Greater Paraburdoo

Targeted Stygofauna Survey Memo

Biologic Environmental Survey Pty Ltd

Prepared for Rio Tinto Iron Ore

September 2019

Greater Paraburdoo
Targeted Stygofauna Survey Memo

DOCUMENT STATUS				
Version No.	Author	Review / Approved for Issue	Approved for Issue to	
			Name	Date
1	S. Callan	B. Durrant	J. McShane (RTIO)	30/08/2019
2	S. Callan	S. Callan	J. McShane (RTIO)	12/09/2019

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1. INTRODUCTION

Rio Tinto Iron Ore Pty Ltd (Rio Tinto) owns and operates the Greater Paraburdoo mining operations in the Pilbara region of Western Australia, approximately 6 kilometres (km) to the south of the town of Paraburdoo. Rio Tinto, on behalf of the joint venture participants, is evaluating the development of several iron ore deposits within the Greater Paraburdoo Iron Ore Hub. This includes the development of a new iron ore mine at Western Range (mainly above water table - AWT), and the extension of existing operations at Eastern Range and at Paraburdoo below water table (BWT) at 4 East Extension (4EE).

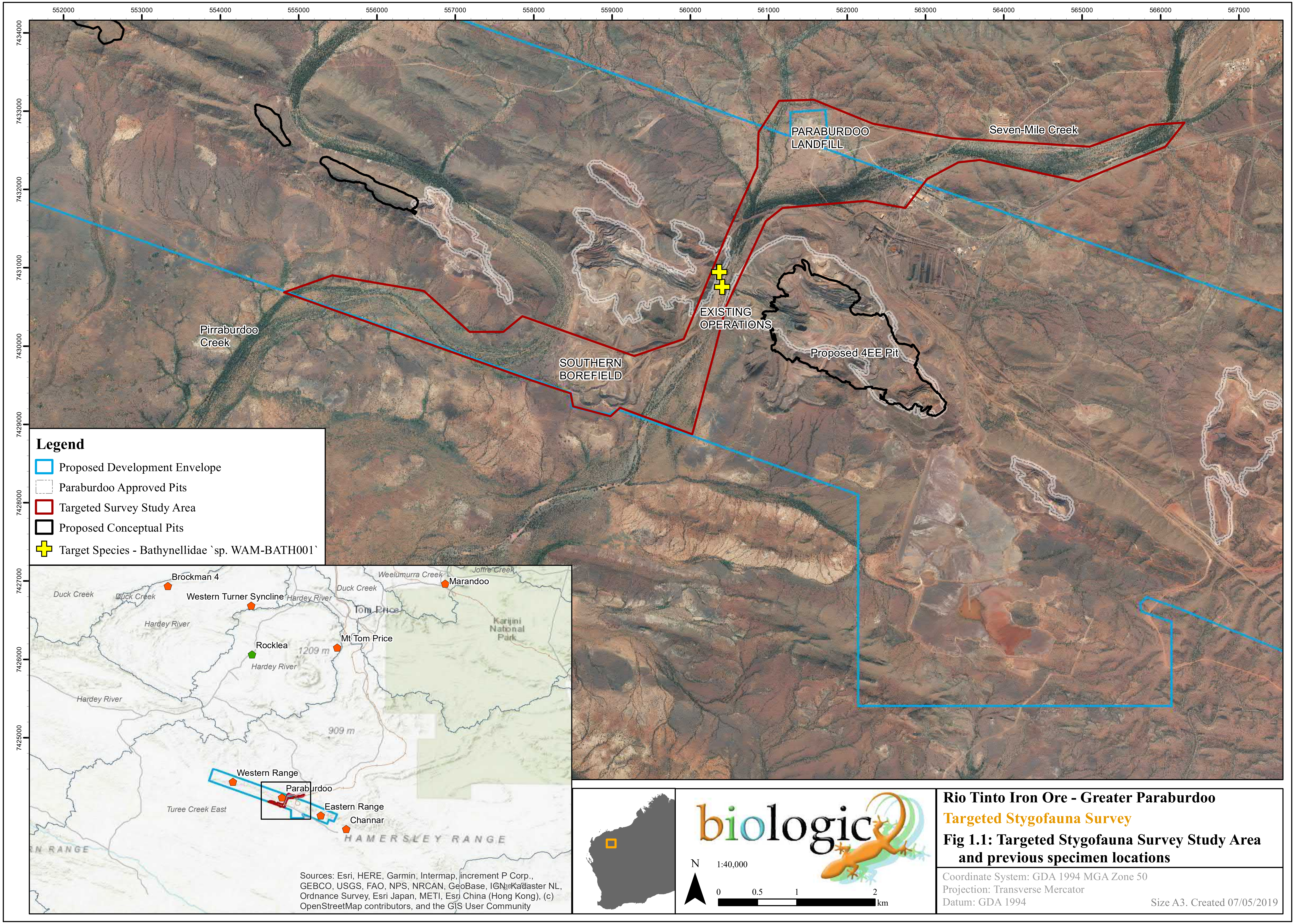
Biologic Environmental Survey Pty Ltd (Biologic) completed the baseline survey and risk assessment for subterranean fauna (troglofauna and stygofauna) throughout the Greater Paraburdoo Iron Ore Study Area (approximately 17,422 ha) (Biologic 2019). The baseline survey detected a species of Syncarida, *Bathynella* 'WAM-BATH001' from three sites within Seven-Mile Creek where the creek intercepts the Paraburdoo Range. Owing to the restricted ranges and limited dispersal capabilities of the taxonomic group, this species is regarded as a potential short-range endemic (SRE) stygobitic taxon. As the species was recorded only from a small, compartmentalised aquifer beneath Seven-Mile Creek, limited by impermeable Mt McRae Shales and dolerite intrusives, the proposed mining and dewatering associated with the Paraburdoo mining operations was considered to potentially form a risk to the known extent of the species' habitat.

