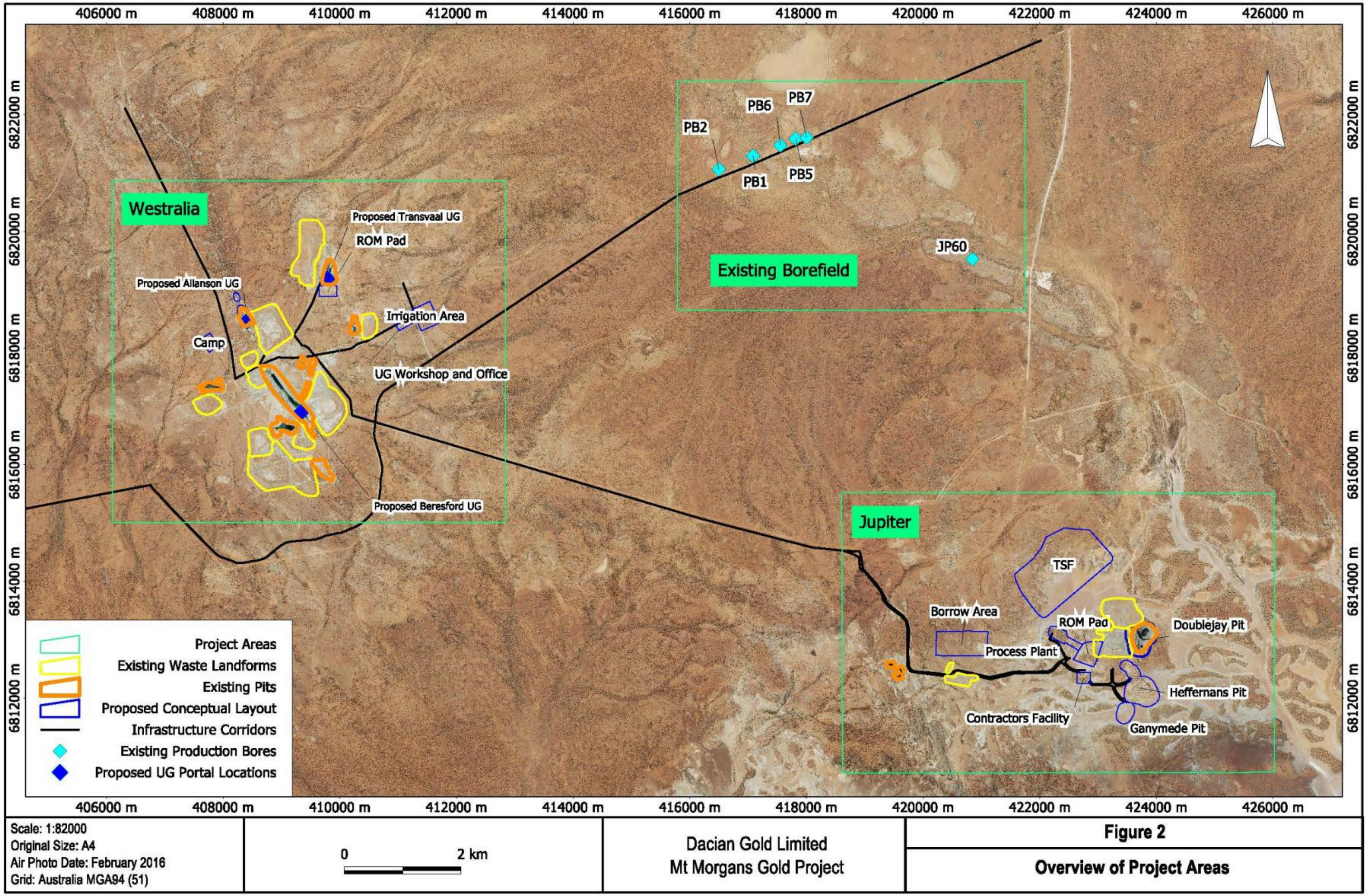


Figure 2. Overview of Project tenement layout.

2.2 Environmental Setting

The Project is located in the East Murchison subregion (Cowan 2001; DSEWPC 2012) within the Yilgarn Plateau of Western Australia, approximately 35 km south west of Laverton. The East Murchison is characterised by low hills and mesas separated by flat colluvium and alluvial plains. The regional geology within the Project area is characterised by belts of greenstone separated by granites, with areas of sedimentary and volcanic rocks associated with the greenstone (Blueprint 2015).

Landforms of the broader Project area comprise Banded Ironstone Formations (BIF) elevated ridges (20-30 m) with associated stony footslopes; sandy plains and intermittent drainage lines (Outback Ecology 2009a; 2009b; RPS 2011). Generally, within the region the vegetation is dominated by Mulga Woodlands often rich in ephemerals, hummock grasslands, saltbush shrublands and *Halosarcia* shrublands (Cowan 2001).

The Project is located in the Goldfields groundwater area. Groundwater in the region typically occurs in the following units: fresh and weathered Archaean basement fractured rock aquifers; tertiary palaeochannel sands and surficial deposits including lacustrine sediments, alluvium/colluvium and calcrete.

2.3 Conservation framework

Protection of native flora and fauna in Western Australia is provided at both state and federal levels. At the federal level, a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places is provided via the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

At the state level, native flora and fauna are protected under the *Wildlife Conservation Act 1950* (in particular Section 14, pp. 8-9). The highest level of protection is given to Schedule 1 species that are considered rare, likely to become extinct, or otherwise in need of special protection. The Department of Parks and Wildlife (DPaW) also maintains a list of priority fauna species that are of conservation importance but, for various reasons, do not meet the criteria for listing as threatened. The current list of threatened and priority species is given in the Wildlife Conservation (Specifically Protected Fauna) Notice 2015. The current list includes 113 terrestrial invertebrate species: seven insects, 26 arachnids, 22 crustaceans, 22 millipedes, one bristle worm and 35 molluscs (DPaW, 2015). Five priority invertebrate species are from the goldfields bioregion (DPaW 2015) but none of these are subterranean species.

In addition to protection mechanisms for species, the EPBC Act lists Threatened Ecological Communities (TECs) for protection. The WC Act has no provision for listing TECs but the Minister for the Environment has endorsed a list of TECs. Other communities of potential conservation concern, but for which there is little information, are listed informally as Priority Ecological Communities (PECs).

Sampling methods for subterranean fauna are outlined in the Guidance Statement 54A (EPA 2007), while Environmental Assessment Guidance 12 (EPA 2013) provides a theoretical framework for subterranean fauna assessments.

2.4 Subterranean Fauna of the Yilgarn

The vast majority of subterranean fauna in Western Australia are invertebrates, although stygofaunal fish and troglofaunal reptiles have been recorded (Aplin 1998; Whitely 1945). Subterranean fauna usually show morphological modifications to life underground that include loss (or reduction) of eyes and skin pigmentation, elongation of appendages and sensory setae, and development of a vermiform body shape.

The occurrence and distribution of subterranean fauna is closely related to geology. Both stygofauna and troglofauna inhabit subterranean spaces, which may include interstices, voids, vugs, cavities and fissures. Geologies that contain many such spaces represent potential habitat. Both vertical and lateral connectivity of spaces are factors that contribute to determining the distribution of subterranean fauna. Calcretes and shallow alluvial aquifers are prospective habitat for aquatic subterranean invertebrates (stygofauna) in the Goldfields while air-breathing subterranean species (troglofauna) also occur in fractured BIF habitats, although at low abundance.

2.4.1 Troglofauna

Whether troglofauna occur in an area is dependent on the availability of habitat, which can be inferred with moderate accuracy from the geology of the area. Potential troglofauna habitat extends from the lower layers of loose soil and sand (usually 1-3 m below the ground surface in arid areas) to the interface with groundwater (Halse and Pearson 2014). The richness of the community in these spaces is affected by the degree to which the subterranean spaces are connected to the ground surface to supply energy and nutrients to the troglofauna community (plant roots are an important surface connection), while lateral connectivity of spaces is crucial to underground dispersal of species (Korbel and Hose 2011). Geological features such as major faults, dykes, rock formations with no voids, and valleys may block continuity of habitat and act as barriers to dispersal, which may lead to troglofauna species having restricted ranges.

Troglofauna are typically classified as troglobite (obligate subterranean species), troglophile (subterranean species with either a life stage or populations occurring above ground) and trogloxene (species primarily found on the surface but with facultative occurrence below ground) (Sket 2008) although the lack of life history information for Yilgarn troglofauna often makes it difficult to assign species to their correct classification. Both troglobites and troglophiles are effectively dependent on subterranean habitats for species persistence and this may also be the case for trogloxenes if the species uses subterranean habitat as a refuge.

Data in the public domain indicate that troglofauna communities in ranges of the Yilgarn are less rich than in the Pilbara. Nevertheless, Yilgarn ironstone formations have been shown to support a range of troglofaunal groups including pseudoscorpions, isopods, millipedes, centipedes, spiders, silverfish, beetles, symphylans, cockroaches, pauropods, bristletails and bugs (Bennelongia 2008b; 2008c; Biota 2007). Surveys in ironstone at the Koolyanobbing Range, Mount Jackson Range, Hunt Range, Mt Dimmer and Yendilberin Hills and Mummaloo have documented either depauperate or moderately developed troglofauna communities, depending on the characteristics of the site (Bennelongia 2008b; 2008c; 2012c).

2.4.2 Stygofauna

Stygofauna are aquatic invertebrates that inhabit fissures and voids in an array of groundwater habitats including porous, karstic and fractured-rock aquifers, springs and the hyporheos of streams (Eberhard *et al.* 2005). Mining activities may potentially threaten stygofauna species with small ranges if mining occurs below the groundwater table. This could be through both physical excavation and more widely through the groundwater dewatering required for dry-pit mining. In addition, when significant groundwater abstraction is required for mineral processing (e.g. beneficiation of magnetite ore), there may be impacts on stygofauna because of habitat loss in the water production borefields.

Rich stygofauna communities have been documented from calcrete bodies in the palaeovalleys of the Yilgarn (Guzik *et al.* 2008; Karanovic and Cooper 2011b; Karanovic *et al.* 2014) and endemism is generally high, with many species restricted to single calcrete bodies or aquifers. Groups commonly occurring in calcrete with high species richness include copepod, syncarid and amphipod crustaceans (Guzik *et al.* 2008; Karanovic and Cooper 2011b; Karanovic *et al.* 2014). These restricted stygofauna communities have often been listed as either TECs or PECs (DEC 2009; DEC 2010). In both cases, the communities are seen as having high conservation value during the assessment process. A Priority 1 PEC, the '*Mt Morgan calcrete groundwater assemblage*', coincides with the production borefield.

In contrast, surveys in geologies other than alluvium and calcrete have recorded very low levels of stygofauna richness (Bennelongia 2009). For example, past surveys have recorded one potential stygobitic nematode species at the Hinge Iron Ore deposit (Rockwater 2014), one amphipod at Jack Hills (GHD 2009) and two cycloid copepods at Kirkalocka (Bennelongia 2011b). While these results demonstrate that stygofauna do occur in BIF habitats if sufficient groundwater is present, the overwhelming picture is that the BIF aquifers in the Yilgarn support very few stygofauna species. Furthermore, irrespective of the suitability of the geology, few species and only low abundances are expected to occur where depth to groundwater is much more than 30 m (Halse *et al.* 2014).

3. DESKTOP REVIEW

A desktop assessment was undertaken to examine whether suitable habitat for subterranean fauna might be present at the Project, and to assess whether any listed invertebrate species or a significant subterranean fauna community was likely to occur locally.

3.1 Habitat Characterisation

3.1.1 Geology and Hydrogeology

The geological, hydrogeological setting and associated subterranean habitat potential of each operational area is described below and presented in Figure 3.

Westralia

The stratigraphy of the Westralia area is dominated by mafic volcanics (predominantly massive tholeiitic basalt), mafic intrusives, minor ultramafics and metasediments, and a narrow band (<80 m wide) of a regionally continuous BIF. All of these units have been intruded by concordant and discordant felsic porphyry dykes and sills and by discordant lamprophyric dykes.

Groundwater entering mines in the Westralia area is associated with low yielding fractured rock aquifers. Airlift and water level recovery testing on four holes in the Westralia area suggested the geology of the area has a very low permeability (between 1.99 x 10^{-4} m/day and 1.49 x 10^{-1} m/day). Water storage is likely to correspond only with localised fracture zones. A high variation in measured permeabilities is likely due to some of the drill-holes intersecting fracture zones. The estimated inflows to mine pits are low and are not anticipated to have any significant impact on the wider groundwater system or any groundwater dependent ecosystems. Based on the low yields, the requirements for dewatering are predicted to be minor and it is anticipated in-mine dewatering methods will be sufficient to cope with the volumes of groundwater involved.

Water quality analysis completed as part of the 2014/15 Groundwater Monitoring Summary showed water quality in Westralia area to be:

- pH neutral to slightly alkaline
- Low to moderate salinity with TDS values ranging between 6000 mg/L and 14,500 mg/L (Westralia)
- Elevated sulphate levels of 2000mg/L.
- Low concentrations of metals and metalloids.

The water levels in the Westralia area are approximately 20 m below ground surface.

Jupiter

Mineralisation at Jupiter is centred on a series of syenite intrusive stocks aligned in a north-south orientation. The syenite intrudes into a sequence of host basaltic rocks. A major shear zone, termed the Cornwall Shear Zone, runs parallel to the western margin of the syenite intrusives and where it intersects these intrusive bodies mineralisation has occurred within both the syenite and the host basaltic rocks. This mineralisation is primarily centred on the intrusive bodies but also extends several hundred metres into the basaltic rocks.

The mineralisation is predominantly associated with alteration to albite and sericite, and quartz veining and pyrite development are commonly encountered within the mineralised basalt hosted lodes.

The Archean basement is considered to have a low aquifer potential, apart from a possible fractured rock aquifer which trends east-west across the southern end of the Heffernans deposit. The low permeability of the basement rocks is consistent with historic dewatering rates at the earlier mined Jupiter pit. Weathered basement rocks are thought to have low to modest permeabilities.

A programme of hydraulic testing was carried out on eight angled resource drill-holes and falling head tests completed on nine vertical resource and metallurgical drill-holes (Appendix 1) located within the Heffernans deposit area. The following conclusions were made on the results of hydraulic testing:

- Permeability values are mostly low in the intact fresh rock;
- Permeability values in the weathered rock are moderately low; and
- There is a linear feature of higher permeability trending east-west across the southern edge of the deposit, possibly associated with the northern contact of the steeply dipping intermediate intrusive across the southern limit of the deposit.

The groundwater modelling of the Heffernans deposit has shown a base case dewatering rate of 5 to 9 L/s.

The groundwater level data showed that away from outcropping portion of the Heffernans deposit (syenite hill) the groundwater levels range from 396.48 mAHD on the edge of the lake at the south-eastern side of the deposit to 399.37 mAHD at the northern end of the deposit. The groundwater level contours indicate a low hydraulic gradient from north to south consistent with groundwater discharge towards Lake Carey.

Groundwater samples collected from seven resource drill-holes within the Heffernans deposit (Appendix 3) show groundwater to be:

- pH neutral;
- Hypersaline, ranging from 150,000 to 260,000 mg/L;
- Sodium chloride type;
- High in nitrate, with slightly elevated concentrations of manganese.

Although the buffer of the PEC also overlaps part of the Jupiter area, extensive drilling has confirmed that no calcrete habitat occurs within the Jupiter area.

Production Borefield

The production borefield is located in a calcrete aquifer of the Lake Carey drainage system.

The aquifer covers an area of about 60 km^2 and forms an elongate unit that broadly trends northwest from the northern margin of Lake Carey (MMA 1990). The unit is thin, sub-cropping close to surface with a maximum depth of about 10 m. It comprises vuggy carbonate rock interbedded with alluvium and silcrete. Dissolution of the carbonate is common, which results in the development of secondary porosity and on occasion good aquifer yields. The results of groundwater field programmes indicate that higher permeabilities generally occur on the western side of the calcrete unit. Groundwater flows in the calcrete are likely to be towards the east and south, ultimately discharging to the Carey trunk palaeochannel and Lake

Carey, respectively. The aquifer is subject to direct rainfall recharge resulting in rapid groundwater level rises after major storm events.

The aquifer and borefield coincides with a Priority 1 PEC - 'Mt *Morgan calcrete groundwater assemblage on Carey palaeodrainage on Mt Weld Station*' which is identified as having a unique assemblage of invertebrates in the groundwater calcretes.

3.1.2 Potential Subterranean Fauna Habitat

Stygofauna typically inhabit fresh to brackish groundwater, but they may occur in salinities up to 50,000 mg/L total dissolved solids). Both troglofauna and stygofauna depend on the presence of suitable underground spaces such as interstices, voids, vugs, cavities and fissures. Based on review of the Project geology and hydrogeology, the following assessment is made regarding potential subterranean fauna habitat:

Stygofauna Habitat Potential

- **Westralia –** Stygofauna could persist in the groundwater which is of relatively good quality (i.e. <20,000mg/L TDS), however low permeability aquifers and fine grained geological units limit habitat potential.
- **Jupiter –** Unlikely to provide suitable habitat due to high salinity (>150,000 mg/L TDS). Additionally, low permeability aquifers limit habitat potential.
- **Production Borefield** – Likely to provide good habitat for stygofauna due to the fresh – brackish water quality, high permeability formation and vuggy nature of the calcrete.

Troglofauna Habitat Potential

- **Westralia –** BIF units above the water table may provide suitable habitat for troglofauna.
- **Jupiter –** The relatively shallow water table (less than 10 mbgl away from outcropping portion of the Heffernans deposit) is likely to constrain the quantity of habitat available to troglofauna. This is because the arid environment and high plant transpiration would dry out the most of the habitat above water table and make establishment of troglofauna populations unlikely. Additionally, rock units above the water table (syenite and weathered basalt) do not provide extensive voids for troglofauna to inhabit (see Appendix 1).
- **Production borefield** - The relatively shallow water table (level ranging between 2.97 to 6.25 mbgl) is likely to constrain the quantity of habitat available to troglofauna, however a depauperate community could occur.