In response to the perceived risks to this taxon, Rio Tinto commissioned Biologic to undertake a targeted stygofauna survey of bores and drill holes in a range of nearby hydrogeological habitats to investigate the wider occurrence of the species beyond potential impact areas (Figure 1.1). This report details the methods and results of the targeted survey for the syncarid *Bathynella* 'WAM-BATH001' and discusses implications for the perceived risks to this taxon from future mining activities at Paraburdoo.

1.1 Objectives

The objectives of the targeted survey were to:

- Investigate the wider occurrence of the target species (*Bathynella* 'WAM-BATH001') by undertaking a single phase of stygofauna sampling throughout hydrogeological habitats nearby, and potentially connected to, the host aquifer within Seven-Mile Creek;
- Identify all syncarid specimens to species-level, and confirm whether these may represent additional specimens of the target species using a combination of morphological and genetic analyses; and
- Update the assessment of risks to the target species based on updated sampling information, taxonomic/ genetic analyses, and impact information.



Rio Tinto Iron Ore - Greater Paraburdoo

Targeted Stygofauna Survey

Fig 1.1: Targeted Stygofauna Survey Study Area and previous specimen locations

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

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1.2 Legislation and guidance

Western Australia’s subterranean fauna is considered globally significant due to an unprecedented richness of species and high levels of short-range endemism (EPA 2016a). The EPA’s primary objective for subterranean fauna is to "*maintain representation, diversity, viability and ecological function at the species, population and assemblage level*" (EPA 2016a).

The targeted survey was undertaken in consideration of the following guidance:

- EPA (2016a) Technical Guidance Subterranean Fauna Survey; and
- EPA (2016b) Technical Guidance Sampling Methods for Subterranean Fauna.

2. METHODS

2.1 Site selection and survey effort

Figure 2.1 shows locations of sites sampled during the targeted survey. The number and location of bores for sampling were determined in consultation with RTIO hydrogeologists and based upon:

- the location of accessible, suitably constructed water bores (including piezo monitoring bores and larger diameter bores for pump sampling);
- ensuring good spatial spread throughout the hydrogeological units nearby the target aquifer which are most likely to provide habitat for the target species
- targeting hydrogeological habitats immediately upstream and downstream from the target aquifer within Seven-Mile Creek, and then also in other highly prospective habitats further downstream (such as the Southern Borefield); and
- local knowledge of groundwater conditions within monitoring bores, based on the experience of RTIO site personnel and previous sampling results.

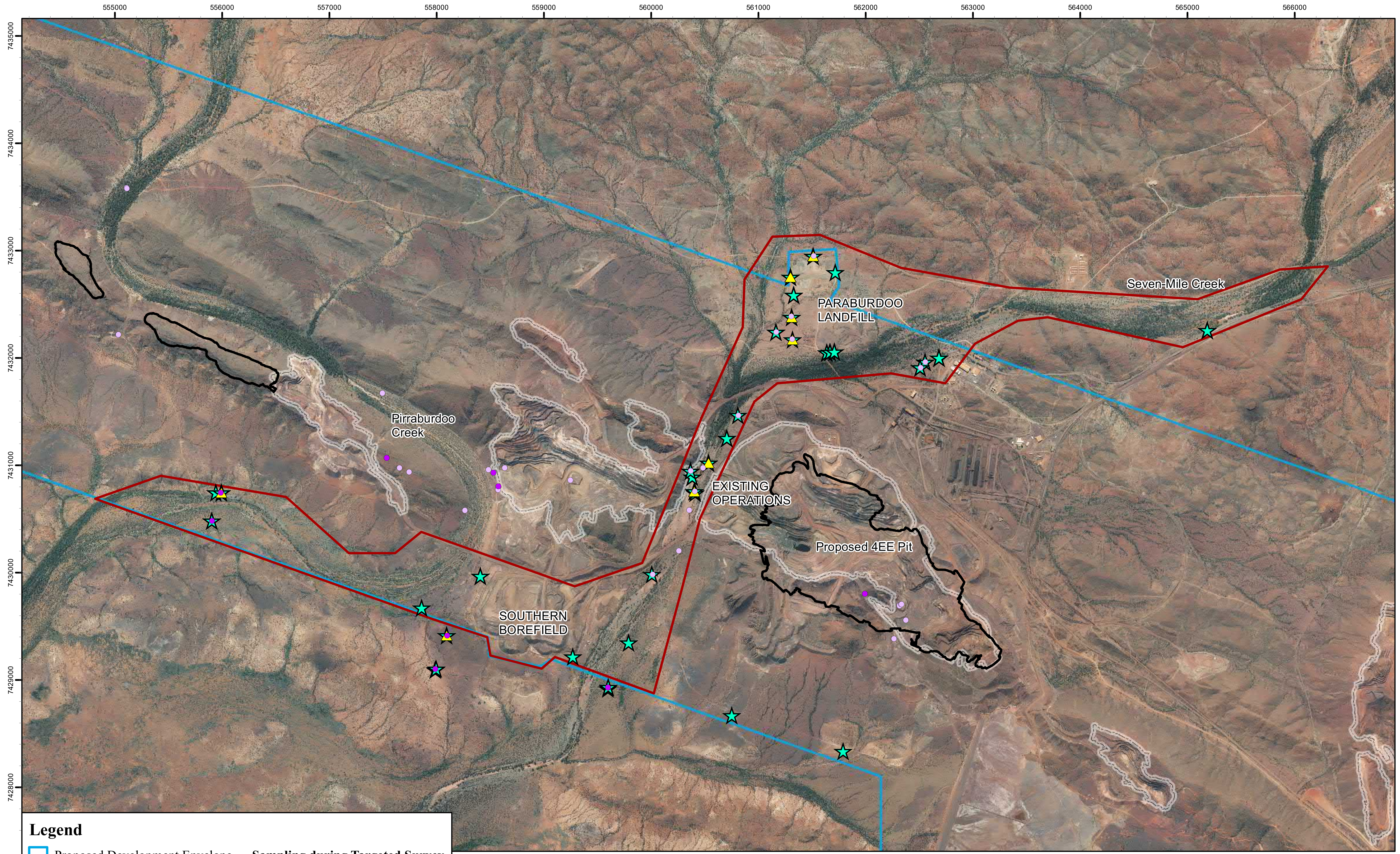
A total of 38 sites were chosen for sampling within four hydrogeological habitats:

- 10 sites at the existing operations (OPS) (*i.e.* target aquifer and bores immediately nearby),
- 7 sites at Seven-Mile Creek north (SMC_N),
- 2 sites at Seven-Mile Creek south (SMC_S),
- 10 sites at the Southern Borefield (SBF),
- 7 sites at the Landfill Bores (LFL) and
- 2 Tailings Storage Facility (TSF) sites near Seven-Mile Creek.

Table 2.1 and Figure 2.1 show 38 stygofauna samples were collected by net-hauling, and nine by pumping, while 47 water quality samples were taken from the 38 sites (multiple water quality samples during pumping).

Table 2.1: Bore construction, location, and sampling details

Bore name	Bore type	UTM zone 50 East, North	Depth (mbgl)		Sampling		
			EOH	DTW	Haul	Pump	WQ
LFL							
MB 3	50 mm Piezo, PVC	561290, 7432663	10.5	7	1		1
MB15PAFL001	100 mm Cased, PVC	561700, 7432883	25	13	1		1
MB15PAFL002	100 mm Cased, PVC	561496, 7432995	25	12	1	1	2
MB15PAFL003	100 mm Cased, PVC	561290, 7432774	22	7	1	1	2
MB16PAFL0001	100 mm Cased, PVC	561289, 7432442	26	6	1	1	2
MB16PAFL0002	100 mm Cased, PVC	561084, 7432332	23	7	1		1
MB16PAFL0003	100 mm Cased, PVC	561288, 7432221	21	5	1	1	2
SMC_N							
MB 10	50 mm Piezo, PVC	562412, 7431994	7	5	1		1
MB 13	50 mm Piezo, PVC	562515, 7431994	7	5	1		1
MB 15	50 mm Piezo, PVC	562617, 7432104	9	6	1		1
MB 7	50 mm Piezo, PVC	561594, 7432109	6	4	1		1
MB 8	50 mm Piezo, PVC	561594, 7432109	8	4	1		1
MB 9	50 mm Piezo, PVC	561697, 7432108	6	4	1		1
PZ06SMC0001	50 mm Piezo, PVC	565176, 7432315	13	5	1		1
OPS							
MB15NLC001	120 mm Cased, Steel	560362, 7431007	48	9	1		1
MB15NLC002	50 mm Piezo, PVC	560361, 7430896	42	25	1		1
MB15NLC005	120 mm Cased, Steel	560362, 7431007	32	9	1		1
MB17NLC0001	50 mm Piezo, PVC	559742, 7429459	90	29	1		1
MB17NLC0002	50 mm Piezo, PVC	560361, 7430785	36	23	1		1
MB17NLC0004	50 mm Piezo, PVC	560670, 7431337	78	4	1		1
MB17NLC0005	50 mm Piezo, PVC	560773, 7431558	59	4	1		1
MB17NLC0006	50 mm Piezo, PVC	560670, 7431337	61	4	1		1
WB17NLC0001	200 mm Prod., Steel	560361, 7430785	41	25	1	1	2
WB18NLC0001	200 mm Prod., Steel	560465, 7431117	76	28	1	1	2
SMC_S							
MB094W01	50 mm Piezo, PVC	559229, 7429240	36	25	1		1
PMO7	50 mm Piezo, PVC	559949, 7430012	57	51	1		1
SBF							
MB154W003	50 mm Piezo, PVC	558312, 7430018	67	26	1		1
MB17SB0001	80 mm Cased, PVC	557799, 7429688	88	16	1		1
PMO2A	80 mm Cased, Steel	559535, 7429017	34	17	1		1
PMO3	200 mm Prod., Steel	558003, 7429466	86	16	1	1	2
PMO3A	200 mm Prod., Steel	557899, 7429134	55	15	1		1
PMO4	50 mm Cased, Steel	555859, 7430803	93	10	1		1
PMO4A	200 mm Prod., Steel	555858, 7430581	86	9	1		1
PMP2	200 mm Prod., Fibreglass	559535, 7429017	54	16	1	1	2
PMP3	200 mm Prod., Fibreglass	557899, 7429134	81	17	1		1
PMP4	200 mm Prod., Fibreglass	555962, 7430802	93	12	1	1	2
TSF							
MB18TSF0003	50 mm Piezo, PVC	561783, 7428344	60	26	1		1
MB18TSF0004	50 mm Piezo, PVC	560659, 7428680	63	25	1		1
Grand Total					**38**	**9**	**47**



Legend

- Proposed Development Envelope
- Paraburdoo Approved Pits
- Targeted Survey Study Area
- Proposed Conceptual Pits

Previous net hauling (baseline survey)

- 1 sample
- 2 samples

Sampling during Targeted Survey

- Pumping
- Net Haul

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Targeted Stygofauna Survey

Fig 2.1: Sampling during the Targeted Survey and previous sampling locations

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

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2.2 Sampling methods

The sampling methods used were consistent with EAG #12 (EPA 2016a), Guidance Statement #54A (EPA 2016b) and the Stygofauna Sampling Protocol developed for the Pilbara Biodiversity Study Subterranean Fauna Survey (Eberhard *et al.* 2005, 2009). The field work was undertaken by Shae Callan and Morgan Lythe, while laboratory sorting was undertaken by Shae Callan, Juliana Pille-Arnold, Syngeon Rodman and Stephanie Floeckner.