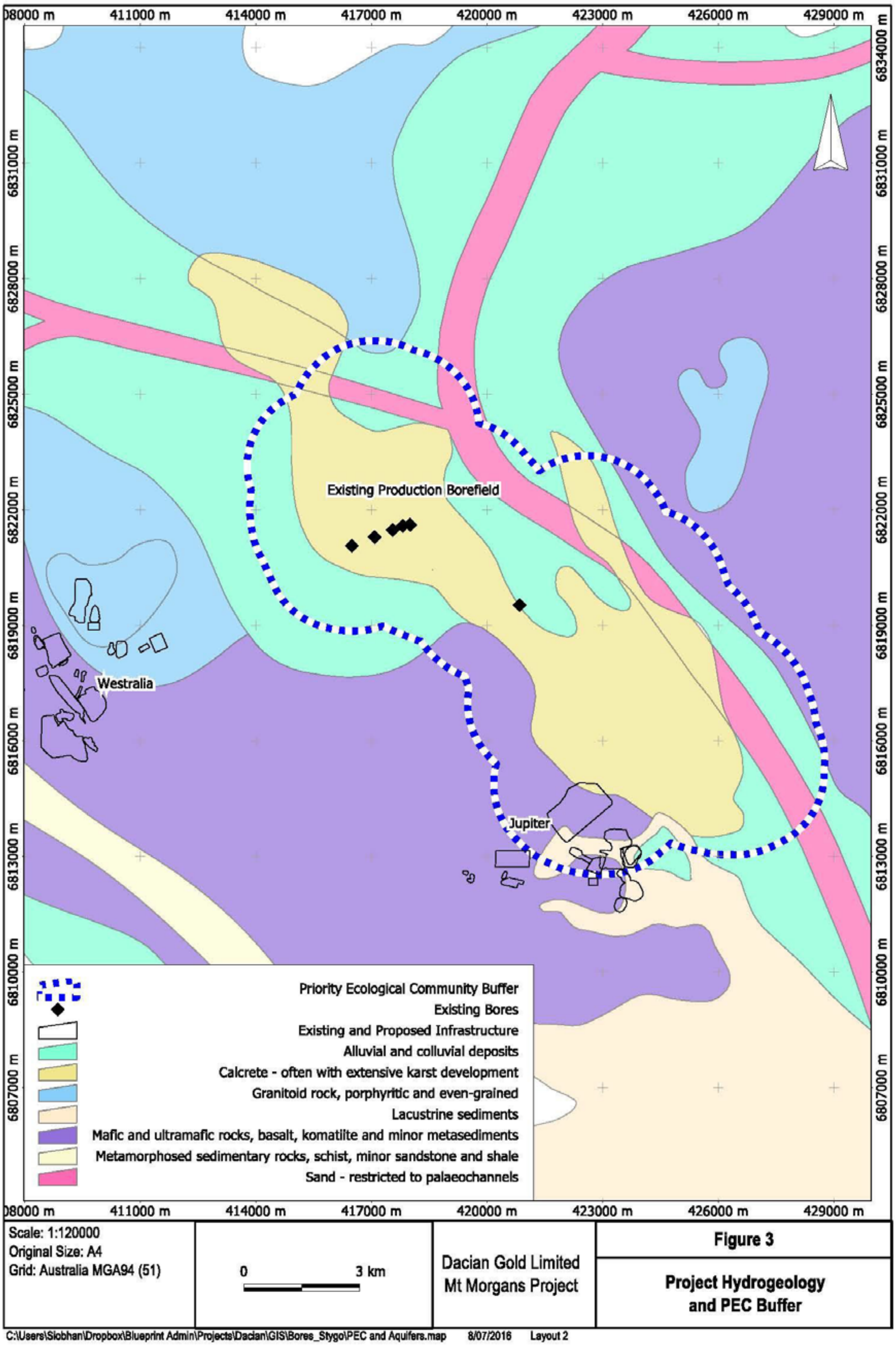


Figure 3. Project Hydrogeology and PEC Buffer.

3.2 Subterranean Fauna in the Vicinity of the Project

3.2.1 Database and Literature Searches

To assess the likelihood of subterranean fauna occurring in the Project area, a review was conducted of troglofauna and stygofauna records in the Western Australian Museum (WAM) databases (arachnids, myriapods and crustaceans). Data were reviewed for a search area of 100 km by 100 km around the Project (defined by - 27.900S; 121.200E and -29.70S; 123.200E). Published research papers, online databases and available environmental reports (Table 1) were also reviewed. Higher level identifications were not included in counts of species within the search area unless it was certain they represented a species that was not already recorded (e.g. *Enchytraeus sp.* was not included as an additional species because the genus *Enchytraeus* was already represented by *Enchytraeus* Pilbara sp. 1).

Table 1. Reports included in the desktop assessment.

Author	Year	Report Name	Produced for	Distance from the Project
BEC	2007	Report on Subterranean Fauna of the Duketon Gold Project Area, North of Laverton	Regis Resources NL	93 km N
BEC	2011	Duketon Gold Project: Subterranean Fauna Assessment at Garden Well and Erlitoun	Regis Resources NL	93 km N
BEC	2013	Yamarna Project Subterranean Fauna Assessment	Gold Road Resources	133 km NE
BEC	2015	Duketon Gold Project: Subterranean Fauna Desktop Assessment for Gloster Deposit	Regis Resources NL	93 km N
BEC	2016	Duketon Gold Project: Subterranean Fauna Desktop Assessment for Baneygo Deposit	Regis Resources NL	93 km N

BEC = Bennelongia Environmental Consultants Pty Ltd

3.2.2 Troglofauna

The limited troglofauna surveys in the public domain that have been undertaken in the Yilgarn have recorded modest to rich troglofauna communities in calcretes above the watertable, with the groups present including palpigrads (Barranco and Harvey 2008), pseudoscorpions (Edward and Harvey 2008), spiders (Baehr *et al.* 2012; Platnick 2008) and isopods (S. Taiti in litt.). Outback Ecology (2012) collected 20 troglofauna species at Lake Way near Wiluna and cited unpublished WAM reports referring to “numerous [other] troglomorphic species” in Lake Way calcretes (250 km NNE), while Bennelongia (2015) reported the collection of 45 species of troglofauna from calcrete at Yeelirrie (250 km NW).

Other lithologies in the Yilgarn support fewer troglofauna species, especially where gold occurs. Only four species in four taxonomic groups (isopods, centipedes, diplurans and cockroaches) were collected at the gold deposits of Tropicana (ecologia Environment 2009a, 2009b, 2010). Depending on the site, studies in BIF at Koolyanobbing, Mount Jackson Hunt Range, Mt Dimmer and Yendilberin Hills have documented depauperate through to moderately rich troglofaunal communities that included species of isopods, millipedes, centipedes, spiders, silverfish, beetles, symphylans, cockroaches, pauropods, bristletails and bugs (Bennelongia 2008b; 2008c; 2009).

Eleven troglofauna species were identified in the desktop assessment within the search area (Table 2) representing a depauperate community within the area. The nearest known records of troglofauna to the Project are from Duketon, 93 km north of the Project where three troglofauna species were recorded at Erlistoun and Garden Well (Bennelongia 2011a). They were the isopod *Trichorhina* sp. B8, dipluran Japygidae sp. and silverfish Atelurinae sp. B14. *Trichorhina* ` sp. B8 has a known linear range of 6.8 km. Japygidae sp. belongs to a family that appears to contain widespread species compared with typical troglofauna ranges (Halse 2010). The silverfish Atelurinae sp. B14 also belongs to a sub-family characterised by moderately widespread species (Halse 2010). No troglofauna was recorded from bores in the mine pit area at Moolart Well (Bennelongia 2007).

3.2.3 Stygofauna

A literature search undertaken as part of the subterranean desktop assessment identified that stygofaunal communities of the calcretes within the Yilgarn are generally very rich. Stygofauna survey at the Yamarna Project (133 km NE) yielded 2,852 specimens from at least 33 species and eight higher order groups including Nematoda (1 species), Aphanoneura (1 species), Oligochaeta (4 species), Turbellaria (1 species), Copepoda (18 species), Syncarida (2 species), Amphipoda (2 species) and Coleoptera (4 species). (Bennelongia 2013). Copepods were both the most diverse and the most abundant group, representing 68% of all specimens collected. Amphipods also represented a significant proportion of total abundance (23%) (Bennelongia 2013).

Stygofaunal communities in other lithologies in the Yilgarn are less rich compared to those in calcrete habitats (Bennelongia 2007; 2011a). Stygofauna sampling yielded only 14 specimens from Erlistoun (93 km N) consisting of at least three species. No species were collected at Garden Well (Bennelongia 2011a).

In summary, a rich community of stygofauna was identified in parts of the region surrounding the Project. A total of 62 stygofauna species were identified through the desktop assessment and are known to occur within the search area. These species are presented below in Table 3

3.2.4 Listed Species and Threatened/Priority Communities

No subterranean invertebrate species from the vicinity of the Project are listed under the WC Act.

The production borefield occurs within the Priority 1 PEC: '*Mt Morgan calcrete groundwater assemblage type on Carey paleodrainage on Mount Weld Station*'. This community is described as a unique assemblages of invertebrates that has been identified in the groundwater calcretes and is currently threatened by mining (DEC 2009). The presence of a PEC within the production borefield prompted further work to determine the composition of the stygofaunal community in the production borefield and Bennelogia undertook a comprehensive two-phase field survey. The findings of this survey are presented below.

Table 2. Troglofauna species recorded in the search area defined by -27.900S; 121.200E and -29.70S; 123.200E.

Taxonomy	Species	No. of specimens	Reference/Source	Comment/ Known Range
Arthropoda				
Chelicerata				
Arachnida				
Palpigradida	Palpigradida sp. B14	1	BEC 2013	
Araneae	*Prethopalpus framenaui*	3	WAM	
Crustacea				
Malacostraca				
Isopoda	*Trichorhina sp. B8*	6	BEC 2011a	Known range of 6.8 km
	Trichorhina sp. B15	117	BEC 2013	
Hexapoda				
Insecta				
Thysanura	*Atelurinae* sp. B14	1	BEC 2011a, Halse 2010	Family mostly contains widespread species
	Atelurinae sp. B15	2	BEC 2013	
Diplura	Japygidae sp.	1	BEC 2011a, Halse 2010	Family mostly contains widespread species
Myriapoda				
Chilopoda				
Scolopendromorpha	*Cryptopidae* `genus?` `sp.` Laverton Downs Station	1	WAM	
Pauropoda				
Tetramerocerata	*Pauropus* sp. B02	4	WAM	
Symphyla				
Cephalostigmata	*Scutigerella* sp. B07	1	BEC 2013	
	Scutigerella sp. B08	1	BEC 2013	

Table 3. Stygofauna species recorded in the search area defined by -27.900S; 121.200E and -29.70S; 123.200E.

Taxonomy	Species	No. of specimens	Reference/Source	Comment/ Known Range
Platyhelminthes				
Turbellaria	Turbellaria sp.	20	BEC 2013	Not identified to species level and not part of the assessment
Rotifera				
Eurotatoria				
Bdelloidea	Bdelloidea sp	3	BEC 2007	Not identified to species level and not part of the assessment
Nematoda				
	Nematoda sp.	31	BEC 2013	Not identified to species level and not part of the assessment
	Nematoda sp.	8	BEC 2007	Not identified to species level and not part of the assessment
	Nematoda sp.	11	BEC 2011a	Not identified to species level and not part of the assessment
Annelida				
Aphanoneura				
	Aeolosomatidae sp.	3	BEC 2013	Uncertain
Clitellata				
Enchytraeida	*Enchytraeus* sp.	1	BEC 2013	Uncertain
	Enchytraeus Pilbara sp 1	9	BEC 2007, Bennelongia Unpublished	Widespread in arid WA
Haplotaxida	*Insulodrilus* sp.	1	BEC 2013	Uncertain
	Tubificidae sp. B01	44	BEC 2013	Not identified to species level and not part of the assessment
	Tubificidae sp. B02	53	BEC 2013	Not identified to species level and not part of the assessment
	Tubificidae stygo type 5	3	BEC 2007, Bennelongia Unpublished	Widespread in WA
	Phreodrilid slim vent chaetae	1	BEC 2007, Bennelongia Unpublished	Widespread in WA
Crustacea				
Malacostraca				
Isopoda	*Paraplatyarthrus subterraneus*	6	WAM;	Probably restricted to the local calcrete
	Paraplatyarthrus nahidae sp. nov.	7	WAM; Javidkar 2014	Probably restricted to the Mt Morgan calcrete
Maxillopoda (sub-class Copepoda)				
Harpacticoida	Ameiridae sp.	1	BEC 2011a	
	Nitokra lacustris sp. B02	9	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nitokra lacustris regis ms	1	BEC 2007	
	Nitokra l pacificus X regis	2	BEC 2007	Known from single bore in Moolart Well area
	Nitocrella sp B02A	1	BEC 2007	Moolart Well calcrete
	Nitocrella sp. B06	7	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete

Taxonomy	Species	No. of specimens	Reference/Source	Comment/ Known Range
	Nitocrella sp. B07	840	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nitocrellopsis halsei	11	BEC 2007, WAM	Moolart Well calcrete and alluvium, known linear range >40km
	Nitocrellopsis sp B03	5	BEC 2007	Moolart Well calcrete
	Nitocrellopsis sp. B04	1	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nitocrellopsis sp. B05	147	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nitocrellopsis sp. B06	53	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nitocrellopsis sp. B07	106	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nitocrellopsis sp. B08	53	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Parapseudoleptomesochra? sp. B03	214	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Australocamptus hamondi	2	BEC 2007, Karanovic 2004	Known linear distribution of >150 km in Murchison Region
	Schizopera sp B01	3	BEC 2007	Moolart Well calcrete
	Schizopera sp. B08	5	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Schizopera sp. B09	15	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Schizopera sp. B11	6	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Schizopera sp. B14	32	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Schizopera jundeei	1	BEC 2007	
	Kinnecaris solitaria		Karanovic 2004, BEC 2007	
	Parastenocaris sp B2	1	BEC 2007	
	Parastenocaris sp. B24	4	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Parastenocaris solitaria	1	BEC 2007	
Cyclopoida	*Fierscyclops* (*Fierscyclops*) *fiersi*	198	BEC 2013	Widespread in Murchison; linear range 450 km
	Cyclopoida sp	1	BEC 2007	
	Goniocyclops uniarticulatus	23	BEC 2013, BEC 2007	Widespread in Murchison; linear range 400 km
	Goniocyclops sp B01	2	BEC 2007	Known from single bore in Moolart Well area
	Halicyclops eberhardi	188	BEC 2013	Murchison and Gascoyne; linear range 750 km
	Microcyclops varicans	3	BEC 2007, Karanovic 2004	Cosmopolitan
	Mesocyclops brooksi	2	BEC 2007, Karanovic 2004	Widespread in Pilbara and arid WA
Ostracoda				
	Plesiocypridopsis sp A	8	BEC 2007,	Not applicable, not species level
Podocopa	?Candoninae sp 1	4	BEC 2007	Known linear range of 50 km
	Candonidae sp.	2	BEC 2011a	
Malacostraca				
Bathynellacea	*Bathynella* sp B1	*2*	BEC 2007	

Taxonomy	Species	No. of specimens	Reference/Source	Comment/ Known Range
	Atopobathynella sp. B13	1	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Atopobathynella sp B1	3	BEC 2007	Moolart Well calcrete and alluvium, known linear range 50 km
	Hexabathynella sp. B07	6	BEC 2013	Probably restricted to the local calcrete
	Parabathynellidae n gen PS	3	BEC 2007, WAM	Moolart Well calcrete and alluvium, known linear range 30 km
Amphipoda	*Stygochiltonia* sp. B02	500	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Yilgarniella sp. B02	148	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
Hexapoda				
Insecta				
Coleoptera	*Limbodessus* sp. B05	31	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Limbodessus sp. B06	43	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Limbodessus sp. B07	19	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete
	Nirripirti sp. B01	2	BEC 2013	Probably restricted to the Yeo Palaeovalley calcrete

4. STYGOFAUNA FIELD SURVEY

4.1 Methods

4.1.1 Site Selection and Sampling Effort

Sampling sites were categorised according to their occurrence inside or outside the predicted 2 m drawdown contour based on drawdown modelling completed by Red Creek Water Solutions Pty Ltd (2016) (Figure 4). The 2 m drawdown contour utilised for this assessment represents a conservative assessment of drawdown. Bores inside the 2 m contour were considered as impact sites that will potentially be affected by groundwater abstraction. Bores outside the 2 m drawdown contour were considered to be reference sites. Historical groundwater monitoring data suggests that negligible drawdown was observed at distances greater than 400 m from abstraction points.

A total of 66 stygofauna samples from 39 sites were collected from within the survey area over the three surveys: 20 in phase one; 20 in phase two; and 26 in phase three (Figure 4) comprising:

- Reference sites – 23 sites located outside the predicted 2 m drawdown contour of the production borefield.
- Impact sites – 16 sites located within the predicted 2 m drawdown contour associated with the production borefield; and

Sampling was conducted on 10-12 February 2016, 16-18 May 2016 and 2-4 November 2016. A complete list of bores sampled is provided in Appendix 3.

4.1.2 Sampling Methods

Stygofauna sampling followed the methods recommended by the EPA (2007). At each bore, six net hauls were collected using a weighted plankton net. After the net was lowered to the bottom of the bore it was bounced up and down briefly to agitate benthic and epibenthic stygofauna into the water column prior to a slow retrieve of the net. Contents of the net were transferred to a 125 ml polycarbonate vial after each haul and the contents were preserved in 100% ethanol and stored below 4°C for up to four days for possible sequencing. Nets were washed between bores to minimise contamination between sites. Three hauls were taken using a 50 µm mesh net and three with a 150 µm mesh net.

4.1.3 Sampling Sorting and Identification

In the laboratory, samples were elutriated to separate out heavy sediment particles and sieved into size fractions using 250, 90 and 53 µm screens. All samples were sorted under a dissecting microscope. Sorted animals were identified to species or morphospecies using available keys and species descriptions. When necessary, animals were dissected and examined under a compound microscope. Morphospecies determinations were based on characters used in species keys. Higher order identifications were only regarded as distinct 'species' if that taxonomic unit had not otherwise been recorded (e.g. *Schizopera* sp. was not included in the final list of species as it probably corresponded to a recorded species of that genus).

4.1.4 Personnel

Fieldwork was undertaken by Michael Curran and Jim Cocking in phase one, Mike Scanlon and Renee Young in phase two, and Michael Curran and Jim Cocking in phase three. Samples were sorted by Mike Scanlon and Jane McRae and identifications were made by Jane McRae and Stuart Halse.

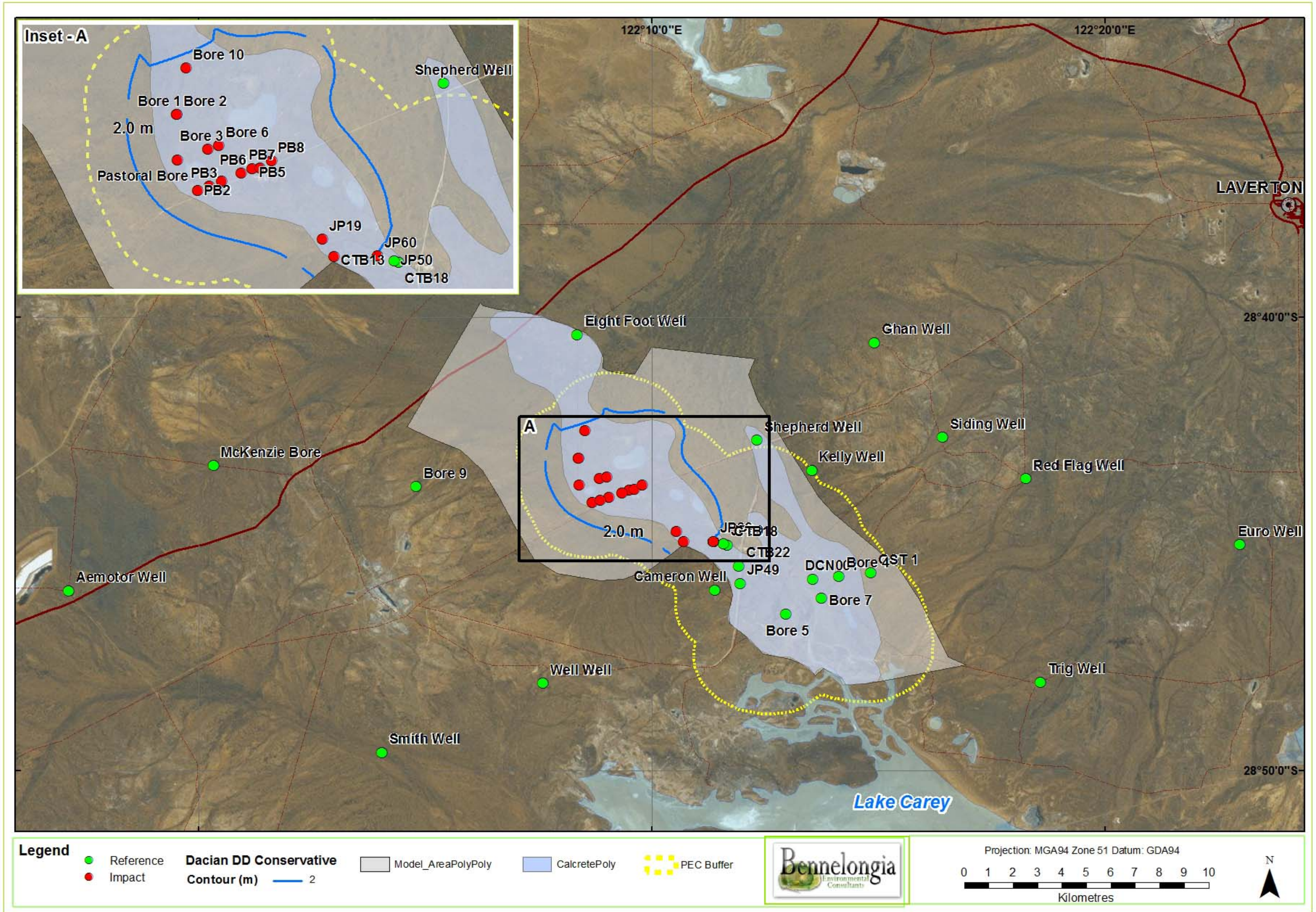


Figure 4. Locations of bores sampled for stygofauna.

4.2 General Results

A total of 2,179 specimens belonging to at least 45 species of stygofauna were collected during this survey (Table 4). Most bores yielded, containing from 1–13 species and 1–314 individuals per bore. Reference sites Bore 9, Eight Foot Well, Smith Well, Trig Well and Well Well and the impact site Bore 10 did not yield stygofauna. Crustaceans were by far the most diverse group with 31 species of six orders collected: harpacticoid copepods (10 species), cyclopoid copepods (7), isopods (6), ostracods (3), syncarids (4) and calanoid copepods (1). Five oligochaete taxa were collected, although four of these represent higher level identifications and only one naidid worm could be identified to species level. Insects were represented by three species of diving beetle (Dytiscidae), as well as indeterminate larvae of that family. Rotifers (3 species), turbellarian flatworms (2 species) and nematodes (1 species) were also recorded.

Cyclopoid and harpacticoid copepods were the most abundant groups, with 481 and 743 specimens collected, respectively. The most abundant species were the undescribed harpacticoid Ameiridae gen. nov. sp. B05 (470 specimens) and the cyclopoid *Fierscyclops* (*Fierscyclops*) *fiersi* (262 specimens). Eight species were collected as singletons.

A list of higher order identifications that were removed from the final species list to avoid artificial inflation of richness is given in Appendix 4.

4.3 Summary of Recorded Fauna

Details on the taxa collected are provided in the sections below. Figures 5-8 show collection locations of taxa that are known only from (and are possibly restricted to) the study area or else are of potential conservation concern. Exemplar stygofauna taxa of the Project area are shown in Figure 9.

4.3.1 Flatworms, nematodes, oligochaetes and rotifers

The taxonomy of worms and rotifers in Australia is poorly resolved and the taxonomic papers available focus on other bioregions than the Yilgarn (e.g. Pinder 2003; Pinder *et al.* 2006). It is usually not possible to identify stygal rotifers to species level (most are bdelloids) and this group is excluded from environmental impact assessments because the ranges of species cannot be readily determined. A rotifer species belonging to the genus *Brachionus* was collected from two reference bores, but could not be identified further. Two bdelloid rotifer species, Bdelloidea sp. 2:2 and Bdelloidea sp. 7:7 were recorded from five and one reference bores, respectively (Figure 5). Nematodes (roundworms) and flatworms (Platyhelminthes) collected in stygofauna samples cannot be identified to species level and these groups are excluded from impact assessments.

Juvenile stages of oligochaetes can also be difficult to identify to species level. Nevertheless, the survey area seems to have a moderately diverse oligochaete fauna that comprises four families (Aeolosomatidae, Enchytraeidae, Naididae and Tubificidae). Two oligochaete taxa recorded were collected only from impact sites (Figure 5A) but are probably more widely distributed (see Section 5.3.1). *Pristina aequiseta* was only collected from the impact area but has a cosmopolitan distribution.

4.3.2 Isopoda

Six aquatic isopod species were collected across 12 bores and all are possibly restricted to the study area (Figure 6). The most abundant were *Haloniscus* sp. B08, of which 65 specimens were collected across seven bores and *Haloniscus* sp. B09, of which 21 individuals were collected across five sites. These species differ in the length of the uropod furca and antennae ratios. *Haloniscus* is a very diverse genus in the Yilgarn and some species have been described (e.g. Taiti and Humphreys 2001) but many more undescribed species have been collected from calcretes and surface waters in the last decade. Like other onisicdean genera, species of *Haloniscus* are often endemic to single calcrete aquifers, having diverged within calcretes following independent colonisation events. Six putative species are currently recognised from the Carey palaeodrainage based on genetic data, demonstrating high species richness and endemism in this fauna (Cooper *et al.* 2008).

The species *Andricophiloscia* sp. B01, *Andricophiloscia* sp. B02 and ?*Adoniscus* sp. B02 are presently known from one, three and one specimens, respectively. *Andricophiloscia* sp. B01 was recorded from JP49, *Andricophiloscia* sp. B02 from PB6 and Bore 6 and ?*Adoniscus* sp. B02 from DCN001. All three species are probably endemic to the Mt Morgan calcrete. Four specimens of *Angeliera* sp. B01 were recorded from reference bore DCN001. The species is of biogeographic significance, being the first record of the family Microparasellidae in Western Australia. The family has marine origins.

The collection locations of all six recorded isopod species are shown in Figure 5B. All isopod species were recorded from reference bores except *Andricophiloscia* sp. B02, which is discussed further in Section 5.3.1.

4.3.3 Syncarida

Syncarids are a common element of stygal communities worldwide and are frequently collected during stygofauna surveys in Australia. The Western Australian fauna has been studied both genetically (Abrams *et al.* 2012; Guzik, Abrams *et al.* 2008) and taxonomically (e.g. Cho and Humphreys 2010; Cho *et al.* 2005). The data available indicate high species diversity and pronounced regional endemism, with species typically endemic to single calcretes or subterranean waters within them. Species ranges are typically small but differ according to physico-chemical characteristics of the groundwater habitats. Four new species of syncarid were collected at the Project Area – *Bathynella* sp. B27, *Atopobathynella* sp. B22, *Atopobathynella* sp. B23 and *Atopobathynella* sp. B24 (Figure 6). *Bathynella* sp. B27 was recorded only from DCN001 (two individuals); *Atopobathynella* sp. B23 from five bores (17 individuals); *Atopobathynella* sp. B22 was recorded from seven bores (54 individuals); and *Atopobathynella* sp. B24 was recorded from the regional reference site Ghan Well (9 individuals). These species are likely restricted ranges but were all recorded in reference bores (Figure 6A).

4.3.4 Calanoid copepods

Only one species of calanoid was collected in this survey and it belongs to the genus *Boeckella*, which has Australasian distribution (Bayly 1992). Species of *Boeckella* in Australia are known from surface waters so it is likely that *Boeckella* sp. B01 is a trogloxene or the accidental occurrence of a surface species. While *Boeckella* sp. B01, represented by 17 animals from bore JP49 (Figure 6B), is an undescribed species, it is likely to occur outside the study area with a localised range in the context of surface species. It belongs to the *Boeckella triarticulata* complex. Other new species in this complex occur in Western Australia (Jane McRae, unpublished data)

4.3.5 Cyclopoid copepods

Cyclopoids are diverse in groundwater habitats throughout Western Australia and are probably the richest stygal group worldwide. The taxonomy of stygal cyclopoids in Western Australia is comparatively well resolved (e.g. Karanovic 2004). The fauna recorded from the survey area comprises seven species from six genera: *Dussartcyclops*, *Fierscyclops*, *Halicyclops*, *Mesocyclops*, *Metacyclops* and *Pescecyclops* (Table 4). All of the recorded species are widespread across the Yilgarn and have been collected from multiple calcretes and palaeochannels. All were described from material collected in the Murchison and Gascoyne regions (Karanovic 2004). *Pescecyclops laurentiisae* is less-common than other cyclopoids in the study area and was only recorded from the impact area, but is known to occur in the Murchison and Gascoyne regions. None of these species are of conservation concern as all were recorded in reference bores and occur outside the study area.

4.3.6 Harpacticoid copepods

Harpacticoids are another diverse stygofauna group. There are at least 11 harpacticoid species in the survey area belonging to five genera: *Australocamptus*, *Nitokra*, *Pseudectinosoma*, *Schizopera* and a genus of the family Ameiridae that is currently undescribed. Some species are widespread and have been collected elsewhere in the Yilgarn, such as *Australocamptus similis*. Other species may be more tightly restricted. All the harpacticoid species were recorded occurred in both impact and reference sites, with the exception of *Pseudectinosoma* sp. B03, of which one and two individuals were recorded from reference bores Bore 7 and DCN001, respectively (Figure 7).

The genus *Schizopera* is very diverse in the Yilgarn and Pilbara regions of Western Australia and a number of species have been described (e.g. Karanovic and McRae 2013). Species diversity and abundance in the calcretes of the Yilgarn can be very high. For example, multiple species of *Schizopera* were collected from individual bores at Yeelirrie (Karanovic and Cooper 2011a). The *Schizopera* fauna of the Project Area comprises three undescribed species that differ in the relative length, shape and supination of the operculum and furca. *Schizopera* sp. B18 and *Schizopera* sp. B19 collected from seven and nine bores and were represented by 15 and 52 individuals, respectively. *Schizopera* sp. B20 was less common with 11 individuals collected from four bores.

The genus *Nitokra* is not as diverse as *Schizopera* and includes both wide-ranging and restricted species (Karanovic, Eberhard *et al.* 2014; Karanovic and Pesce 2002). Of the three species collected in the study area, *Nitokra lacustris pacifica* is a described and wide-ranging species, whereas *Nitokra* sp. B05 and *Nitokra* sp. B06 may be restricted to the Mt Morgan calcrete aquifer. Eight individuals of *Nitokra* sp. B05 were recorded across four bores, while 16 individuals of *Nitokra* sp. B06 were recorded across five bores. These species differ from one another in the number of spines on the operculum and the presence or absence of the internal chitonus rib of the anal segment (present in *N. lacustris pacifica* and *N.* sp. B06; absent in *N.* sp. B05). *Nitokra* sp. B06 differs from in *N. lacustris pacifica* by the more angular shape of the chitonus rib, the shape of the furca, the very long hyaline fringe on the somites and only five setae on exopodite of P5 of females (six in *N. lacustris pacifica*).

Two species of a presently undescribed genus of Ameiridae were also collected. The specimens of the new genus most closely align with the genus *Stygonitocrella*, but differ in the setation patterns of the fourth endopodite. One of the species, Ameiridae gen. nov. sp. B05, was very abundant, with 470 individuals collected across 13 bores. The second species, Ameiridae gen. nov. sp. B06, was less common, with 27 individuals collected across five bores. The two species clearly differ in the number of setae of the operculum (B05 with 25-30 spines; B06 with 13 spines). All Harpacticoids occurred in reference bores.

4.3.7 Ostracoda

Three species of ostracods were collected in the survey area. *Sarscypridopsis ochracea* is the name that has been widely applied in Western Australia (e.g. Halse et al. 2014) to the cypridopsid ostracod collected from the Project. It is a cosmopolitan species (e.g. Martens et al. 1996) and further taxonomic work may show that Australian animals belong to a different species. *Sarscypridopsis ochracea* was recorded from one reference bore in the study area, Cameron Well, where 36 individuals were collected. A congeneric species, *Sarscypridopsis aculeata*, was recorded at four bores from which 29 individuals were collected. This species, which inhabits surface waters as well as subterranean habitats, is a stygophile with a near cosmopolitan distribution and has been recorded by Bennelongia across WA (De Deckker 1981). Five indeterminate specimens belonging to a species of the family Cyprididae were also collected as immature specimens or valves and, although it was not possible to identify them to species level, they could be differentiated from *Sarscypridopsis* and are therefore included in the final species list as Cyrididae sp. BOS668. Several surface genera of Cyprididae are frequently found in bores, including *Cyprinotus, Riocypris* and *Bennelongia* (Karanovic 2008) and it is considered that Cyrididae sp. BOS668 is likely to have similar biology. It is likely to be a species that inhabits both surface and subterranean habitats and consequently is widespread at the scale of the Project.

4.3.8 Coleoptera

At least three species of diving beetles belonging to the genus *Limbodessus* were collected from the study area (Figure 8B). The genus is extremely diverse in subterranean calcrete habitats across the Yilgarn and includes more than 30 described species (Leys *et al.* 2003; Watts and Humphreys 2006; Watts and Humphreys 2009). Stygal species of this genus are short-range endemics that are restricted to single calcretes, or specific habitats within these calcretes. The three species in the Project area are undescribed and differ from each other in body size (*Limbodessus* sp. B08 is much larger than *Limbodessus* sp. B09) and morphology of the pronotum, elytra and gentalia. *Limbodessus* sp. B13 is similar to *Limbodessus* sp. B08 but there are differences in the shape of the aedeagus. *Limbodessus* sp. B08 and *Limbodessus* sp. B09 were abundant and have been collected from six and 17 bores, respectively, whereas *Limbodessus* sp. B13 was recorded only at Bore 7 where just two individuals were collected. Larval *Limbodessus* were collected from 15 bores across the study area and probably correspond to the three recorded species. All three species of *Limbodessus* were recorded in reference bores and are not currently of conservation concern.

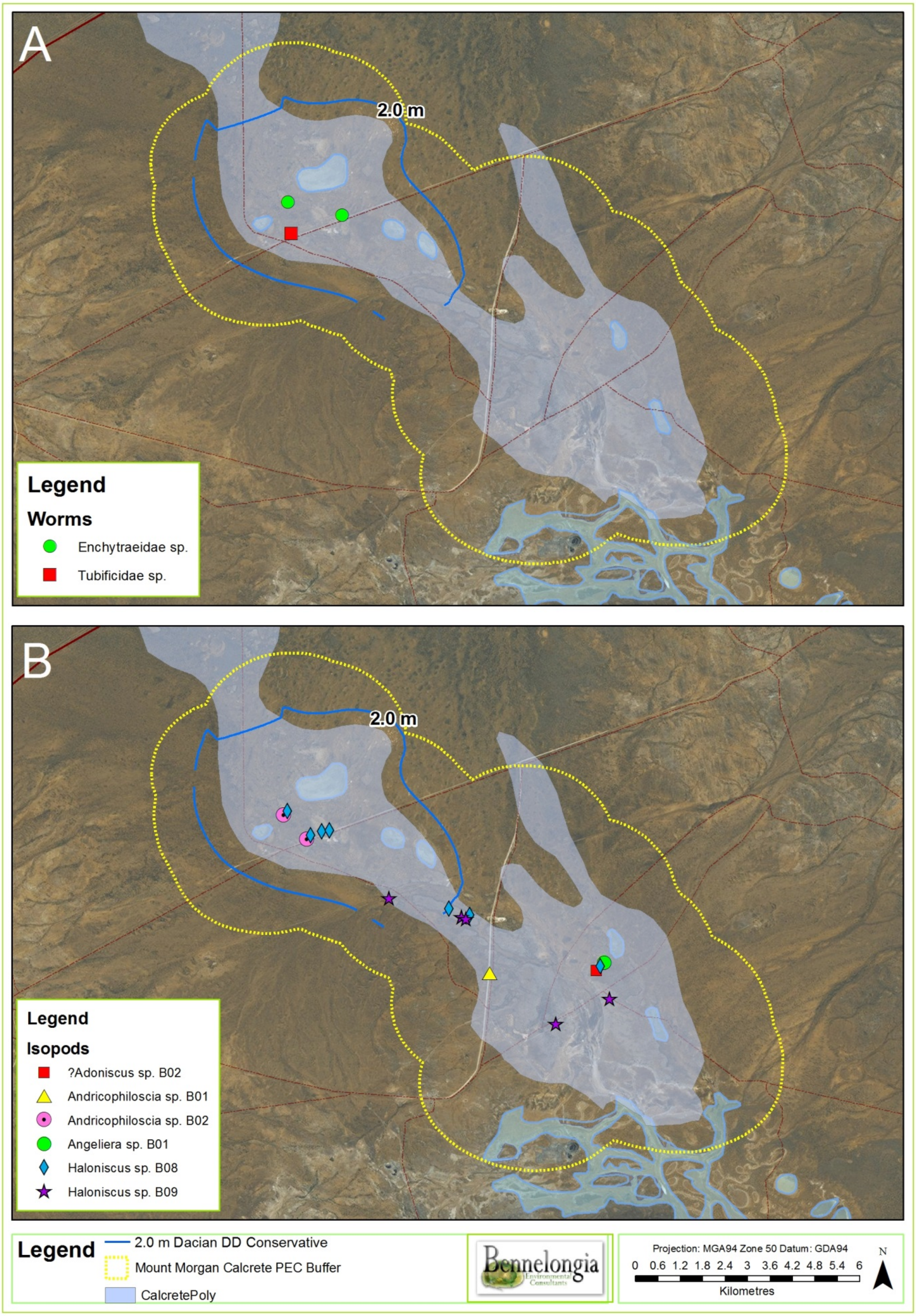


Figure 5. Collection locations of (A) oligochaetes and (B) isopods possibly restricted to the Project area.

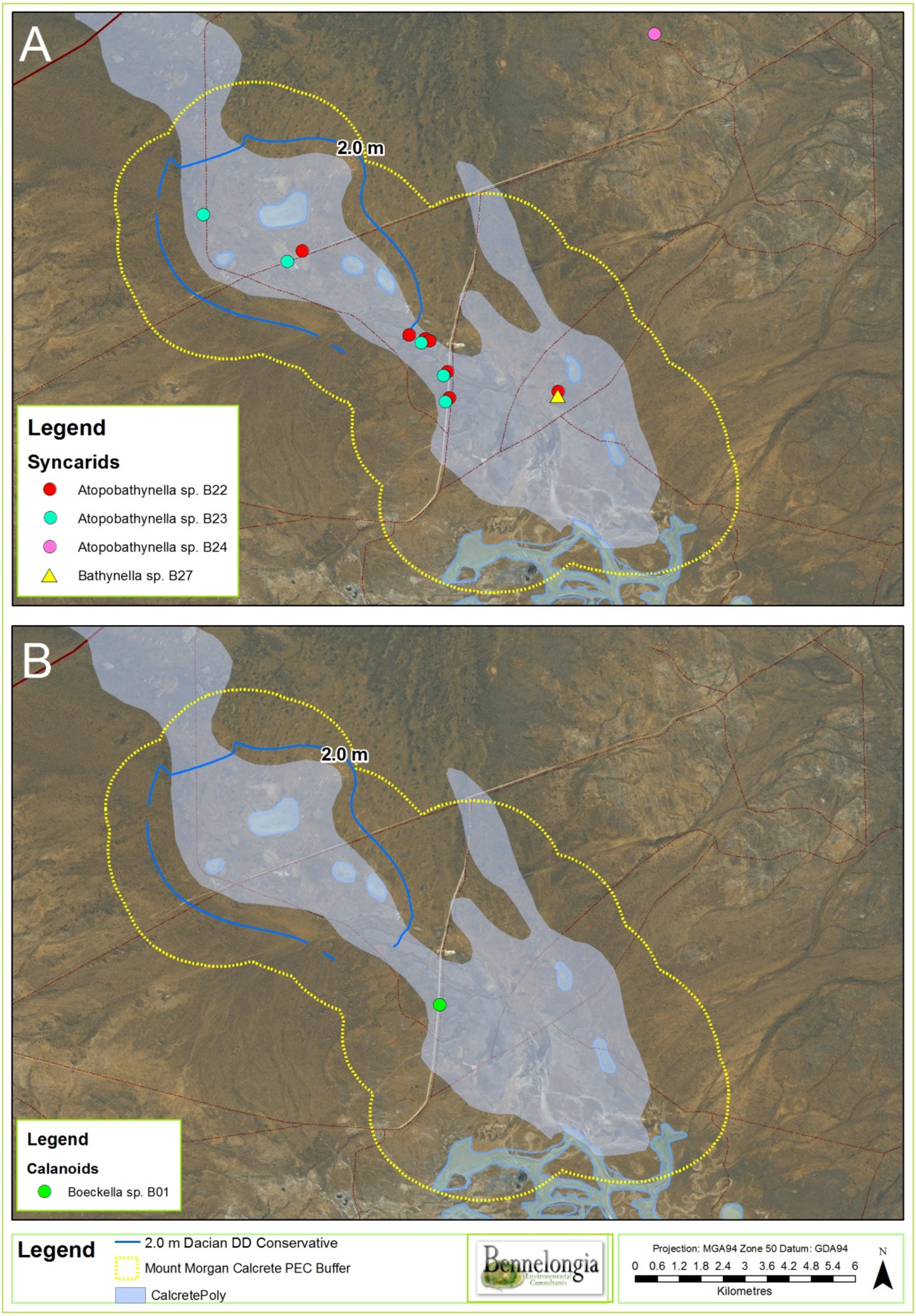


Figure 6. Collection locations of (A) syncarids and (B) calanoid copepods possibly restricted to the Project area.