2.2.1 Water physicochemistry

Prior to stygofauna sampling, a groundwater sample was collected using a 1 m plastic cylindrical bailer, for the purposes of physicochemical measurements. The bailer was lowered down the hole until reaching groundwater and a water sample was collected at a depth of 2 m below the surface. As such the results were not indicative of water parameters throughout the entire bore (or aquifer) but rather provide a general indication of conditions near the top of the water table. Conditions sampled during pumping were measured using a sample collected from the pump outflow, which would have artificially increased the dissolved oxygen readings. Groundwater physicochemical data (including EC, pH, TDS, Redox, and Dissolved O_2) was measured using a multi-parameter water meter. Constrictions in piezometer bores as well as blockages and root material inhibited the collection of groundwater physicochemical readings at some sites.

2.2.2 Stygofauna net hauling

Stygofauna were sampled by net hauling, using a plankton net of a diameter to suit each bore or drill hole (in most cases 30-80 mm nets). Each haul sample comprised a total of six hauls from the bottom of the hole to the top, with three hauls using a 150 µm mesh and three hauls using a 50 µm mesh. The base of the net was fitted with a lead weight and a sample receptacle with a base mesh of 50 µm. To stir up sediments, the net was raised and lowered at the bottom of the hole prior to retrieval and hauled at an even pace through the water column to maximise filtration of the water.

The sample from each haul was emptied into a bucket, which was elutriated after the final haul to remove coarse sediments and filtered back through the 50 µm net/ sample receptacle to remove as much water as possible. The sample was transferred to a 120 mL preservation vial and preserved in chilled 100% ethanol. The ethanol and the samples were kept chilled on ice to facilitate cool-temperature DNA fixation.

2.2.3 Pump sampling

Stygofauna were sampled by pumping at select sites where bore diameter was sufficient to allow a submersible pump to extract groundwater. Although this method can damage some stygofauna specimens, it has the advantage of overcoming poor groundwater conditions within the bore by drawing in water from the surrounding aquifer.

The pump used was a Grundfos SQ2-55 submersible pump, with an (unimpeded) flow rate of approximately 1L/sec, and a screen guard entry aperture of approximately 3 mm. Each hole that was pumped was first net-hauled for stygofauna as described above (within 1-3 days prior to pumping). The pump was manually lowered to the bottom of the hole or to 45 m below surface, which was the maximum length of hose able to be safely handled manually (when full of water/ sediment). The pump was secured via a wire cable and operated using a small generator. The outflow of the pump was filtered through a 150 μm mesh plankton net as described above for net hauling.

Most bores were pumped for 30 min in total (*i.e.* bores that showed no change in inflow/ pumping rate), with 15 min pumping at the end of hole (EOH) depth, and 15 min pumping at 10 m above EOH, in order to ensure multiple habitat strata were sampled, if present. If EOH depth exceeded 45 m, the pumping depths were 45 m below casing and 35 m below casing, where sufficient groundwater occurred. For certain bores that showed a decrease in water inflow/ pumping rate during the initial 15 min, pumping was ceased for 15 min to allow recharge, before commencing again at the same depth to a total duration of 15 min pumping.

2.2.4 Sorting and taxonomy

Sorting and parataxonomy were undertaken in-house using dissecting microscopes. The personnel involved (S. Callan, J. Pille-Arnold, S. Rodman, S. Floeckner) were suitably trained and experienced in both sorting and parataxonomy of subterranean fauna.

Parataxonomy of the specimens utilised published literature and taxonomic keys where available. Each morphospecies from each sample was assigned a separate labelled vial and labelled with a specimen tracking code. Taxonomic groups were examined in as much detail as possible using in-house expertise, before sending target specimens (Syncarida) to Giulia Perina, a pre-eminent specialist taxonomist for the group (refer Appendix 1). Species comparisons and alignments were performed using regional specimens collected beyond the Study Area throughout the wider sub-regional area.

2.2.5 DNA analysis

Molecular genetic analysis (DNA barcoding using genes COI and 16s) was conducted on certain stygofauna taxa to validate morphological identifications and to provide a basis for species-level identifications or regional comparisons where taxonomic resolution was limited. Refer to Appendix 2 for further details regarding the methods of DNA extraction, primers, sequencing, and analysis.

2.3 Survey timing and weather conditions

The current survey was conducted from 13-19 May 2019, following an atypically dry wet season. Figure 2.2 shows a comparison of long-term climatic data for Paraburdoo Aero (Bureau of Meteorology Station 7185), approximately 10 km north east of the Study Area, with temperatures and rainfall data observed prior and during the targeted survey.

During 2018-19, the summer months (Nov-April) were considerably hotter and drier than long term average conditions, with mean maximum temperatures ranging from 35.1°C to 43.7°C during these months (on average 2.28°C hotter than the long-term average), and total observed rainfall reaching only 113 mm, or 44% of the long-term average (258 mm). The summer of 2018-19 had only four significant rainfall days: Nov 16, 2018 (10.4 mm), April 15, 2019 (11 mm), Jan 6, 2019 (25.8 mm) and Jan 28, 2019 (28 mm). Observed rainfall did not exceed 10 mm on any other day during the wet season.

These conditions were considered highly likely to influence the results of the targeted survey, with infiltration to groundwater likely to be minimal and groundwater levels likely to be at very low levels, potentially influencing stygofauna occurrence and activity levels.