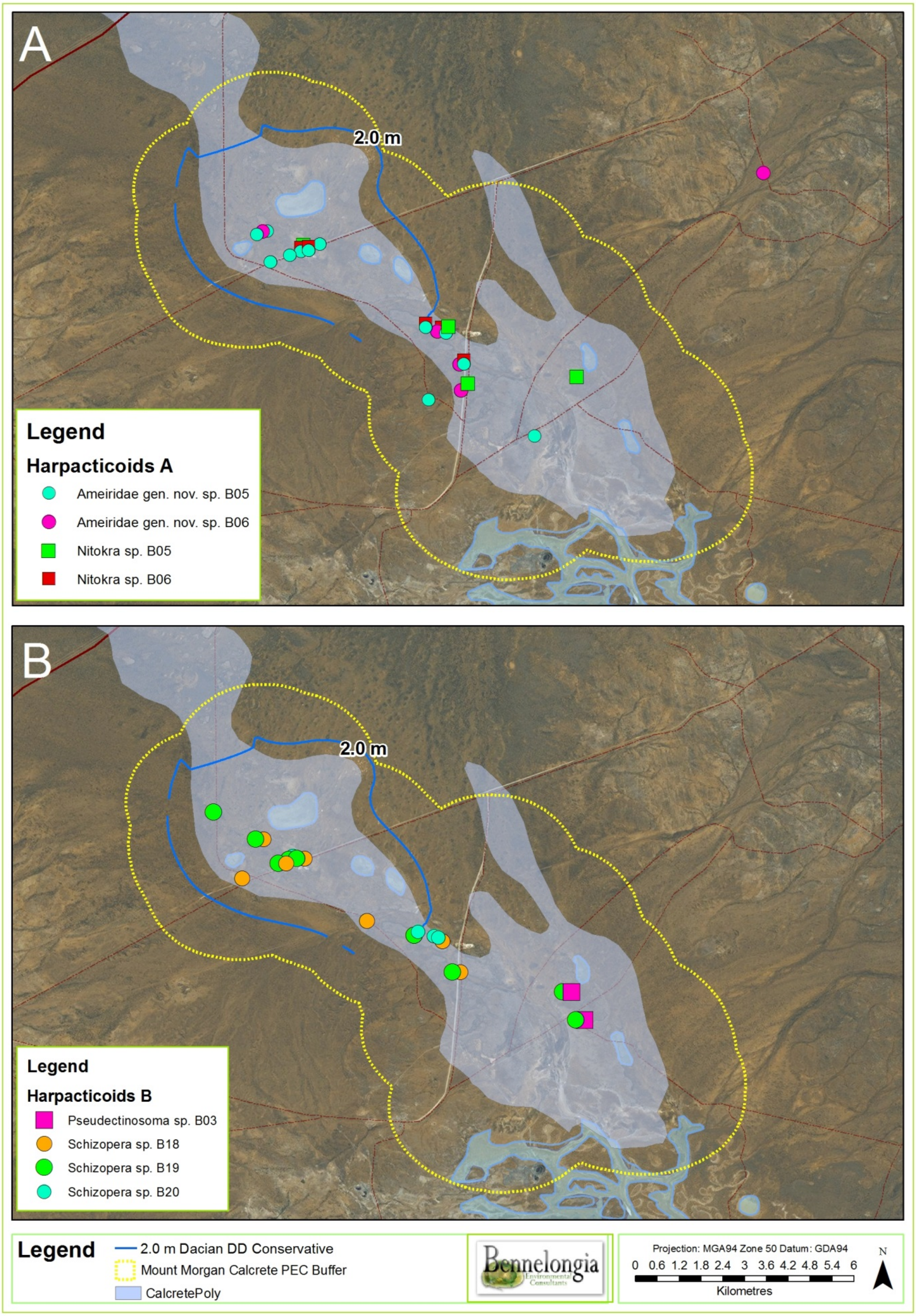


Figure 7. Collection locations of harpacticoid copepods (both panels) possibly restricted to the Project area.

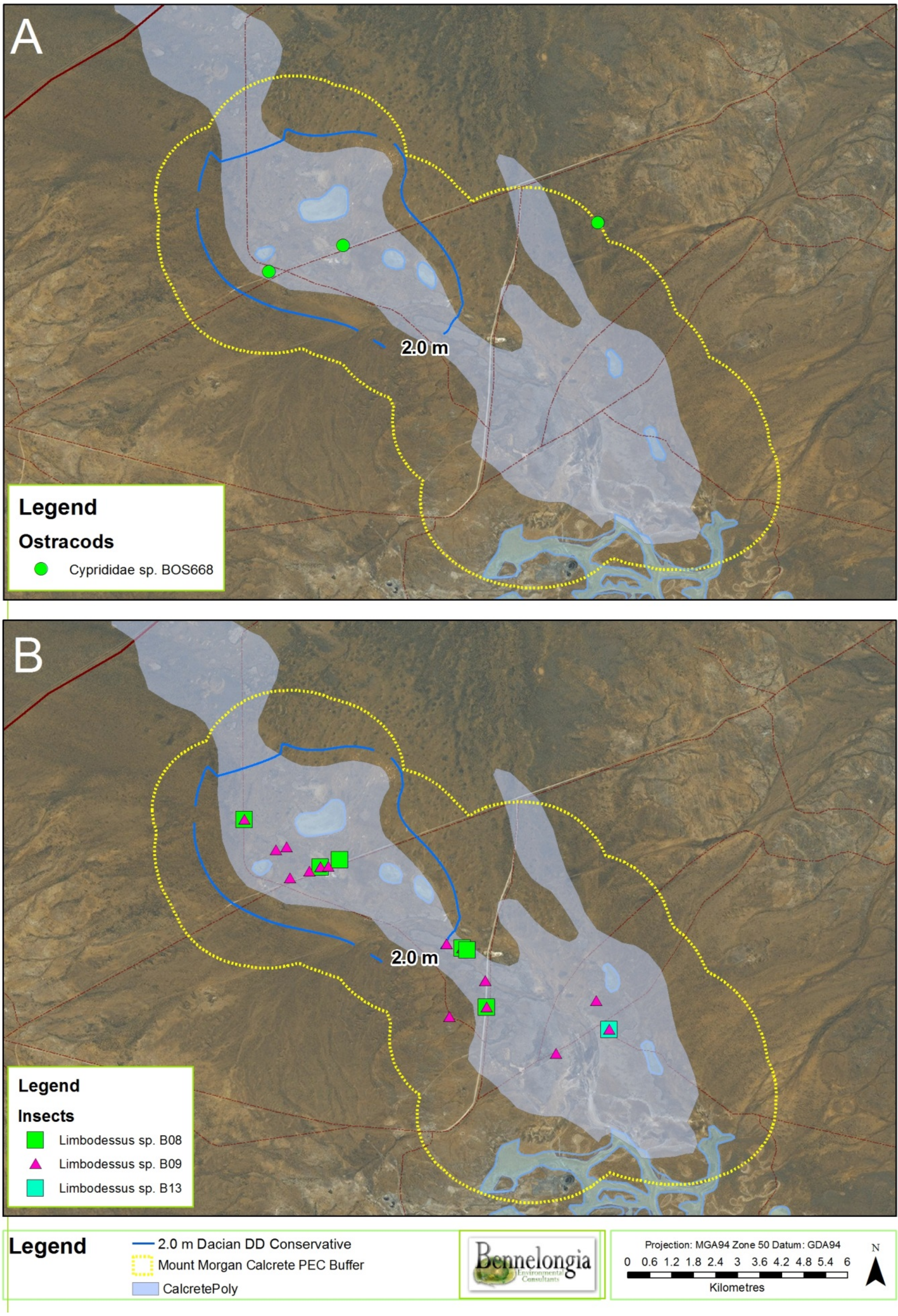


Figure 8. Collection locations of (A) ostracods and (B) dytiscid beetles possibly restricted to the Project area.

Table 4. Impact assessment of stygofauna species recorded in the Project area.
Grey shading indicates species that are known only from impact areas.

Taxonomy	Lowest Identification	No. of individuals	Bores	Impact	Reference	Comments on distribution
Platyhelminthes						
Turbellaria	Turbellaria sp.	10	PB5	10	0	Not currently assessed in EIA.
	Microturbellaria sp.	1	PB7	1	0	Not currently assessed in EIA.
Rotifera						
Bdelloidea	Bdelloidea sp. 2:2	304	Euro Well, Kelly Well, Red Flag Well, Shepherd Well, Siding Well	0	304	Morphospecies is widespread throughout WA but may contain multiple species. Group not currently assessed in EIA.
	Bdelloidea sp. 7:7	1	McKenzie Bore	0	1	Morphospecies is widespread throughout WA but may contain multiple species. Group not currently assessed in EIA.
Eurotatoria						
Monogononta						
Ploima	*Brachionus* sp.	4	Cameron Well, JP60	2	2	Linear range >1.5 km; recorded outside 2 m drawdown.
Nematoda						
	Nematoda sp.	9	Bore 4, PB1, Bore 6, Shepherd Well	3	6	Species range over 9 km including within southern bore area which will not be impacted by drawdown; group not currently assessed in EIA.
Annelida						
Aphanoneura	*Aeolosoma* sp.	25	Cameron Well	0	25	Not identified to species but genus widespread across WA. Recorded outside 2 m drawdown.
Clitellata						
Enchytraeida	Enchytraeidae sp.	6	PB8, Bore 6	6	0	Common family with incomplete taxonomy. Species tend to be restricted to single catchments (scales of tens to hundreds of kilometres), although some are widespread (Brown et al. 2015). Likely to occur in reference areas.
Haplotaxida	*Pristina aequiseta*	1	Pastoral Bore	1	0	Widespread species that occurs across WA.
	Phreodrilidae `with similar ventral chaetae`	3	Kelly Well	0	3	Morphospecies that is widely distributed across WA. Recorded outside drawdown.
	Tubificidae sp.	1	PB1	1	0	Not identified to species level but species of the family are usually widely distributed. Collected as singleton so range unclear, but likely to occur widely across study area.
Arthropoda						

Taxonomy	Lowest Identification	No. of individuals	Bores	Impact	Reference	Comments on distribution
Crustacea						
Malacostraca						
Isopoda	*Angeliera* sp. B01	4	DCN001	0	4	Probably endemic to Mt Morgan Calcrete. Recorded outside 2 m drawdown.
	?*Adoniscus* sp. B02		DCN001	0	1	Probably endemic to Mt Morgan Calcrete. Recorded outside 2 m drawdown.
	Andricophiloscia sp. B01	1	JP49	0	1	Probably endemic to Mt Morgan Calcrete. Recorded outside 2 m drawdown.
	Andricophiloscia sp. B02	3	Bore 6, PB6	3	0	Known linear range of <1 km; probably endemic to Mt Morgan calcrete.
	Haloniscus sp. B08	65	Bore 6, DCN001, JP60, CTB18, PB5, PB6, PB7	47	18	Species range over 7 km including southern bore area. Recorded outside predicted 2 m drawdown.
	Haloniscus sp. B09	21	Bore 5, Bore 7, JP19, JP50, CTB18	20	1	Species range over 7 km including southern bore area. Recorded outside predicted 2 m drawdown.
Syncarida	*Bathynella* sp. B27	2	DCN 001	0	2	Probably endemic to Mt Morgan Calcrete. Recorded outside 2 m drawdown.
	Atopobathynella sp. B22	54	DCN001, JP49, JP50, JP60, CTB18, PB8	3	51	Species range over 7.5 km including southern bore area. Recorded outside predicted 2 m drawdown.
	Atopobathynella sp. B23	17	Bore 1, CTB22, JP49, JP50, PB7	3	14	Species range over 7 km including within southern bore area. Recorded outside predicted 2 m drawdown.
	Atopobathynella sp. B24	9	Ghan Well	0	9	Probably range restricted; recorded at a single regional reference bore outside impact area.
Maxillopoda						
Calanoida	*Boeckella* sp. B01	17	JP49	0	17	Trogloxene; congeners known from surface waters. Recorded outside 2 m drawdown and probably widespread.
Cyclopoida	*Dussartcyclops uniarticulatus*	53	Pastoral Bore, Cameron Well, Kelly Well	1	52	Species distributed outside study area (Murchison region, Karanovic 2004). Presently recorded in reference bores.
	Fierscyclops (*Fierscyclops*) *fiersi*	262	Bore 1, Bore 3, Bore 4, Bore 6, Bore 7, DCN001, JP49, JP60, CTB18, PB1, PB2, PB3, PB5, PB6, PB7, PB8	220	42	Species known from outside study area (Murchison region; Karanovic 2004). Presently recorded from reference bores.
	Halicyclops eberhardi s.l.	28	CTB22, JP49, McKenzie Bore, JP50, JP60	22	6	Known from outside the study area (Murchison and Gascoyne regions; Karanovic 2004).

Taxonomy	Lowest Identification	No. of individuals	Bores	Impact	Reference	Comments on distribution
	Halicyclops kieferi	79	Bore 3, Bore 5, Bore 6, CTB22, JP19, JP49, JP50, JP60,CTB18, PB5, PB6, PB8	51	28	Species distributed outside study area (Murchison region, Karanovic 2004). Presently recorded in reference bores.
	Mesocyclops brooksi	52	Pastoral Bore, Cameron Well	51	1	Widespread across Australia (Australian Faunal Directory).
	Metacyclops superincidentis	1	JP49	0	1	Known from outside the study area (Murchison region, Karanovic 2004).
	Pescecyclops laurentiisae	5	JP19, PB7	5	0	Species known from locations outside the study area (Murchison region; Karanovic 2004).
Harpacticoida	Ameiridae gen. nov. sp. B05	470	Bore 3, Bore 5, Bore 6, Cameron Well, CTB18, CTB22, JP50, JP60, CTB18, PB1, PB5, PB6, PB7, PB8	402	68	Species range over 8.5 km including southern bore area which will not be pumped.
	Ameiridae gen. nov. sp. B06	28	Bore 6, CTB22, JP49, JP50, Siding Well	12	16	Species range over 6 km including southern bore area which will not be pumped.
	Nitokra lacustris pacifica	15	CTB22, PB2, PB5, PB6	14	1	Widely distributed in WA including Murchison (Karanovic 2004) and South West (Knott and Tang 2009), as well as abroad (Australian Faunal Directory)
	Nitokra sp. B05	8	JP49, CTB18, DCN001, PB5	1	7	Linear range over 4 km. Presence at both Jupiter and Mt Morgans impact areas suggests continuity of habitat between the two areas. Recorded in reference bores.
	Nitokra sp. B06	16	CTB22, JP50, JP60, PB5, PB7	7	9	Range over 3.5 km. Presence at both Jupiter and Mt Morgans impact areas suggests continuity of habitat between the two areas. Recorded in reference bore CTB22.
	Australocamptus similis	119	Aemotor Well, Cameron Well, GST1, Kelly Well, Red Flag Well, Pastoral Bore	1	118	Species distributed outside study area (Murchison region, Karanovic 2004). Presently recorded in reference bores.
	Pseudectinosoma sp. B03	3	Bore 7, DCN001	0	3	Known linear range of <1 km. Recorded in reference bores.
	Schizopera sp. B18	15	Bore 6, CTB22, CTB18, PB2, PB6, PB7, JP19	13	2	Range over 4 km. Recorded in reference bores.
	Schizopera sp. B19	52	Bore 1, Bore 6, Bore 7, DCN001, CTB22, JP60, PB5, PB6, PB7	21	31	Range over 7 km. Recorded in reference bores

Taxonomy	Lowest Identification	No. of individuals	Bores	Impact	Reference	Comments on distribution
	Schizopera sp. B20	11	CTB18, JP50, JP60, PB5	5	6	Range over 4 km. Presence at both Jupiter and Mt Morgans impact areas suggests continuity of habitat between the two areas. Recorded in reference bores.
Ostracoda						
	Cyprididae sp. BOS668	5	Kelly Well, PB2, PB8	2	3	Specimens incomplete or immature; may include genus *Cyprinotus*, a stygophile inhabiting both surface and subterranean aquatic habitats and consequently likely to be widespread.
	Sarscypridopsis aculeata	29	Cameron Well, Bore 2, Pastoral Bore, PB2	28	1	Cosmopolitan surface water species/stygophile (AFD)
	Sarscypridopsis orchracea	36	Cameron Well	0	36	Cosmopolitan surface water species/stygophile (e.g. Martens et al. 1996)
Hexapoda						
Insecta						
Coleoptera	*Limbodessus* sp. B08	49	Bore 1, JP49, JP50, CTB18, PB5, PB8	16	33	Range over 10 km including southern bore area which will not be pumped.
	Limbodessus sp. B09	210	Bore 1, Bore 3, Bore 6, Bore 7, Cameron Well, CTB22, DCN001, JP49, JP50, CTB18, PB1, PB5, PB6, PB7, PB8	111	99	Range over 10 km including southern bore area which will not be pumped.
	Limbodessus sp. B13	2	Bore 7	0	2	Recorded from single reference bore the southern bore area.

5. IMPACT ASSESSMENT AND MANAGEMENT OF SUBTERRANEAN FAUNA

5.1 Overview

Two types of mine-related impacts are recognised in this report: 1) *Primary Impacts* from proposed mining have the potential to threaten the persistence of subterranean fauna through direct removal of habitat, and 2) *Secondary Impacts* reduce population densities rather than threatening species persistence. Reduction in the quality of subterranean fauna habitat as a result of nutrient enrichment through increased surface inputs from sewerage, or increased turbidity from mine blasting, are examples of secondary impacts (Masciopinto *et al*. 2006; Scarsbrook and Fenwick 2003).

When assessing the threat to subterranean fauna species from the proposed Project, only primary impacts are considered, although it is recognized that the cumulative effect of secondary impacts may also be detrimental. A background on factors causing secondary impact is given in Appendix 2.

5.2 Troglofauna Impacts

Excavation of open pits is considered to be the main mining-related threat to troglofauna. Impacts at Westralia are limited to a small pit cutback and underground mine developments that will be accessed via existing pits. It is therefore not anticipated that there will be any impacts on troglofauna in the Westralia area.

Pit excavation at Jupiter has the potential to result in loss of troglofauna habitat. However, as previously stated, habitat for troglofauna is limited due to the narrow band of suitable substrate bounded between the surface and the high water table. The proposed mine pits are not expected to cover more than 80 ha (Figure 3), with considerable parts of this area already having been previously mined, so that it is highly unlikely mining would threaten any troglofaunal species at Jupiter. Even highly restricted troglofaunal species in habitats with strong topographical relied and the potential for barriers to dispersal usually have ranges larger than 100 ha.

Activities proposed within the production borefield are limited to groundwater abstraction, with no surface disturbance proposed. There are no troglofaunal impacts are expected within the borefield.

5.3 Stygofauna Impacts

Two activities lead to most of the stygofauna habitat loss associated with mining. These are:

(1) *Groundwater drawdown*. Drawdown of aquifers from dewatering of mine pits or the abstraction of groundwater for ore processing can threaten the persistence of any stygofauna species restricted to the area of drawdown.

(2) *Pit excavation*. Removal of stygofauna habitat when excavating mine pits can threaten the persistence of any stygofauna species restricted to the mine pit. This impact can be assessed when considering groundwater drawdown because the mine pits are contained within the area of drawdown.

Potential impacts to stygofauna and habitat associated with each project area are discussed below.

Westralia

Dacian proposes to develop three underground mines within the Westralia area, which will require dewatering to allow mining at depths below the water table. Although the groundwater quality is considered suitable for stygofauna, the low permeability of the surrounding geology suggests that significant stygofauna populations are unlikely to occur and that any drawdown associated with mine dewatering will be limited in terms of spatial extent.

Jupiter

Owing to the hypersaline nature of groundwater at Jupiter, combined with the low permeability of the surrounding geology, Jupiter is unlikely to support significant stygofauna populations. Dewatering at Jupiter is therefore not considered to present a potential impact to stygofauna.

Production Borefield

Reference and impact sites were classified based on predictive drawdown modelling conducted by Red Creek Water Solutions Pty Ltd (2016), whereby bores outside the predicted 2 m drawdown contour were deemed reference sites and those inside this contour were deemed impact sites.

Of the 45 stygofauna species recorded in the study area, 38 species were collected from bores in reference areas, while two species (*Pristina aequiseta* and *Pescesyclops laurentiisae*) were only recorded in the impact area but are known to occur outside the study area. These species are not of conservation significance, even though many of them also occur in the area of groundwater drawdown associated with the borefield. A further two species (flatworms Turbellaria sp. and Micorturbellaria sp.) were collected only in the impact area but belong to groups not assessed in environmental impacts assessments (EPA 2007).

The remaining three species are known only from the area of groundwater drawdown. They are the immature oligochaetes Enchytraeidae sp. and Tubificidae sp. and the isopod *Andricophiloscia* sp. B02. The occurrence of these species is discussed in detail below.

5.3.1 Assessment of taxa restricted to impact areas

Tubificidae sp. and Enchytraeidae sp.

The oligochaete Tubificidae sp. was damaged during collection from bore PB1, leaving the animal as a fragment that could be identified only to family level. Thus, there is little basis for inferring a likely species range. While some stygal tubificid species have large ranges (e.g. *Monopylephorus* sp. nov. WA29 and Tubificidae sp. WA21 which extend across large parts of the Pilbara, Halse *et al*. 2014), other species appear to more restricted, although this may be a sampling artefact (Pinder *et al*. 2006). Many of the wide-ranging species occur in both surface and groundwater. A study in Spain suggested a third of stygal oligochaetes in the region had tightly restricted distributions, almost another third had linear ranges of <240 km and the remaining species were widespread (Achurra *et al.* 2015).

The oligochaete Enchytraeidae sp. was recorded in low numbers at two impact sites, Bore 6 (five individuals) and PB8 (1 individual), resulting in an inferred minimum linear range of approximately 1.3 km. This is likely to be a substantial underestimation of the actual species range, which needs to be several kilometres larger to extend outside the area of drawdown.

While there is some genetic information from assessment reports that can be interpreted as suggesting enchtraeids have small ranges, it is considered that stygal oligochaetes, including enchytraeids, tend to

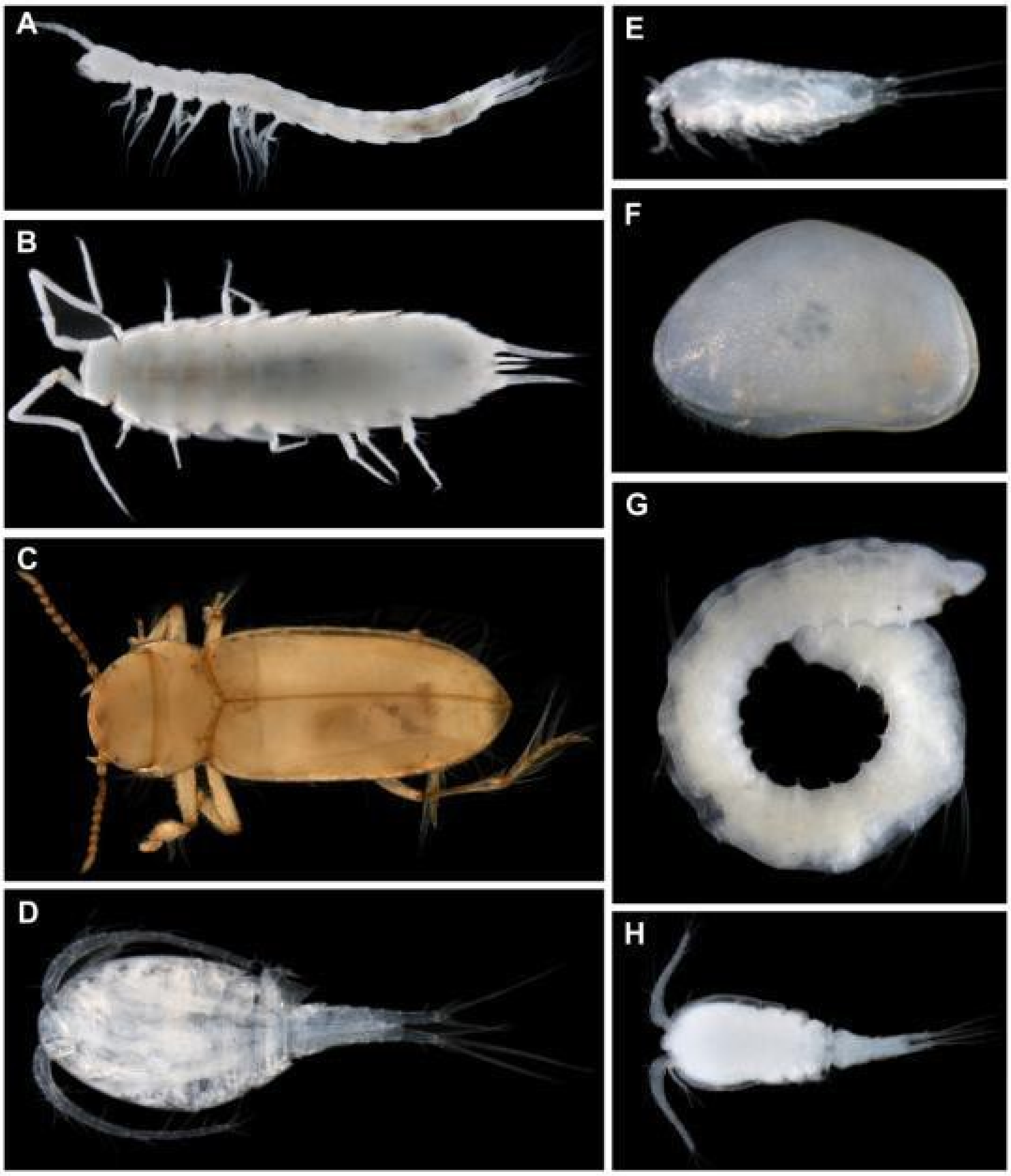


Figure 9. Exemplar taxa of the stygofauna recorded at the Project area.

A) *Atopobathynella* sp. B22; B) *Haloniscus* sp. B08; C) *Limbodessus* sp. B09; D) *Mesocyclops brooksi*; E) *Schizopera* sp. B18; F) *Sarscypridopsis ochracea*; G) *Pristina aequiseta*; and H) *Fierscyclops (Fierscyclops) fiersi*.

have catchment-scale distributions (i.e. tens to hundreds of kilometres in the Pilbara and, by analogy, the Yilgarn (Brown *et al.* 2015). However, haplotypes are typically restricted to single catchments (although some occur across multiple creek catchments and river basins), suggesting the level of dispersal is low (Brown *et al.* 2015). The current study area coincides with the Mt Morgan Calcrete PEC, which exhibits considerable transmissivity and, presumably, habitat continuity. It can therefore be reasonably expected that both Enchytraeidae sp. (as well as Tubificidae sp.) occur widely across the Project area and, therefore, are unlikely to be significantly impacted by groundwater abstraction.

***Andricophiloscia* sp. B02**

The oniscidean isopod *Andricophiloscia* sp. B02 was recorded from the impact Bore 6 (2 individuals) and PB6 (1 individual), giving an inferred linear range of approximately 0.8 km. Based on evidence from previous biogeographic studies of subterranean isopods in the Yilgarn, it is highly likely that this species is a short range endemic that is restricted to the Mt Morgan Calcrete. In a study of 12 calcrete aquifers along three palaeodrainages in the Yilgarn, Javidkar (2014) identified 28 discrete lineages of subterranean oniscidean isopods, each of which probably represents a new species. Furthermore, only three of these lineages were recorded from more than one calcrete, invariably from nearby calcretes within a single palaeodrainage, while the remaining species were restricted to individual aquifers.

These results exemplify the high incidence of short range endemism among subterranean isopods in Western Australia (see also Cooper *et al*. 2008). However, it is suggested that the range of *Andricophiloscia* sp. B02 is likely to extend outside the area of groundwater drawdown for two reasons. First, the high transmissivity of the calcrete aquifer provides continuous habitat between the area of drawdown and its surrounds. In regards to the distribution capabilities of stygal species, Guzik et al. (2009) suggested that population structure in a stygal dytiscid was influenced by body size, with smaller species having greater dispersal capabilities. *Andricophiloscia* sp. B02 has a much smaller body size than the more widely spread *Haloniscus* B08 and so could be expected to have a similar or greater distribution throughout the aquifer.

Second, the wider occurrence of the related *Haloniscus* sp. B08 (as well as *Haloniscus* sp. B09) provides biological evidence there is suitable continuous habitat for *Andricophiloscia* sp. B02 outside the drawdown area (Figure 5). *Haloniscus* sp. B08 occurs together with *Andricophiloscia* sp. B02 at both Bore 6 and PB6, as well as having a range extending south-east outside the area of groundwater drawdown. The occurrence of *Haloniscus* sp. B09 to the south-east is further evidence of suitable habitat for isopods outside the drawdown area. Thus, it is considered unlikely that *Andricophiloscia* sp. B02 will be significantly impacted by groundwater abstraction.

5.3.2 Stygofauna community composition between impact and reference sites

Further information about the likely level of threat to the potentially conservation significant species is provided by examination of the past effects of groundwater drawdown. Analyses of stygofauna data using *t*-tests (assuming equal or unequal variance as appropriate) reveal that there is no significant difference in mean abundance (df= 20.21, p= 0.32) or mean number of species (df= 37, p= 0.21) per bore between reference and impact sites (Table 5). This suggests that historical pumping has not had a significant impact on the abundance and diversity of stygofauna communities in the study area. For example, production bores JP60, PB5, 6 and 7, which were historically pumped, all recorded higher than average abundance (314, 235, 87 and 140 individuals, respectively) and richness (12, 13, 10 and 10 species, respectively) (Table 5).

Table 5. Summary table of stygofaunal communities at impact and reference sites.
Mean values are given as mean ± SE.

	Site type		All sites
	Reference	Impact	
No. of bores (n)	23	16	39
Total count (abundance)	1054	1125	2179
Mean abundance per bore	45.83 ± 9.08	70.31 ± 23.06	55.87 ± 10.67
Total richness	38	31	45
Mean richness per bore	4.57 ± 1.02	6.56 ± 1.14	5.38 ± 0.77
Number of species exclusive to site type	14	7	NA

5.3.3 Historic groundwater hydrology

Historic groundwater abstraction and water level data from March 1988 to May 1990 and July 1992 to June 1997 (the period during which the borefield operated) has been collated by GRM (2016) and used to assess the impacts from earlier groundwater production on the groundwater environment. A summary of the maximum drawdown and minimum saturation layer are included in Table 6. Key findings of the GRM assessment are given below, with the full memo report provided as Appendix 5.

Groundwater levels in all the bores show a good response to rainfall recharge. In particular, the rapid rise observed after Cyclone Bobby in February 1995, which delivered a three-day rainfall total of 225 mm locally resulted in a groundwater level rise of approximately 2–4 m.

Lower yielding bores, PB1 in particular, were severely impacted by pumping, with saturated thicknesses in the calcrete aquifer reduced by up to 80%, equivalent to a residual saturated thickness of about 1 m at PB1. These severe impacts were sustained over many months in response to continued pumping. Despite this, PB1 yielded five species and a total of 31 individuals. These values were comparable to overall averages for abundance and richness per bore, and were higher than yields obtained from Bores 2, Bore 7, JP19 and PB3, none of which was historically pumped. This indicates suggests that the inherent fauna may be robust to substantial drawdown. It is possible, however, that the low yields from the aforementioned bores are a consequence of their position or construction (Hahn and Matzke 2005; Halse et al. 2014).

The negligible drawdowns observed in non-pumping bore PB3, located about 400 m from PB1 and 200 m from PB2, suggest drawdown associated with abstraction will be localised around future operating production bores. This interpretation is consistent with the lack of impact seen in higher yielding bores PB5, 6 and 7 that were pumped consistently over the later period of mining, despite their proximity to each other (i.e. 270 m from PB5 to PB6; 200 m from PB5 to PB7). Overall, these results show that borefields at Mt Morgan have been able to sustain a combined mean pumping rate of around 26 L/s over a period of about 10 years, with a recorded maximum annual abstraction of approximately 1 GL.

Water levels in the aquifer appear to have recovered from historical pumping and depths to standing water levels are similar to the baseline values. Bores PB5, PB6 and PB7 have an average standing water level of 1.65 m higher than levels recorded prior to historical pumping, whereas bores JP60, PB1 and PB22 are on average 0.73 m lower (Table 6). It is also apparent from available data that pH values recorded before and after historical pumping are similar (Table 6).

The salinity in the calcrete aquifer varies considerably, both spatially and temporally. At the production bores, salinities range from 2,600–17,000 mg/L TDS based on records from 1996. Similar ranges in salinity were recorded by Bennelongia in 2016 (3,310–23,500 mg/L TDS). However, a maximum value of 28,100 mg/L was recorded at groundwater exploration hole JP45 at the southern end of the unit (MMA 1990). The impacts of dewatering on EC and salinity gradients (vertical and horizontal) are unclear, although five out of six historically pumped bores showed increases in EC of between 1.51 mS/cm and 8.44 mS/cm.

5.3.4 Management of Future Groundwater Abstraction from the Borefield

Dacian proposes to abstract groundwater from existing production bores, supplemented by additional bores constructed in the calcrete aquifer (all to be located within the survey area) to meet the Project raw water demands of about 105 L/s, or 9.1 ML/day over a period of eight years.

Drawdown modelling was completed by Red Creek Water Solutions Pty Ltd (2016). The modelling assumed a groundwater abstraction rate of 106 L/s from 20 production bores within the Calcrete Aquifer. The combined abstraction rate from the 20 production bores was 9100 m^3/d (106L/s). The volume of groundwater abstraction is about 3.3 GL per year and 26.7 GL over the 8 years of mining operations. The modelling included a base case scenario and a conservative scenario. The conservative (worst case) model has been used by Bennelongia to assess impacts to stygofauna. This model assumes that groundwater levels are sustained by rainfall recharge only (i.e. they do not include other hydrogeological processes such as groundwater inflow from the underlying palaeochannel). Additionally, the conservative model used to derive the 2 m drawdown contours in this assessment assumes that a large rainfall event does not occur until Year 7 during the 8 years of proposed operations.

After 7 years of operations and before the onset of the large rainfall event, groundwater levels are lowered by up to 4 m in the central portion of the borefield. Saturated thickness in the central areas of the borefield is predicted to be about 2 m (40% of the aquifer thickness). Saturated thickness at JP60 is predicted to be 2.5 m (50% of the aquifer thickness).

Groundwater levels outside of the central borefield area are predicted to be lowered gradually during the borefield operations, with slightly more than 0.5 m drawdown occurring after 2 years of operations, after which groundwater levels continue to lower during the remaining 5 year of operations. The southern region of the Calcrete Aquifer (i.e. 100 m south of JP60), is predicted to remain largely unaffected by drawdown (e.g. between 0.5 to 1.5 m drawdown). To the north, loss of saturated thickness as a result of drawdown is greater than to the south.

The model predicts that groundwater levels rapidly recover in response to the large rainfall event in year 7, with groundwater levels increasing by about 1.5 m. For the worst case modelling scenario, it is predicted that 70% of the saturated thickness of the calcrete aquifer will be retained for the duration of operations. Additionally, a layer of sand underlies the calcrete and will remain saturated during and after the dewatering period.

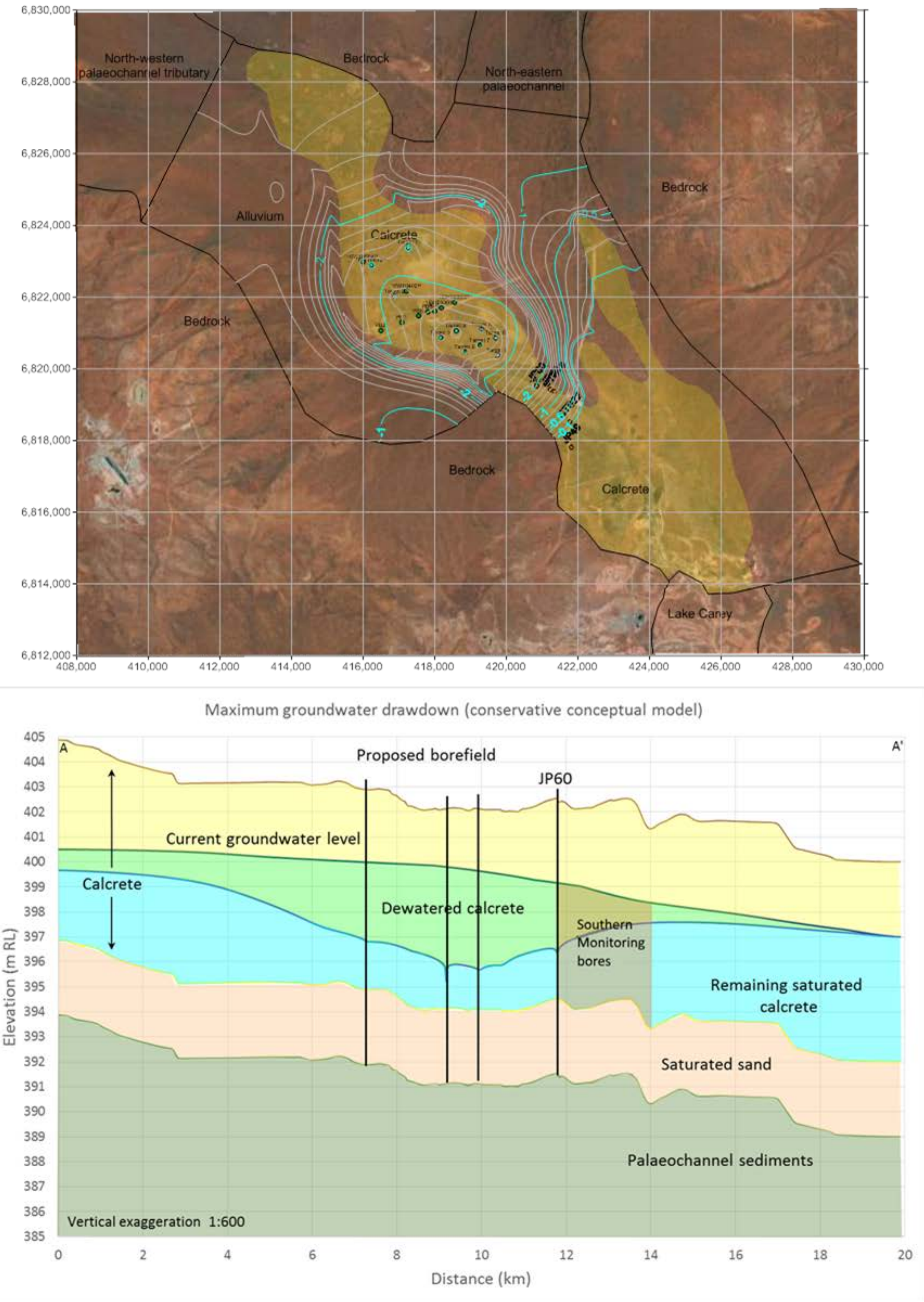


Figure 10. (From top) Predicted drawdown and long-section of the Mt Morgan Calcrete 7 years after the commencement of dewatering from the proposed production borefield under base case scenario.