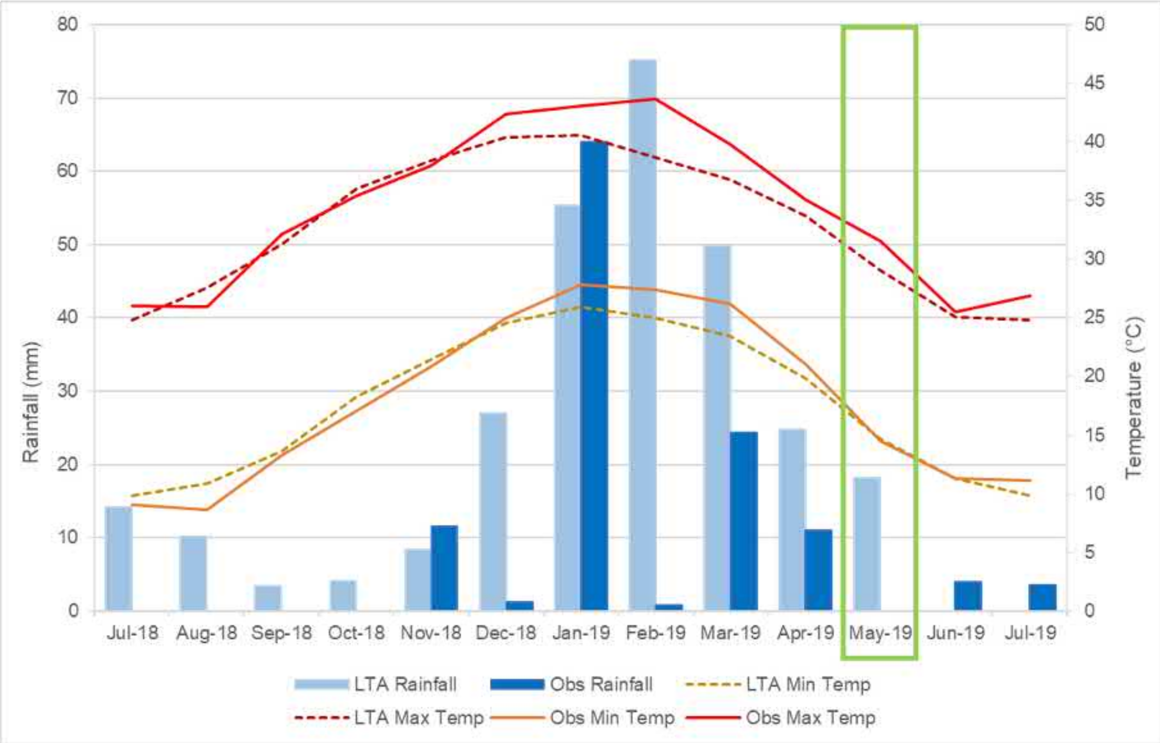


Figure 2.2. Long-term averages (LTA) and observed climatic data for the Study Area (total monthly rainfall, and mean minimum and maximum temperatures).

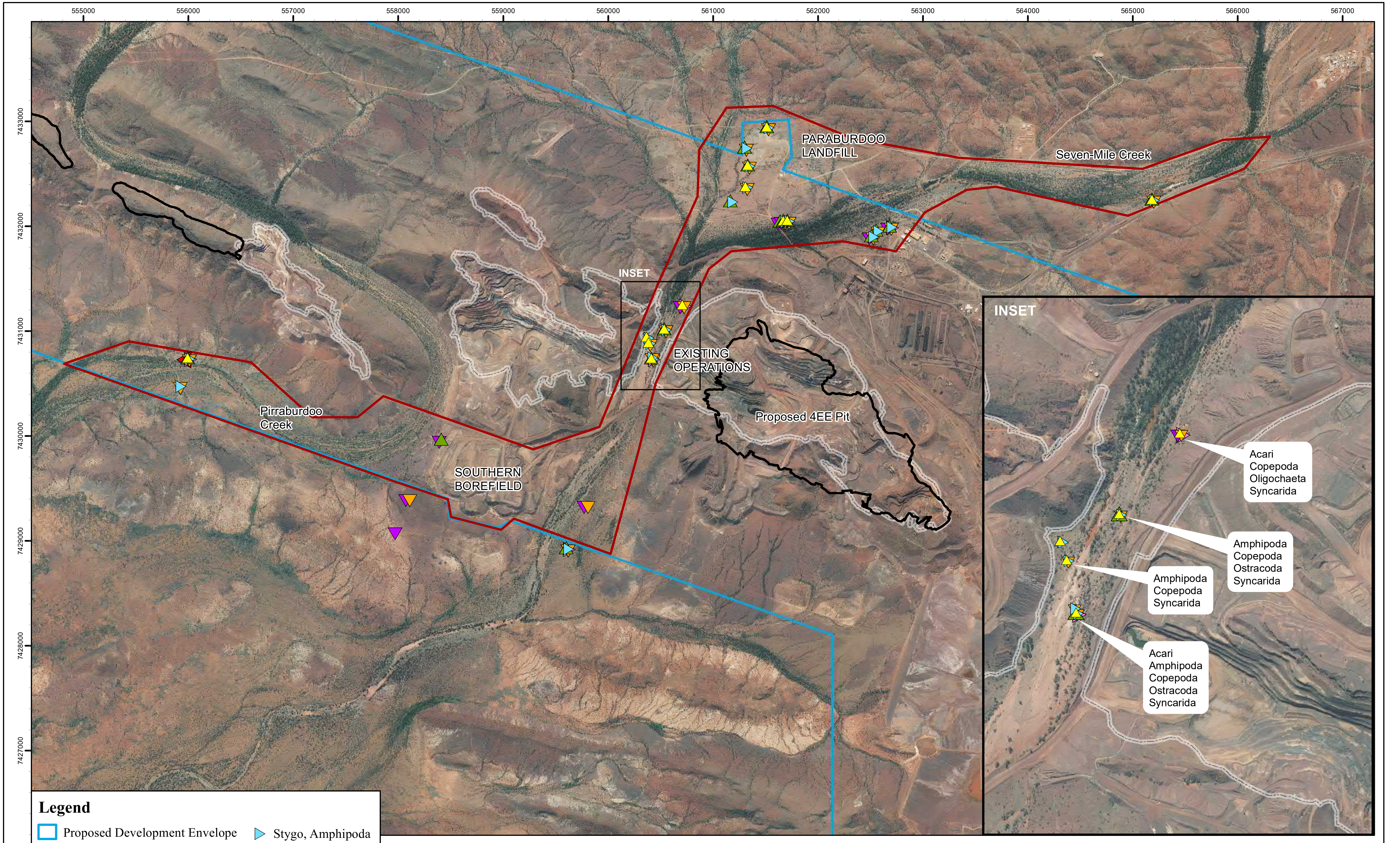
3. RESULTS

3.1 Stygofauna results

A total of 2522 stygofauna specimens were collected during the targeted survey, plus 123 troglofauna specimens collected as bycatch (Table 3.1, Figures 3.1, 3.2). The stygofauna comprised bathynellid and parabathynellid syncarids, amphipods, cyclopoid and harpacticoid copepods, aquatic isopods (*Pygolabis*), ostracods, water mites (Acari), and oligochaete worms (Table 3.1, Figures 3.1).

Table 3.1: Subterranean fauna detected during the survey. Red font indicates target taxonomic group.

Higher taxon	Morphospecies	TSF	SBF	SMC_S	OPS	SMC_N	LFL	Total specimens
Stygofauna								
Syncarida								
	Bathynellidae `sp. WAM-BATH0001`				9			**9**
	Bathynellidae `sp. GP2`				1			**1**
	Parabathynellidae sp. indet (juv.)				1			**1**
	Atopobathynella `sp. GP3`					7		**7**
	Billibathynella `sp. GP4`		1				1	**2**
	Hexabathynella `sp. GP5`				9		5	**14**
Amphipoda								
	Amphipoda sp. indet.		168		102	77	43	**390**
Isopoda								
	Pygolabis sp. indet.		3					**3**
Copepoda								
	Cyclopoida sp. indet.		353		583	222	90	**1248**
	Harpacticoida sp. indet.		10		8	26	4	**48**
	Parastenocaris sp. indet.		11		1	1		**13**
Ostracoda								
	Candonidae sp. indet.					61	55	**116**
	Gomphodella sp. indet.					87	49	**136**
	Ostracoda sp. indet.		61		6	166	174	**407**
Oligochaeta								
	Oligochaeta sp. indet.		61		26	18	5	**110**
	Phreodrillidae sp. indet.				7			**7**
Acari								
	Acari sp. indet.				3			**3**
	Hydracarina sp. indet.					2		**2**
	Pezidae sp. indet.		4		1			**5**
Total stygofauna taxa		**0**	**6**	**0**	**8**	**8**	**6**	**11**
Troglofauna (bycatch)								
	Diplopoda sp. indet.					1		**1**
	Diplura sp. indet.					3	1	**4**
	Isopoda sp. indet.					110		**110**
	Meenoplidae sp. indet.			1				**1**
	Palpigradi sp. indet.						3	**3**
	Polyxenida sp. indet.					3		**3**
	Symphyla sp. indet.					1		**1**
Total troglofauna taxa		**0**	**0**	**1**	**0**	**5**	**2**	**7**



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Targeted Stygofauna Survey

Fig 3.1: Targeted survey fauna results by higher taxonomic group (stygofauna)