Table 6. Comparison of historical and current water properties at monitoring bores.

	JP60		PB1		PB2		PB5		PB6		PB7	
Location	Jupiter borefield		Mt Morgans Borefield		Mt Morgans Borefield		Mt Morgans Borefield		Mt Morgans Borefield		Mt Morgans Borefield	
Period of operation	Feb 95- Jun 97		Feb 88- Apr 96		Feb 88 – Dec 95		Aug 89 – Jun 97		Aug 89 – Jun 97		Jul 92 - Jun 97	
Max drawdown (m)	1		4		3		3		3		3	
Min saturated thickness (m)	4		1		2		2		3		6	
	Historical	2016	Historical	2016	Historical	2016	Historical	2016	Historical	2016	Historical	2016
SWL (m)	3.00	3.75	2.75	3.40	2.75	3.53	4.10	2.77	3.75	2.78	5.00	2.36
DWL difference	-0.75		-0.65		-0.78		1.33		0.97		2.64	
EC (µs/cm)	14,000	22,440	8,500	10,010	2,600	6,290	13,000	17,785	9,400	13,980	17,000	14,535
EC difference	8,440		1,510		3,690		4,785		4,580		-2,465	
pH [+]	7.55	7.05	7.4	7.26	7.36	8.00	7.38	7.12	7.34	7.24		7.43
Temp °C		23.23		25.35		25.15		25.10		25.60		24.85

Note: salinities were taken from the 1996 to 1997 wellfield assessment (Woodward-Clyde 1996); historical SWL data are estimated from figures provided in GRM 2016 and values represent SWL prior to pumping, where possible. Data for 2016 are means of values recorded during stygofauna sampling phases 1, 2 and 3.

Bore PB3 was never historically pumped, but was also monitored between 1988 – 1990 due to its close proximity to PB1 (400 m) and PB2 (200 m). The drawdowns observed at the bore were negligible over the limited period of record.

6. CONCLUSIONS

This report collated the findings of a desktop review on subterranean fauna and a comprehensive stygofauna assessment for the Mt Morgans Gold Project. Troglofauna survey was not considered to be necessary because the available information suggested that no significant troglofauna community is likely to occur.

The most prospective habitat for stygofauna occurs within the production borefield which is located within a calcrete aquifer that covers an area of about 60 km^2 and forms an elongate unit that broadly trends northwest from the northern margin of Lake Carey. The unit is thin, sub-cropping close to surface with a maximum depth of about 10 m. It comprises vuggy carbonate rock interbedded with alluvium and silcrete and was identified to be good habitat for stygofauna. The calcrete aquifer comprises the Priority 1 PEC, '*Mt Morgan calcrete groundwater assemblage type on Carey paleodrainage on Mount Weld Station*'.

Habitat for troglofauna may be present above the water table at Westralia although this area will only be mined underground and therefore will not impact widely on any troglofauna communities. At Jupiter, habitat for troglofauna is limited because the geology is predominantly syenite and basaltic rock types, with a general absence of vugs and voids in substrate above the water table. At the production borefield there is only a low-moderate likelihood of troglofauna due the shallow depth to water (ranging between 3 to 6 mbgl) which is likely to constrain the extent of habitat available to troglofauna in the area. More importantly, there will be no disturbance of habitat above the water table in the production borefield. Considering also that only eleven troglofauna species were identified in the desktop assessment within the search area, troglofaunal is not considered to be a relevant assessment factor at the Project.

Field sampling of stygofauna yielded a total of 2,179 specimens belonging to at least 45 species of stygofauna. Crustaceans were by far the most diverse group with 31 species in six orders: harpacticoid copepods (10 species), cyclopoid copepods (7), isopods (6), ostracods (2), syncarids (4) and calanoid copepods (1). Forty of these species are known to occur outside the predicted area of groundwater drawdown. Two species of flatworm were recorded from the 2 m drawdown area only, but are currently not assessed in EIA. A further three species are known only from the drawdown area: the worms Tubificidae sp. and Echytraeidae sp. and the isopod *Andricophiloscia* sp. B02. While it is difficult to determine the ranges of species identified only to family level, both worm species are considered likely to be widespread at the Project scale and not threatened by drawdown. The isopod *Andricophiloscia* sp. B02 is likely to be restricted to the Mt Morgan calcrete. However, it is likely to extend beyond the area of groundwater drawdown because of high habitat connectedness across the calcrete, as shown by the wider distribution of the biological surrogate Haloniscus sp. B09. Accordingly, *Andricophiloscia* sp. B02 is unlikely to be threatened by Project-related groundwater drawdown.

Further confidence that drawdown will not significantly affect the stygofauna community in the Project area is provided by analysis of stygofauna communities inside and outside the area affected by previous pumping of up to 1 GL annually. Both mean abundance and species richness per bore are similar between sites inside and outside the previous drawdown, which suggests that stygofauna were not impacted by historic pumping of the borefield.

Based on drawdown modelling, the predicted loss of calcrete aquifer habitat as a result of groundwater abstraction associated with the Project is not likely to exceed 30 %.. A layer of saturated calcrete of 1.5–2 m thick will also persist throughout the most heavily impacted zones surrounding the production borefield. At JP60, a maximum of 2.5 m drawdown is predicted with a remaining saturated thickness of 2.5 m. The saturated layer of underlying sand will not be affected by pumping and may provide refuge/additional habitat for stygofauna.

6.1 Recommendations

In order to protect the habitat and species richness within the Mt Morgans PEC, Bennelongia recommends the following management framework should be adopted by Dacian:

- Ecological monitoring bores to be established within 500 m of production bores.
- Standing Water Level (SWL) measurements to be taken on a quarterly basis when bores are being pumped.
- Where SWLs measured in ecological monitoring bores indicate a trending decline in aquifer saturated thickness, monitoring of SWL to increase to a monthly frequency.
- Where monthly SWL monitoring suggests an ongoing reduction in saturated thickness, pumping rates of the production bore(s) to be reduced to maintain the groundwater levels predicted in the hydrogeological studies associated with this assessment.

Additionally, the potential impacts of groundwater abstraction at the Project on spatial and temporal patterns in salinity are unknown. Four of five bores historically pumped showed increases in electrical conductance (EC) of between 1.51 mS cm^{-1} and 8.44 mS cm^{-1}. Therefore, changes to EC in the dewatering impact zone and ecological monitoring bores should be monitored during and after groundwater abstraction, with follow up stygofauna monitoring if excessive changes in EC are observed.

7. REFERENCES

Abrams, K.M., Guzik, M.T., Cooper, S.J.B., Humphreys, W.F., King, R.A., Cho, J.L., and Austin, A.D. (2012) What lies beneath: Molecular phylogenetics and ancestral state reconstruction of the ancient subterranean Australian Parabathynellidae (Syncarida, Crustacea). *Molecular Phylogenetics and Evolution* **64**, 130-144.

Achurra, A., Rodriguez, P., and Reynoldson, T.B. (2015) Is the Cantabrian region of northern Spain a biodiversity hotspot for obligate groundwater fauna? The case of oligochaetes (Annelida, Clitellata). *Hydrobiologia* **745**, 151-166.

Aplin, K.P. (1998) Three new blindsnakes (Squamata, Typhlopidae) from north western Australia. *Records of the Western Museum* **19**, 1-12.

Baehr, B.C., Harvey, M.S., Burger, M., and Thoma, M. (2012) The New Australasian Goblin Spider Genus Prethopalpus (Araneae, Oonopidae). *Bulletin of the American Museum of Natural History* **369**, 1-113.

Barranco, P., and Harvey, M.S. (2008) The first indigenous palpigrade from Australia: a new species of *Eukoenenia* (Palpigradi: Eukoeneniidae). *Invertebrate Systematics* **22**, 227-233.

Bayly, I.A.E., 1992. The non-marine Centropagidae (Copepoda: Calanoida) of the world. SPB Academic Publishing, The Hague.

Bennelongia (2007) Report on subterranean fauna of the Duketon Gold Project area, north of Laverton. Report 2007/14, Bennelongia Pty Ltd, Jolimont, 23 pp.

Bennelongia (2008a) Subterranean fauna review and sampling program for Poondano Channel Iron Deposit Project, Polaris Metals NL. Report 2008/20, Bennelongia Pty Ltd, Jolimont, 13 pp.

Bennelongia (2008b) Troglofauna survey at Koolyanobbing. Report 2008/49, Bennelongia Pty Ltd, Jolimont, 24 pp.

Bennelongia (2008c) Troglofauna survey of Mount Jackson Range, Western Australia. Report 2008/50, Bennelongia Pty Ltd, Jolimont, 15 pp.

Bennelongia (2009) Yilgarn Iron Ore Project: Carina deposit, subterranean fauna assessment. Report 2009/69, Bennelongia Pty Ltd, Jolimont, 30 pp.

Bennelongia (2011a) Duketon Gold Project: Subterranean Fauna Assessment at Garden Well and Erlistoun. Unpublished report for Regis Resources Ltd.

Bennelongia (2011b) Subterranean fauna assessment: Kirkalocka Gold deposit. Report 2011/132, Bennelongia Pty Ltd, Jolimont, 27 pp.

Bennelongia (2012a) Addendum: Pilbara Iron Ore Project, Blacksmith subterranean fauna surveys. Report 2012/137A, Bennelongia Pty Ltd, Jolimont, 46 pp.

Bennelongia (2012b) Addendum: troglofauna assessment, Ularring haematite project. Report 2012/185, Bennelogia Pty Ltd, Jolimont, 24 pp.

Bennelongia (2012c) Mummaloo Project: Subterranean fauna. Report 2012/173, Bennelongia Pty Ltd, Jolimont, 24 pp.

Bennelongia (2013) Yamarna project subterranean fauna assessment. Report 2013/199, Bennelongia Pty Ltd, Jolimont, 37 pp.

Bennelongia (2015) Yeelirrie Stygofauna Assessment. Unpublished Letter Report to Cameco Australia. Jolimont, WA, 11 pp.

Biota (2007) Hematite and Magnetite Projects desktop subterranean fauna assessment. Project No. 389, Biota Environmental Sciences, Leederville, 29 pp.

Blueprint, E.S. (2015) Mt Morgans Gold Project. Summary of Information Relating to Subterranean Fauna and Short Range Endemics. .

Blueprint, E.S. (2016) Mt Morgans Gold Project Summary of Information Relating to Subterranean Fauna and Short Range Endemics. Unpublished report.

Brown, L., T. Finston, G. Humphreys, S. Eberhard, A. Pinder. (2015) Goundwater oligochaetes show complex genetic patterns of distribution in the Pilbara region of Western Australia. *Invertebrate Systematics* **29**, 405-420.

Cho, J.-L., and Humphreys, W.F. (2010) Ten new species of the genus Brevisomabathynella Cho, Park and Ranga Reddy, 2006 (Malacostraca, Bathynellacea, Parabathynellidae) from Western Australia. *Journal of Natural History* **44**, 993-1079.

Cho, J.-L., Park, J.-G., and Humphreys, W.F. (2005) A new genus and six species of the Parabathynellidae (Bathynellacea, Syncarida) from the Kimberley region, Western Australia. *Journal of Natural History* **39**, 2225-2255.

Cooper, S.J.B., Saint, K.M., Taiti, S., Austin, A.D., and Humphreys, W.F. (2008) Subterranean archipelago: mitochondrial DNA phylogeography of stygobitic isopods (Oniscidea: *Haloniscus*) from the Yilgarn region of Western Australia. *Invertebrate Systematics* **22**, 195-203.

Cowan, M. (2001) Murchison 1 (MUR 1 - East Murchison subregion). Department of Conservation and Land Management, 466-479 pp. pp.

DEC (2009) Priority Ecological Communities for Western Australia Department of Environment and Conservation, Species and Communities Branch,, 17 pp.

DEC (2010) List of Threatened Ecological Communities on the Department of Environment and Conservation's Threatened Ecological Community (TEC) Database endorsed by the Minister for the Environment. Department of Environment and Conservation, 5 pp.

DPaW (2015) Wildlife Conservation (Specifically Protected Fauna) Notice published in November 2015. Department of Parks and Wildlife,

DSEWPC (2012) Australia's bioregions (IBRA). Department of Sustainability, Environment, Water, Population and Communities, Canberra, ACT,

Eberhard, S.M., Halse, S.A., and Humphreys, W.F. (2005) Stygofauna in the Pilbara region, north-west Western Australia: a review. *Journal of the Royal Society of Western Australia* **88**, 167-176.

ecologia Environment (2009a) Tropicana Gold Project - Stygofauna Survey Report. ecologia Environment, West Perth, 40 pp.

ecologia Environment (2009b) Tropicana Gold Project - Troglofauna Survey Report. ecologia Environment, West Perth, W.A., 46 pp.

ecologia Environment (2010) Tropicana Gold Project - Troglofauna Records and Troglobitic Habitat at Tropicana Gold Project. ecologia Environment, West Perth, WA, 11 pp.

Edward, K.L., and Harvey, M.S. (2008) Short-range endemism in hypogean environments: the pseudoscorpion genera *Tyrannochthonius* and *Lagynochthonius* (Pseudoscorpiones: Chthoniidae) in the semiarid zone of Western Australia. *Invertebrate Systematics* **22**, 259-293.

EPA (2007) Guidance for the Assessment of Environmental Factors: Sampling Methods and Survey Considerations for Subterranean Fauna in Western Australia Draft Guidance Statement No. 54A, Environmental Protection Authority, Perth, 37 pp.

EPA (2013) Environmental Assessment Guildline No. 12 - Consideration of Subterranean Fauna in Environmental Impact Assessment in WA. Environmental Protection Authority Western Australia, Perth, 24 pp.

Fontaine, B., Bouchet, P., Van Achterberg, K., Alonso-Zarazaga, M.A., Araujo, R., *et al.* (2007) The European union's 2010 target: Putting rare species in focus. *Biological Conservation* **139**, 167-185.

Gajowiec, B. (1993) Impact of lead/zinc ore mining on groundwater quality in Trzebionika mine (southern Poland). *Mine Water and the Environment* **12**, 1-10.

GHD (2009) Report for Jack Hills expansion project regional stygofauna phase 1 survey. GHD, Perth,

Gibert, J., and Deharveng, L. (2002) Subterranean Ecosystems: A Truncated Functional Biodiversity. *BioScience* **52**, 473-481.

Guzik, M.T., Abrams, K.M., Cooper, S.J.B., Humphreys, W.F., Cho, J.-L., and Austin, A.D. (2008) Phylogeography of the ancient *Parabathynellidae* (Crustacea: Bathynellacea) from the Yilgarn region of Western Australia. *Invertebrate Systematics* **22**, 205-216.

Guzik, M.T., Cooper, S.J.B., Humphreys, C.H.S., and Austin, A.D. (2009) Fine-scale comparative phylogeography of a sympatric sister species triplet of subterranean diving beetles from a single calcrete aquifer in Western Australia. *Molecular Ecology* **18**, 3683-3698.

Hahn, H.J., and Matzke, D. (2005) A comparison of stygofauna communities inside and outside groundwater bores. *Limnologica* **35**, 31-44.

Halse, S., 2010. Distribution patterns of different groups of troglofauna in the Pilbara region, Western Australia: are arachnids the most restricted troglofauna? In: 'International Conference on Subterranean Biology', Postojna, Slovenia. (Eds. A Moskric and P Trontelj), Halse, S., and Pearson, G. (2014) Troglofauna in the vadose zone: comparison of scraping and trapping results and sampling adequacy. *Subterranean Biology* **13**, 17-34.

Halse, S.A., Scanlon, M.D., Cocking, J.S., Barron, H.J., Richardson, J.B., and Eberhard, S.M. (2014) Pilbara stygofauna: deep groundwater of an arid landscape contains globally significant radiation of biodiversity. *Records of the Western Australian Museum Supplement* **78**, 443-483.

Javidkar, S. (2014) Molecular systematics and biogeographic histroy of oniscidean isopod troglofauna in groundwater calcretes of central Western Australia. Ph D Thesis, The University of Adelaide, Adelaide, South Australia.

Karanovic, T. (2004) Subterranean copepods (Crustacea: Copepoda) from arid Western Australia. *Crustaceana Supplement* **3**, 1-366.

Karanovic, T., and Cooper, S.J.B. (2011a) Molecular and morphological evidence for short range endemism in the Kinnecaris solitaria complex (Copepoda: Parastenocarididae), with descriptions of seven new species. *Zootaxa* **3026**, 1-64.

Karanovic, T., and Cooper, S.J.B. (Eds) (2011b) 'Third Genus Of Parastenocaridid Copepods From Australia Supported By Molecular Evidence (Copepoda, Harpacticoida).' Studies on Freshwater Copepoda: a Volume in Honour of Bernard Dussart (Brill)

Karanovic, T., Eberhard, S., Cooper, S.J.B., and Guzik, M.T. (2014) Morphological and molecular study of the genus *Nitokra* (Crustacea, Copepoda, Harpacticoida) in a small palaeochannel in Western Australia. *Organisms, Diversity & Evolution* **15**, 1-35.

Karanovic, T., and McRae, J. (2013) The genus Schizopera (Copepoda, Harpacticoida) in the Pilbara region of Western Australia, with description of a new species and its molecular and morphological affinities. *Records of the Western Australian Museum* **119**, 28.

Karanovic, T., and Pesce, G.L. (2002) Copepods from ground waters of Western Australia, VII. *Nitokra humpreysi* sp. nov. (Crustacea: Copepoda: Harpacticoida). *Hydrobiologia*.

Tang, D., and Knott, B. (2009) Freshwater cyclopoids and harpacticoids (Crustacea: Copepoda) from the Gnangara Mound region of Western Australia. . *Zootaxa* **2029**, 1-70.

Korbel, K., and Hose, G. (2011) A tiered framework for assessing groundwater ecosystem health. *Hydrobiologia* **661**, 329-349.

Leys, R., Watts, C.H.S., Cooper, S.J.B., and Humphreys, W.F. (2003) Evolution of subterranean diving beetles (Coleoptera: Dytiscidae Hydroporini, Bidessini) in the arid zone of Australia. *Evolution* **57**, 2819-2834.

Martens, K., Davies, B.R., Baxter, A.J., and Meadows, M.E. (1996) A contribution to the taxonomy and ecology of the Ostracod (Crustacea) from Verlorenvlei (Western Cape, South Africa). *South African Journal of Zoology* **31**, 23-36.

Masciopinto, C., Semeraro, F., La Mantia, R., Inguscio, S., and Rossi, E. (2006) Stygofauna Abundance and Distribution in the Fissures and Caves of the Nardò (Southern Italy) Fractured Aquifer Subject to Reclaimed Water Injections *Geomicrobiology Journal* **23**, 267-278.

McAuley, S.D., and Kozar, M.D. (2006) Groundwater quality in unmined areas and near reclaimed surface coal mines in the northern and central Appalachian coal regions, Pennsylvania and West Virginia. US Geological Survey, Reston, Virginia, 57 pp.