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A3. Created 07/05/2019

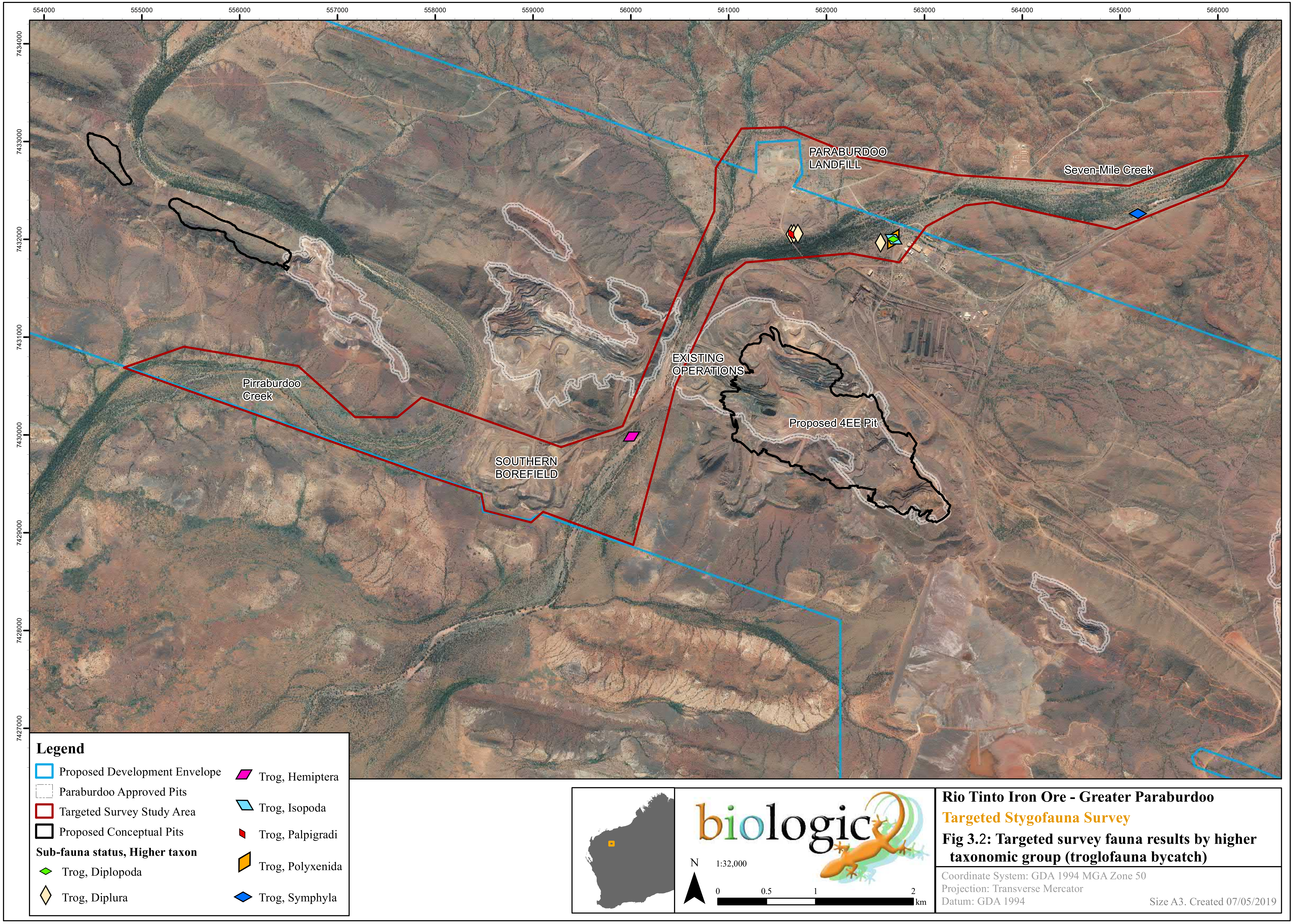

Fig 3.2: Targeted survey fauna results by higher taxonomic group (troglofauna bycatch)

3.2 Syncarida

All bathynellid specimens were slide mounted to enable detailed morphological comparisons at the species level, as well as regional comparisons with other permanent slides made during Giulia Perina's recent research into the taxonomy and phylogeny of Bathynellidae in the Pilbara region (Appendix 1). Prior to the creation of permanent slides, a dissected portion of each bathynellid specimen was taken for DNA analysis to confirm morphological identifications (Appendix 2). Parabathynellid specimens were also examined, primarily to confirm that no bathynellid specimens had been mistakenly sorted with the parabathynellids, and also to undertake preliminary identifications to genus level. The locations of all Syncarida records from the Study Area, including the target taxon, are shown in Figure 3.3.

The morphological identifications revealed five putative species; two from the Bathynellidae, and three from the Parabathynellidae:

1. Bathynellidae WAM-BATH0001;
2. Bathynellidae GP2;
3. *Atopobathynella* sp. GP3 (Parabathynellidae);
4. *Billibathynella* sp. GP4 (Parabathynellidae); and
5. *Hexabathynella* sp. GP5 (Parabathynellidae).

3.2.1 Bathynellidae

The Bathynellidae specimens from the baseline survey (Biologic 2019) had all been morphologically identified as a single species, *Bathynella* (*Pilbaranella*) sp. 'B39' (Jane McRae), and a DNA match was confirmed between baseline specimens from bores MB15NLC001 and MB15NLC005 (B. sp. 'WAM-BATH001'), thus confirming a single species in Seven Mile Creek (Biologic 2019, Appendix 2).

During the current survey, additional bathynellid specimens were collected at MB15NLC001, although the ability to align these morphologically to *Bathynella* (*Pilbaranella*) sp. 'B39' was limited due to the original specimens having been vouchered at the WAM and unable to be used for slide mounting.

In place of morphological comparisons, DNA barcoding of the mitochondrial gene COI was undertaken to confirm that the original and current specimens from MB15NLC001 belonged to the same species. The analysis (Appendix 2) revealed a very low level of genetic divergence (<0.01% COI) between specimens collected at bores MB15NLC001 (both baseline and current specimens), MB15NLC005 (baseline specimens), and MB15NLC006 (current specimens). Therefore, it is reasonable to synonymise all former identifications into a single putative species: *Bathynella* sp. B39 = Bathynellidae `WAM-BATH001`. In total, this species is now known from 74 individuals from the baseline survey at bores MB15NLC001, MB15NLC005, and WB17NLC0001 (specimens vouchered in the WAM), and a further 9 specimens from the current survey at bores MB15NLC001 and MB15NLC006 (Figure 3.3).