MMA (1990) Austmin Gold Mines Pty Ltd and Croesus Mining N.L. Groundwater Investigations Jupiter Project. Unpublished report by Mackie, Martin and Associates Pty Ltd.

Outback Ecology (2012) Toro Energy Ltd Wiluna Uranium Project subterranean fauna assessment. Outback Ecology (MWH Australia Ltd), Jolimont, 95 pp.

Outback Ecology, S. (2009a) Mt Morgans The Craic Project Baseline Assessment of Surfance Soils. Unpublished report by Outback Ecology Services produced for Range River Gold July 2009.

Outback Ecology, S. (2009b) Mt Morgans The Craic Project Level 1 Flora and Fauna Assessment. Unpublished report by Outback Ecology Services produced for Range River Gold June 2009.

Pinder, A.M. (2003) New Species and records of Phreodrilidae (Annelida:Clitellata) from Western Australia. *Records of the Western Australian Museum* **21**, 307-313.

Pinder, A.M., Eberhard, S.M., and Humphreys, W.F. (2006) New phallodrilines (Annelida: Clitellata: Tubificidae) from Western Australian groundwater. *Zootaxa* **1304**, 31–48.

Platnick, N.I. (2008) A new subterranean ground spider genus from Western Australia (Araneae : Trochanteriidae). *Invertebrate Systematics* **22**, 295-299.

Ponder, W.F., and Colgan, D.J. (2002) What makes a narrow-range taxon? Insights from Australian freshwater snails. *Invertebrate Systematics* **16**, 571-582.

Pringle, H.J., Gilligan, S.A., and Van Vreeswyk, A.M.E. (1994) An inventory and condition survey of rangelands in the north-eastern Goldfields, Western Australia.

Red Creek Water Solutions Pty Ltd (2016) Groundwater Model for the Proposed Water Supply Borefield

Rockwater (2014) Hinge Iron Ore Deposit - Subterranean Fauna Desktop Assessment. Rockwater Pty Ltd, Jolimont, Western Australia, 16 pp.

RPS (2011) Level 1 Flora and Fauna Assessment Mt Morgans Mine – Morgans North Project Area. Unpublished report produced for Range River Gold February 2011.

Scarsbrook, M.R., and Fenwick, G.D. (2003) Preliminary assessment of crustacean distribution patterns in New Zealand groundwater aquifers. *New Zealand Journal of Marine and Freshwater Research* **37**, 405-413.

Sket, B. (2008) Can we agree on an ecological classification of subterranean animals? *Journal of Natural History* **42**, 1549-1563.

Taiti, S., and Humphreys, W.F. (2001) New aquatic Oniscidea (Crustacea: Isopoda) from groundwater calcretes of Western Australia. *Records of the Western Australian Museum* **64**, 133-151.

Watts, C.H.S., and Humphreys, W.F. (2006) Twenty-six new Dytiscidae (Coleoptera) of the genera Limbodessus Guignot and Nirripirti Watts & Humphreys, from underground waters in Australia. *Transactions of the Royal Society of Australia* **130**, 123-185.

Watts, C.H.S., and Humphreys, W.F. (2009) Fourteen new Dytiscidae (Coleoptera) of the genera Limbodessus Guignot, Paroster Sharp, and Exocelina Broun from Undergroundwaters in Australia. *Transactions of the Royal Society of South Australia* **133**, 62-107.

Whitely, P.G. (1945) New sharks and fishes from Western Australia. Part 2. *Australian Zoologist* **11**, 1-45.

Woodward-Clyde (1996) Wellfield Assessment 1995-1996 Mt Morgans Gold Mine. Unpublished report for Mt Morgans Gold Mine.

8. APPENDICES

Appendix 1 – Photographic assessment of diamond collars for subterranean habitat

To determine if there are suitable fissures or voids to support subterranean fauna at the Project, Bennelongia assessed photographs from three diamond collars (16JUDD0229; 16JUDD0251 and 16JURD0372) supplied by Dacian. In all, 30 photographs of approximately 204.05 m of core were assessed (example photographs are provided in Figure 10). Bennelongia has previously undertaken assessment of diamond collars in relation to the occurrence of troglofauna in the Pilbara and Yilgarn (Bennelongia 2008a; Bennelongia 2012a; Bennelongia 2012b). Experience from these previous assessments was incorporated into our interpretation of prospective troglofauna habitat.

Within the three collars reviewed, two showed some evidence of the types of vugs and voids observed when significant stygofauna and troglofauna communities are found (Figure 10). There was some apparent fracturing of the rocks at greater depths, but it is unlikely that these features represent subterranean fauna habitat. It is most likely the fissures and cracking are associated with the drilling process breaking the rock. One of the proposed pit areas at the Jupiter project has already been excavated in historical mining activities and thus while subterranean habitat may be present in the areas identified for pit extension, the impact to troglofauna communities is expected to be minimal.

16JUDD0229

16JURD372

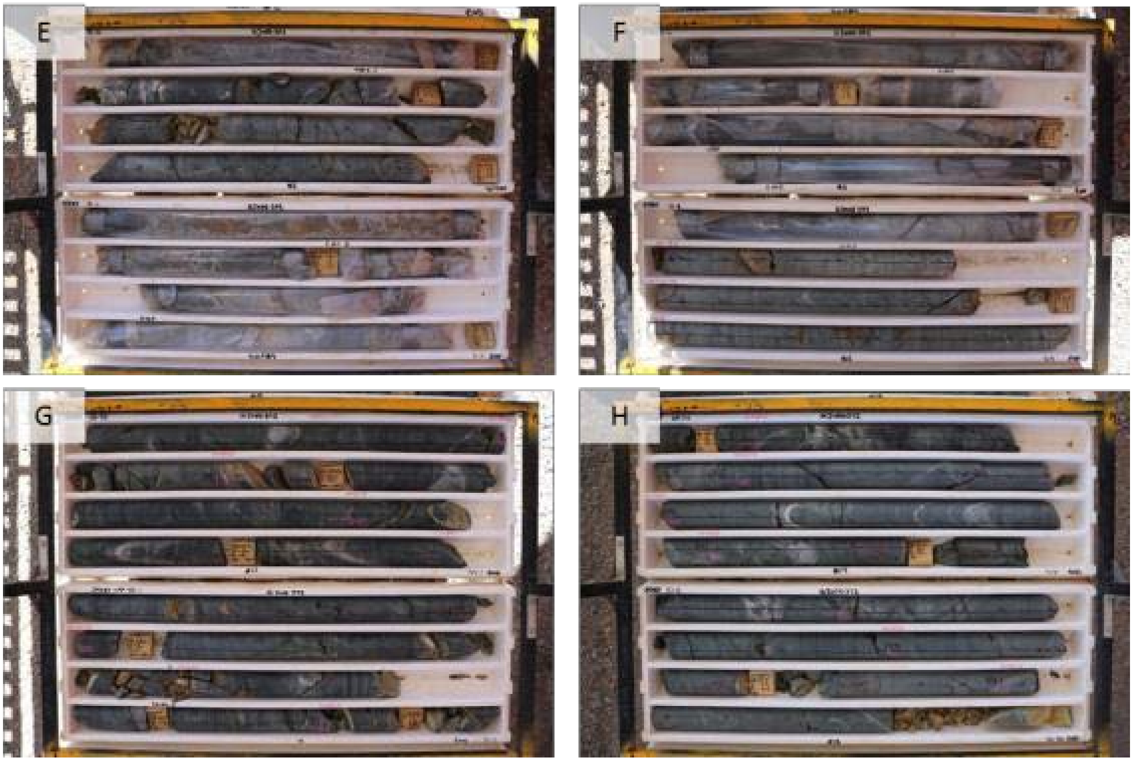


Figure 11. Examples of diamond collars.
(A) 16JUDD0229 at 0 m; (B) 16JUDD0229 at 10.4 m; (C) 16JUDD0229 at 35.6 m; (D) 16JUDD0229 at 55.5 m; (E) 16JURD372 at 3.4 m; (F) 16JURD372 at 9.4 m; (G) 16JURD372 at 28.7 m; (H) 16JURD372 at 43.35 m.

Appendix 2 - 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 watertable 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 (Gajowiec 1993; McAuley and Kozar 2006). 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. *Contamination of groundwater by hydrocarbons*. Any contamination is likely to be localised and may be minimised by engineering and management practices to ensure the containment of hydrocarbon products.

Appendix 3 – Location and properties of bores sampled by Bennelongia

Values for *in situ* water chemistry and, SWL and EOH are means of all sampling phases.

Bore Code	Site Classification	Sample Phase	Latitude	Longitude	SWL (m)	EOH (m)	EC (µs cm^{-1})	pH	Temp (°C)	No. of taxa	No. of individuals	Historically pumped
Aemotor Well	Reference	3	-28.7674	121.9521	6.69	16.00	4190	7.63	22.9	1	63	No
Bore 4	Reference	1, 3	-28.7621	122.2355	2.98	10.00	14910	7.50	27.0	2	31	No
Bore 5	Reference	1, 3	-28.7762	122.2161	2.72	10.00	31900	7.40	25.3	4	39	No
Bore 7	Reference	1, 2, 3	-28.7702	122.2291	3.80	10.67	29363	7.26	25.5	7	23	No
Bore 9	Reference	3	-28.7291	122.0799	12.84	15	3700	7.31	25.9	0	0	No
Cameron Well	Reference	1, 2, 3	-28.7672	122.1899	6.36	7.62	3383	8.16	22.9	10	103	No
CTB18	Reference	1, 2, 3	-28.7507	122.1943	3.89	9.00	25077	7.44	24.5	12	64	No
CTB22	Reference	1, 2, 3	-28.7584	122.1987	3.13	11.00	25630	7.13	25.2	13	107	No
DCN001	Reference	2, 3	-28.7631	122.2259	3.21	9.00	40560	7.10	24.9	12	31	No
Eight Foot Well	Reference	3	-28.6732	122.1393	2.73	5.00	914	7.16	22.1	0	0	No
Euro Well	Reference	3	-28.7621	122.2354	30.44	32.00	3090	7.58	24.2	1	100	No
Ghan Well	Reference	3	-28.6762	122.2486	10.78	16.50	1713	7.26	24.7	1	9	No
GST1	Reference	3	-28.7609	122.2473	3.24	70.00	255	6.63	26.7	1	1	No
JP49	Reference	1, 2, 3	-28.7648	122.1991	3.49	10.76	35867	7.53	25.9	14	69	No
JP50	Reference	2, 3	-28.7502	122.1932	3.24	11.64	25810	7.44	22.5	12	126	No
Kelly Well	Reference	3	-28.7231	122.2256	4.51	16.00	12590	7.65	21.6	6	80	No
McKenzie Bore	Reference	3	-28.7215	122.0055	10.61	17.50	1207	6.80	27.3	2	2	No
Red Flag Well	Reference	3	-28.7263	122.3044	14.16	20.00	1465	7.90	22.1	2	102	No
Shepherd Well	Reference	3	-28.7120	122.2054	3.47	4.00	12290	7.65	21.6	3	3	No
Siding Well	Reference	3	-28.7110	122.2738	20.92	23.00	928	6.76	25.8	2	101	No
Smith Well	Reference	3	-28.8269	122.0673	5.07	10	1620	7.77	24.2	0	0	No
Trig Well	Reference	3	-28.8010	122.3096	16.19	19	4700	7.5	29.0	0	0	No
Well Well	Reference	3	-28.8014	122.1267	4.82	11	4630	7.31	25.6	0	0	No
Bore 1	Impact	1, 2	-28.7187	122.1397	2.34	9.08	7380	367.17	25.7	6	70	No

Bore Code	Site Classification	Sample Phase	Latitude	Longitude	SWL (m)	EOH (m)	EC (μs cm^{-1})	pH	Temp (°C)	No. of taxa	No. of individuals	Historically pumped
Bore 2	Impact	1, 2*	-28.7188	122.1397	2.25	11.00	2150	5.12	25.5	1	1	No
Bore 3	Impact	1, 2	-28.7263	122.1475	2.17	8.00	5235	4.30	25.5	6	30	No
Bore 6	Impact	1, 2	-28.7255	122.1500	2.47	9.00	17490	7.19	26.4	13	57	No
Bore 10	Impact	3	-28.7086	122.1422	2.89	9	1045	3.43	26.8	0	0	No
CTB13	Impact	2, 3	-28.7494	122.1785	3.29	7.00	5300	7.84	25.2	1	1	No
JP19	Impact	1, 2	-28.7457	122.1757	2.49	9.79	6415	7.42	24.1	6	11	No
JP60	Impact	1, 2, 3	-28.7493	122.1893	3.75	9.24	22440	7.05	23.2	12	314	Yes
Pastoral bore	Impact	1, 2*	-28.7286	122.1400	2.54	5.00	6075	8.66	25.2	5	61	No
PB1	Impact	1, 2	-28.7331	122.1509	3.40	10.17	10010	7.26	25.4	5	31	Yes
PB2	Impact	1, 2	-28.7351	122.1449	3.53	13.00	6290	8.00	25.2	6	54	Yes
PB3	Impact	2	-28.7342	122.1478	2.63	9.00	6520	7.35	25.1	1	1	No
PB5	Impact	1, 2	-28.7305	122.1584	2.77	9.00	17785	7.12	25.1	13	235	Yes
PB6	Impact	1, 2	-28.7314	122.1557	2.78	10.00	13980	7.24	25.6	10	87	Yes
PB7	Impact	1, 2	-28.7303	122.1603	2.36	8.94	14535	7.43	24.9	10	140	Yes
PB8	Impact	1, 2	-28.7287	122.1631	2.73	8.79	21390	7.13	25.0	10	32	No

*Only water chemistry data collected.

Appendix 4 – Higher order taxa removed from list of species to avoid artificial inflation.

Taxonomy	Lowest Identification	No. of individuals	Bores	Impact	Reference	Regional reference (no. of individuals)	Comments on Taxonomy
Insecta							
Coleoptera	Limbodessus sp.	40	Bore 1, Bore 6, Bore 7, JP19, JP49, JP50, JP60, PB2, PB5, PB6, PB8	29	11	-	Larval specimens, likely to associate with one of three species recorded as adults from the Project area. All species recorded in reference bores.
Crustacea							
Isopoda	Haloniscus sp.	4	CTB18, JP49, Bore 3	1	3	-	Likely to belong to either *Haloniscus* sp. B08 or *Haloniscus* sp. B09.
Maxillopoda							
Cyclopoida	*Halicyclops* sp.	1	DCN001	0	1	-	Likely to belong to either *Halicyclops eberhardi* or *Halicyclops kieferi*.
Harpacticoida	Ameiridae sp.	14	CTB22	0	14	-	Likely to belong to either Ameiridae gen. nov. sp. B05 or Ameiridae gen. nov. sp. B06.
	Nitokra sp.	2	CTB22	0	2	-	Likely to belong to *Nitokra* sp. B05 or *Nitokra* sp. B06.
	Schizopera sp.	1	PB8	1	0	-	Likely to belong to one of three congeners recorded, all of which occurred in reference bores.

Appendix 5 – Historic groundwater production impacts (GRM 2016)

MEMORANDUM

From: Rob Garnham	Date: 16 March 2016	Project: J150010M02
To: James Howard	Company: Dacian Gold	
Re: Historic groundwater production impacts		

Background

Dacian Gold Ltd (Dacian) is undertaking a Feasibility Study (FS) for their Mt Morgan's Project near Laverton and has engaged Groundwater Resource Management Pty Ltd (GRM) to assist in the groundwater and surface water study components. This includes an investigation to identify a suitable project water supply, which is currently focussing on groundwater abstraction from a large calcrete unit located on Dacian's tenements north of the Jupiter prospect and east of the historical Mt Morgan's mining centre.

The calcrete aquifer has historically supplied make up water to the former Mt Morgan's process plant and a dump leach facility located at the Jupiter prospect. These supplies were drawn from two borefields: the Process Borefield comprising five production bores (PB1, 2, 5, 6 and 7) located along the Old Laverton Road and one bore (JP60) at the Jupiter borefield located about 3.5 km to the south east. The Process Borefield was operated for about 10 years from 1988 to 1998 and bore JP60 for about four years from 1995 to 1998.

Historic groundwater abstraction and water level data from March 1988 to May 1990 and July 1992 to June 1997 have been collected from annual aquifer reviews prepared for the Department of Water (DoW)[1]. These records have been used to assess the impacts from earlier groundwater production upon the groundwater environment.

Local Hydrogeology and Borefield Configuration

The calcrete aquifer at the project covers an area of about 60 km^2 and forms an elongate unit that broadly trends northwest from the northern margin of Lake Carey (Figure 1). The unit is thin, sub-cropping close to surface with a maximum depth of about 10 m. It comprises vuggy carbonate rock interbedded with alluvium and silcrete. Dissolution of the carbonate is common, which results in the development of secondary porosity and on occasion good aquifer yields. The results of earlier groundwater field programmes indicates higher permeabilities generally occur on the western side of the calcrete unit.

Groundwater flows in the calcrete are likely to be towards the east and south, ultimately discharging to the Carey trunk palaeochannel and Lake Carey respectively. The aquifer is subject to direct rainfall recharge resulting in rapid groundwater level rises after major storm events

[1] References are provided at the end of this memo.

A 19 FIELD STREET, BEACONSFIELD, WA 6162 P PO BOX 8110, FREMANTLE HIGH ST, FREMANTLE, WA 6160 T (+61 8) 9433 2222 F (+61 8) 9433 2322 ABN 97 107 493 292

Table 1: Schedule of Previously Operated Mine Production Bores

Production Bore ID	Location mE (MGA Zn 51)	Location mN (MGA Zn 51)	Collar RL (mAHD)	Casing Diameter (mm)	Cased Depth (mbgl)	Screened Interval (mbgl)	Salinity (mg/L TDS)	Aquifer Type
PB1	417,080	6,821,291	403.46	155	7.4	2-6.5	8,500	Calcrete & alluvium
PB2	416,495	6,821,064	403.74	155	8.0	2-8	2,600	Calcrete & alluvium
PB5	417,804	6,821,584	402.66	155	7.9	-	13,000	Calcrete & alluvium
PB6	417,548	6,821,476	402.78	155	9.0	-	9,400	Calcrete & alluvium
PB7	417,999	6,821,608	402.25	155	12.0	6-12	17,000	Calcrete & alluvium
JP60	420,844	6,819,522	403.00	155	8.3	2.3-8.3	14,000	Calcrete & fractured basalt

Note: salinities were taken from the 1996 to 1997 wellfield assessment (Woodward-Clyde 1997).

At least 14 mine production bores have been completed targeting the calcrete aquifer, although records indicate only six have been operated. A schedule for the six mine bores is provided in Table 1 and their locations shown on Figure 1. All the previously operated mine production bores predominantly draw water from the calcrete aquifer, although the drill-hole at JP60 also intersects fractured basalt below 8 m depth.

The salinity in the calcrete aquifer varies considerably, both laterally and temporally. At the mine production bores salinities range from 2,600 to 17,000 mg/L Total Dissolved Solids (TDS) based upon the record from 1996. However, a maximum value of 28,100 mg/L was recorded at groundwater exploration hole JP45 at the southern end of the unit (Mackie Martin 1990). Temporally variations of up to a factor of 2 have also been observed, most likely in response to rainfall recharge.

Groundwater Abstraction and Levels

The recorded pumping rates for the mine production bores and PB3, which was not pumped and used as an observation bore, are shown as time series plots in Figures 2 to 5. The figures also present the groundwater level data and the base of screened interval in each bore, which is generally considered analogous to the depth of the calcrete aquifer.

The plots show the following:

- PB1 – maximum drawdowns of about 4 m, resulting in a saturated thickness in the bore of approximately 1 m.
- PB2 – maximum drawdowns of about 3 m, resulting in a saturated thickness in the bore of approximately 2 m.
- PB3 – the drawdowns observed at the bore were negligible over the limited period of record.
- PB5 – maximum drawdowns of about 3 m, resulting in a saturated thickness in the bore of approximately 2 m.
- PB6 – maximum drawdowns of about 3 m, resulting in a saturated thickness in the bore of approximately 3 m.
- PB7 – maximum drawdowns of about 3 m, resulting in a saturated thickness in the bore of approximately 6 m.
- JP60 – maximum drawdowns of about 1 m, resulting in a saturated thickness in the bore of approximately 4 m.
- Groundwater levels in all the bores show a good response to rainfall recharge. In particular the rapid rise observed after Cyclone Bobby in February 1995, which delivered a three-day rainfall total of 225 mm locally, and resulted in a groundwater level rise of between about 2 and 4 m.

Discussion

Overall the results show the lower yielding bores, bore PB1 in particular, were severely impacted by pumping, with saturated thicknesses in the calcrete aquifer reduced by up to 80%, equivalent to a residual saturated thickness of about 1 m at PB1. These severe impacts were sustained over many months in response to continued pumping.

The negligible drawdowns observed in non-pumping bore PB3 located about 400 m from PB1 and 200 m from PB2 indicate even severe impacts from abstraction are localised and unlikely to affect the groundwater environment away from operating production bores. This interpretation is consistent with the lack of interference effects seen in higher yielding bores PB5, 6 and 7; which were pumped consistently over the later period of mining. This is despite their proximity to each other, i.e. 270 m from PB5 to PB6 and 200 m from PB5 to PB7.

Based on these outcomes it appears unlikely that even sustained groundwater production from the calcrete aquifer will have a long-term impact upon the groundwater environment.

References

Coffey 1990. "Mt Morgans Gold Mine groundwater review 1989/90", report number 1990/000079 dated July 1990. Unpublished report prepared by Coffey Partners International Pty Ltd for Dominion Mining Ltd.

Coffey 1993. "Mt Morgans Gold Mine borefield licensing annual performance report 1992/93", report number 1993/000078 dated September 1993. Unpublished report prepared by Coffey Partners International Pty Ltd for Dominion Mining Ltd.

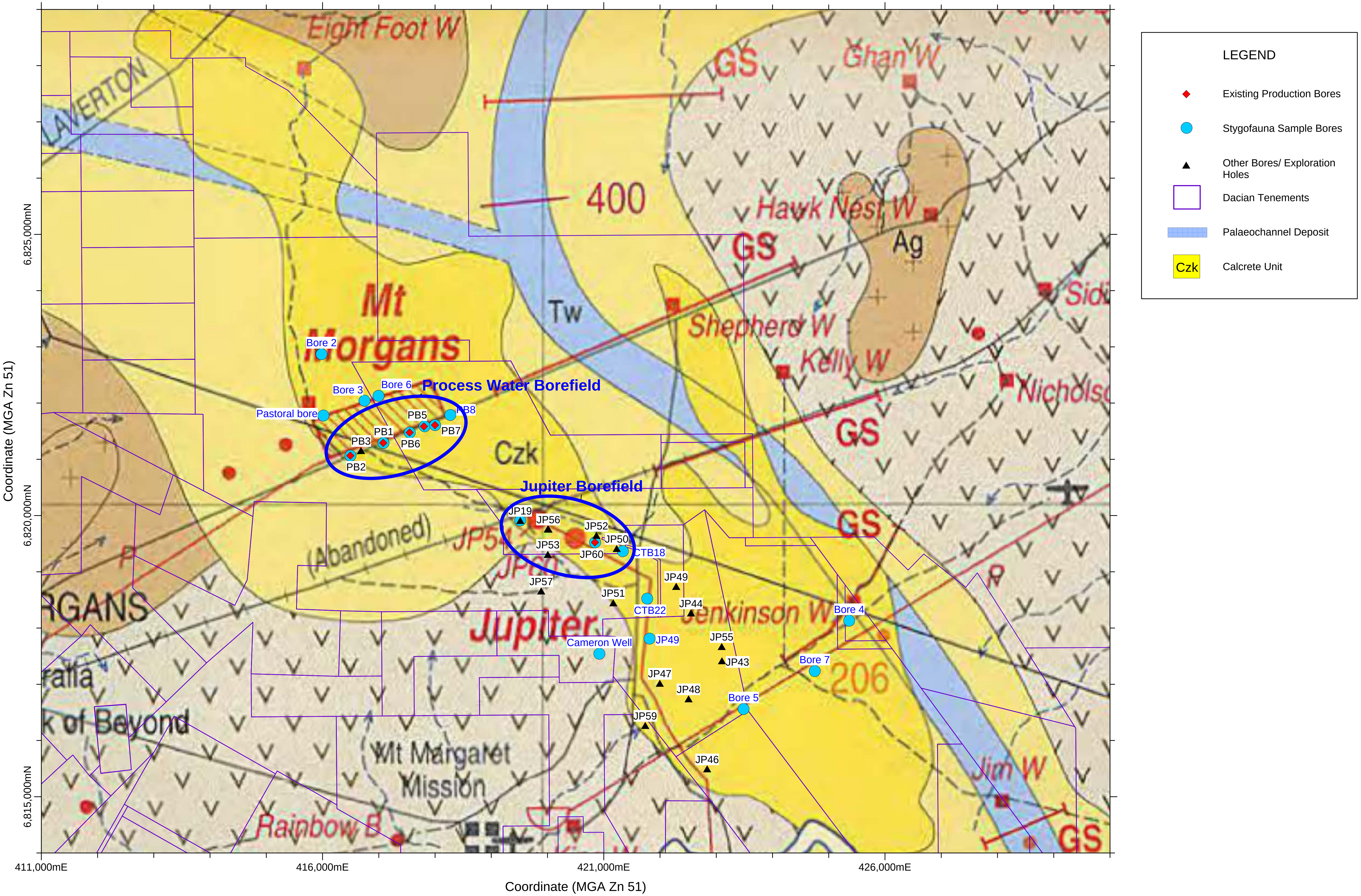
Coffey 1994. "Mt Morgans Gold Mine borefield licensing annual performance report 1993/94", report number 1994/000081 dated October 1994. Unpublished report prepared by Coffey Partners International Pty Ltd for Dominion Mining Ltd.

Mackie Martin 1990. "Groundwater investigations Jupiter Project", report number 1990/000218 dated March 1990. Unpublished report prepared by Mackie Martin and Associates Pty Ltd for Austmin Gold Mines Pty Ltd.

Woodward-Clyde 1995. "Mt Morgans Wellfield Assessment 1994-1995", report number 1995/000087 dated December 1995. Unpublished report prepared by AGC Woodward-Clyde Pty Ltd for Dominion Mining Ltd.

Woodward-Clyde 1996. "Mt Morgans Wellfield Assessment 1995-1996", report number 1996/000088 dated November 1996. Unpublished report prepared by AGC Woodward-Clyde Pty Ltd for Dominion Mining Ltd.

Woodward-Clyde 1997. "Mt Morgans Wellfield Assessment 1996-1997", report number 1997/000089 dated October 1997. Unpublished report prepared by AGC Woodward-Clyde Pty Ltd for Dominion Mining Ltd.



SCALE 1:65,000

0m 1,000m 2,000m 3,000m

Mt Morgan FS (J150010M02)			
Dacian Gold			
RG	Mar 16	FIGURE 1	

EXISTING PRODUCTION BORE AND STYGOFAUNA SAMPLING BORE LOCATIONS

GROUNDWATER RESOURCE MANAGEMENT

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RG

Mar 16

FIGURE 2

Dacian Gold

Mt Morgan FS (J150010M02)

RECORDED GROUNDWATER LEVELS AND PUMPING RATES BORE MPB1 AND MPB2

GROUNDWATER RESOURCE MANAGEMENT

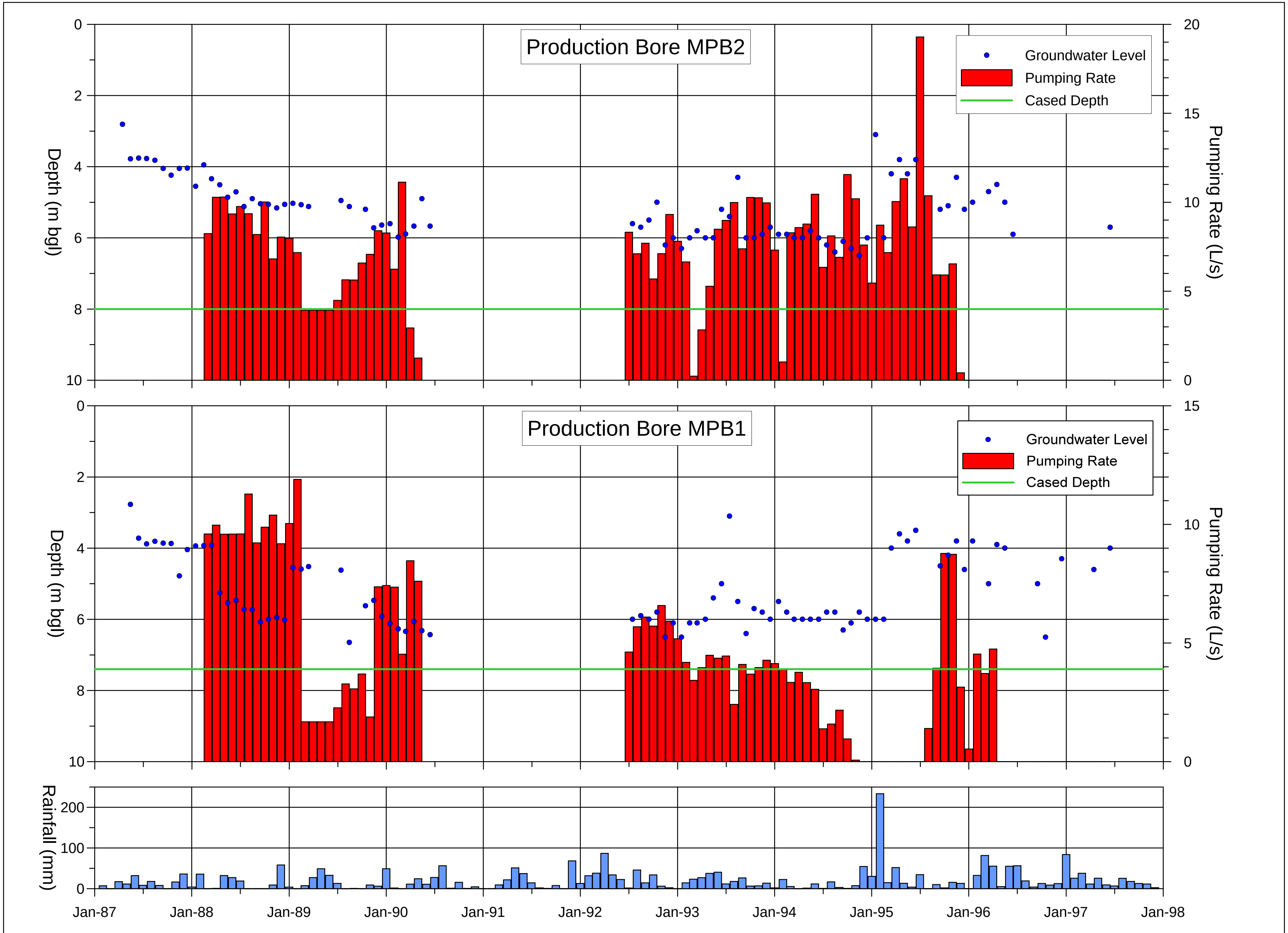

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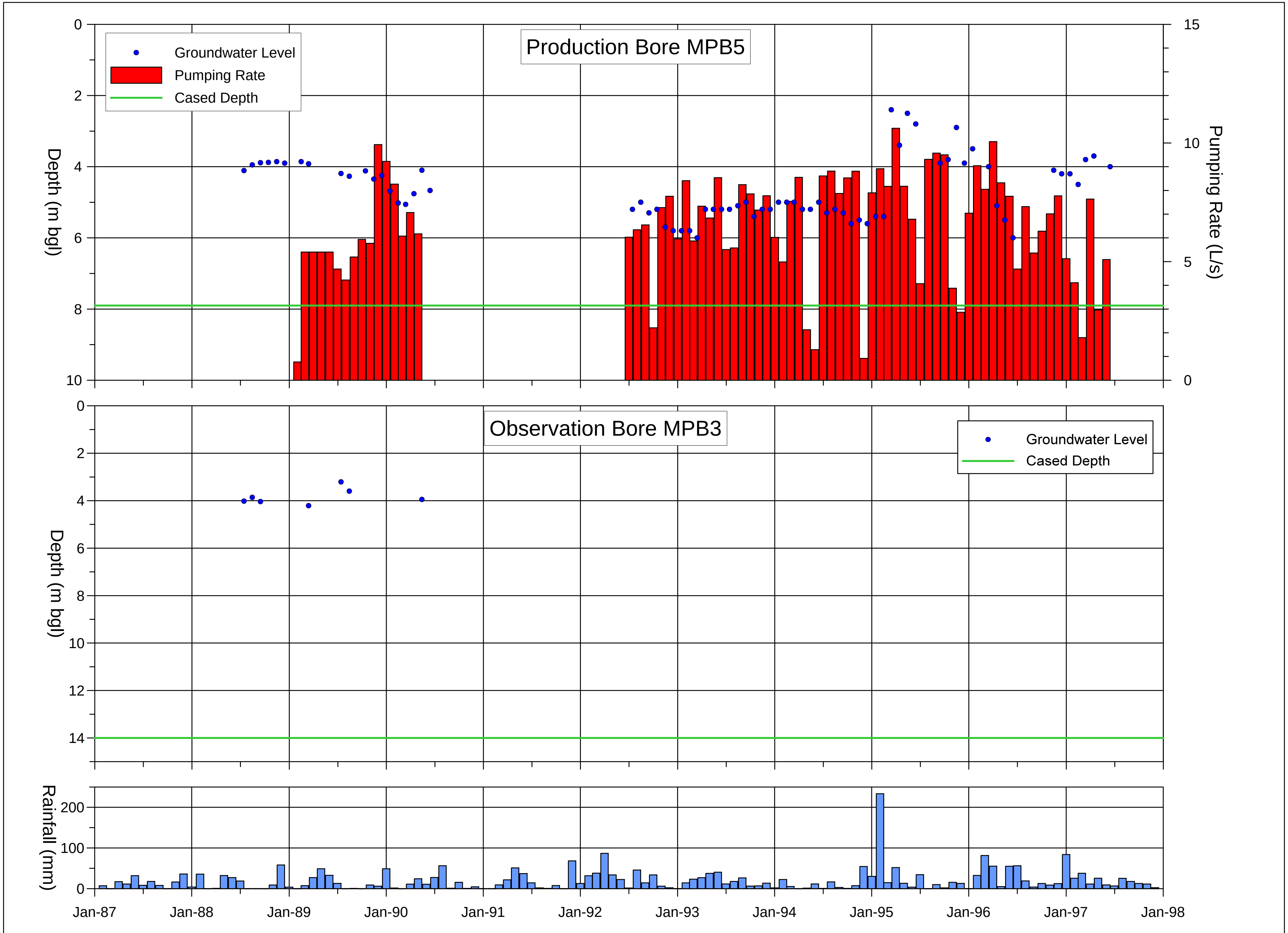
FIGURE 3

Dacian Gold

Mt Morgan FS (J150010M02)

RECORDED GROUNDWATER LEVELS AND PUMPING RATES BORE MPB3 AND MPB5

GROUNDWATER
RESOURCE MANAGEMENT



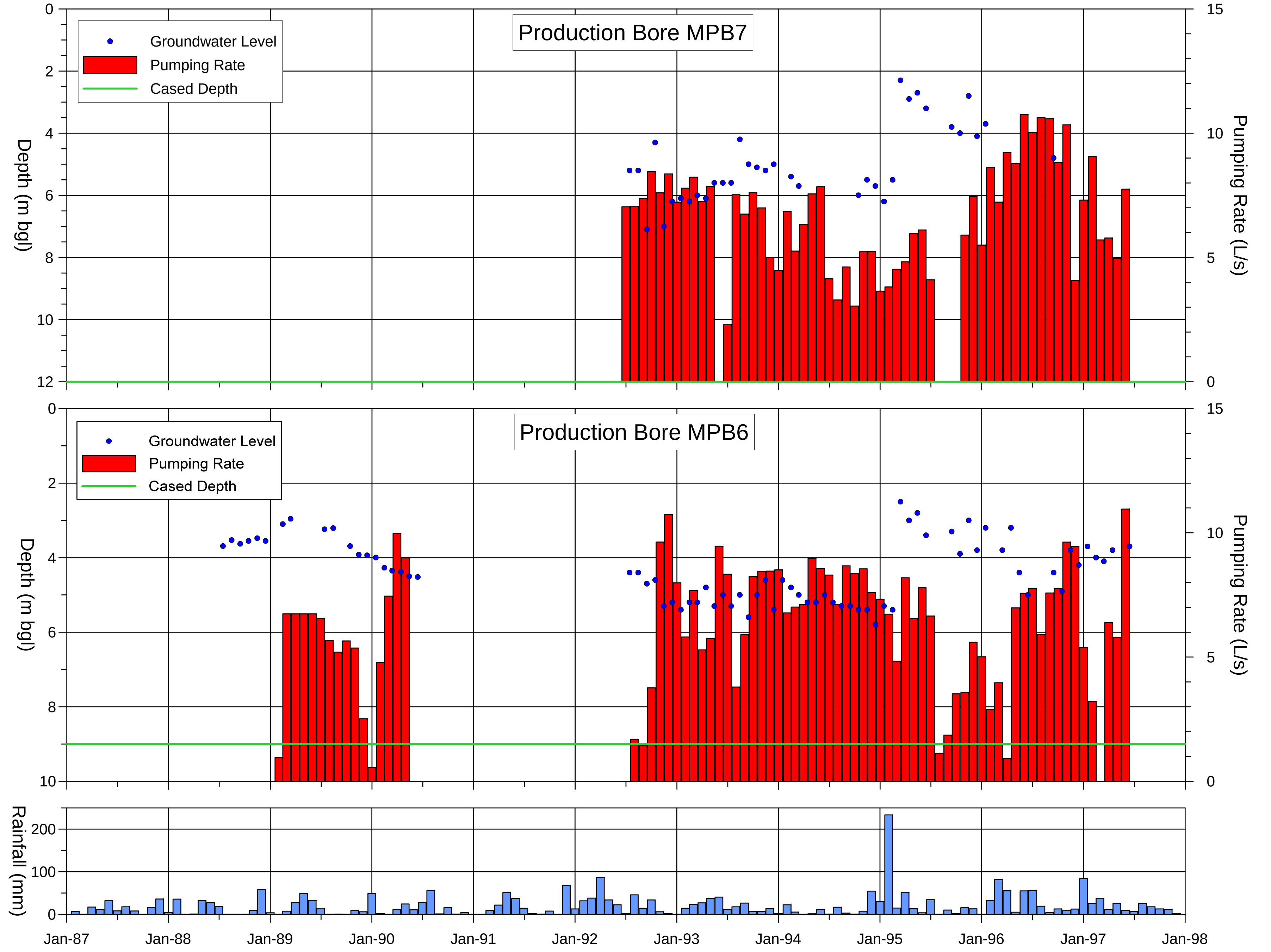


FIGURE 4

RG

Mar 16

Dacian Gold

Mt Morgan FS (J150010M02)

RECORDED GROUNDWATER LEVELS AND PUMPING RATES BORE MPB6 AND MPB7

GROUNDWATER RESOURCE MANAGEMENT

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Mt Morgan FS (J150010M02)

Dacian Gold

RG | Mar 16 | **FIGURE 5**

RECORDED GROUNDWATER LEVELS AND PUMPING RATES BORE JP60

GROUNDWATER RESOURCE MANAGEMENT