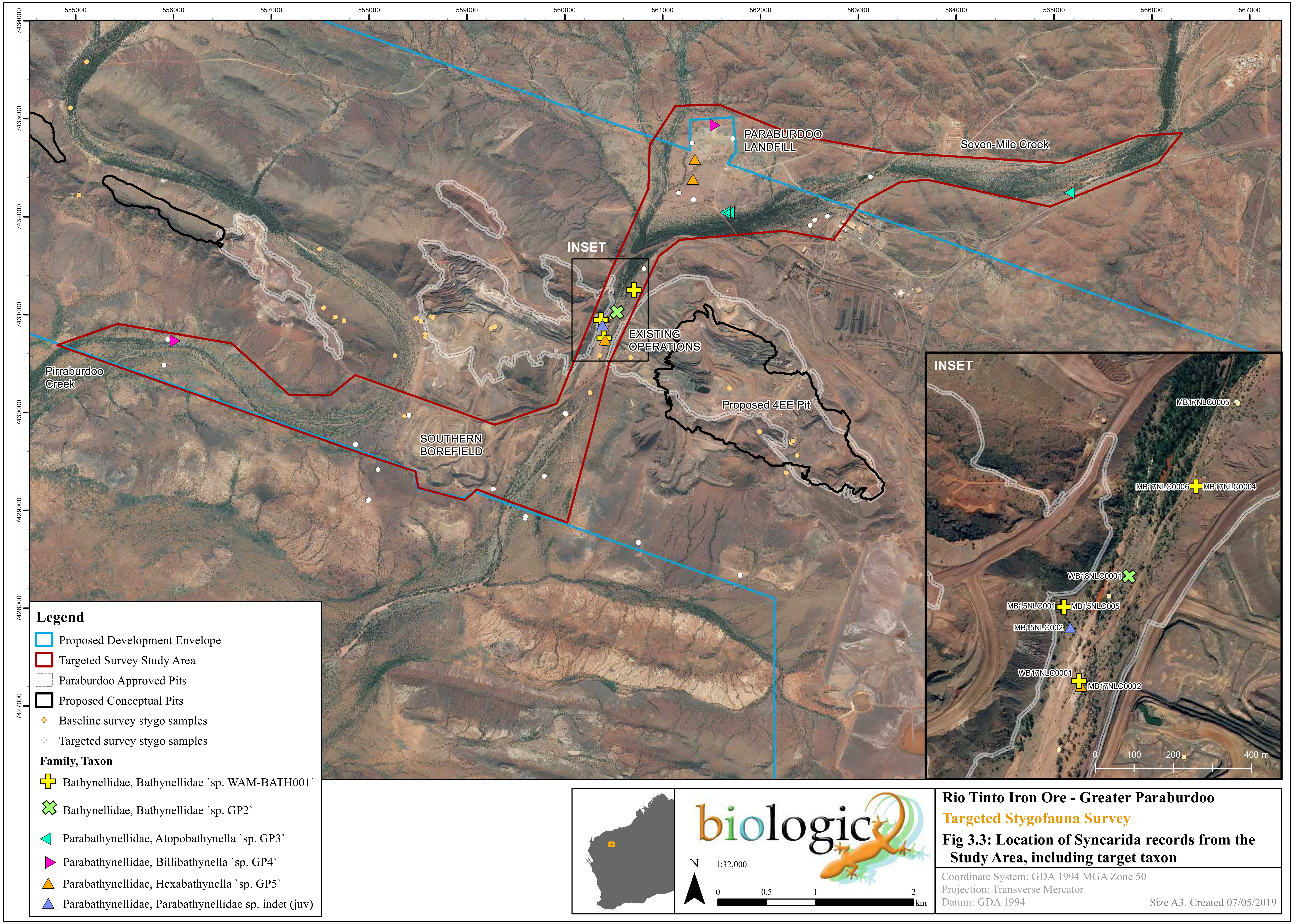

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Fig 3.3: Location of Syncarida records from the Study Area, including target taxon

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A3. Created 07/05/2019

In addition, a single bathynellid specimen collected from bore WB18NLC0001 (also within the existing operations) was morphologically identified as a putative second species (Bathynellidae sp. GP2). Based on the latest research and taxonomic expertise, the morphological characters defining this specimen were regarded as indicative of a potentially different genus (G. Perina pers. comm. 2019). Unfortunately, the only known specimen failed to sequence, therefore we are unable to confirm its genetic relationship to Bathynellidae sp. `WAM-BATH001` (Appendix 2). Nevertheless, under a precautionary approach, it can be considered that Bathynellidae sp. GP2 may represent a second species, and a potentially different genus to Bathynellidae `WAM-BATH001`.

Regional comparisons undertaken by morphology and DNA failed to detect any further representatives of these taxa throughout known/ available reference collections (*i.e.* WAM reference specimens identified by Giulia Perina, the GenBank DNA database, and the Rio Tinto DNA database). Notwithstanding the potential occurrence of other bathynellid specimens in private collections, based on current information it is considered highly likely that both species represent new and undescribed taxa that are known only from bores within the existing operations area of Seven-Mile Creek (G. Perina pers. comm. 2019).

Owing to the poorly developed state of taxonomy of this group, and the extreme short-range endemism shown by described species of Bathynellidae thus far (Perina *et al.* 2018, 2019), it is considered highly likely that both Bathynellidae `WAM-BATH001` and the putative second genus/ species Bathynellidae sp. GP2 are potential SRE stygobitic taxa. Detailed habitat assessment and risk assessment for these species is discussed in section 4.

3.2.2 Parabathynellidae

The survey detected 24 specimens from 3 putative species of Parabathynellidae (each representing a different genus); which were not previously detected during the baseline survey (Biologic 2019). As parabathynellids are as common, if not more commonly found throughout the region than bathynellids (S. Callan pers. obs., Abrams *et al.* 2012), it was not surprising that they should occur at Paraburdoo. Nevertheless, based on current knowledge of parabathynellid biogeography, it was somewhat more surprising to find three different genera within the same catchment, potentially sharing the same connected habitats (Abrams *et al.* 2012).

Atopobathynella sp. GP3 was detected only from Seven-Mile Creek North, at three shallow bores within a 3 km linear range, all bordering Seven-Mile Creek. Although the identifications of this taxon have not been confirmed by DNA, based on their proximity and the similarity of habitat it is considered highly likely that these specimens would represent a single species inhabiting the alluvial habitats of Seven-Mile Creek.

Billibathynella sp. GP4 was detected only from one bore at the Landfill (MB15PAFL002) and another site (PMP4) in the Southern Borefield (approximate linear range 9 km). The Landfill bores are located in the Jeerinah Formation/ overlying colluvium to the north of the Paraburdoo Range, whereas the Southern Borefield occurs in a different hydrogeological setting (Wyloo Formation) to the south of the Range. The two bores where the known specimens of this species were collected are also in different surface water catchments (MB15PAFL002 near a tributary of Seven-Mile Creek vs PMP4 near Pirraburdoo Creek), nevertheless, both catchment systems drain into Turee Creek East many kilometres further south of Paraburdoo. The identifications of these specimens have not been confirmed by DNA or detailed morphological work, nevertheless there are two likely scenarios; either they belong to a single species that occurs relatively widely throughout the local area (potential dispersal through the alluvial/ hyporheic zone), or there may be two different, shorter-ranging species of *Billibathynella* inhabiting different hydrogeological habitats either side of the Paraburdoo Range.

Hexabathynella sp. GP5 was detected from the existing operations as well as the Landfill bores (2 km linear range), both of which feature multiple hydrogeological habitats in fractured rocks and alluvial/ detrital aquifers. Although the identifications of this taxon have not been confirmed by DNA or detailed morphological work, it is considered likely that these specimens represent a single species inhabiting fractured rock aquifers and potentially the alluvial habitats of Seven-Mile Creek and its nearby tributaries.

3.3 Habitat assessment

In the Pilbara region, stygofauna assemblages are highly dependent on inputs of nutrients and dissolved oxygen from the surface via water infiltration. Important factors that influence infiltration and therefore affect the suitability of aquifer habitats for stygofauna include (following Strayer 1994; Hahn and Fuchs 2009):

- the porosity, transmissivity (k), and storage capacity (s) of the host rock;
- the presence of any constraining/ overlying geologies of lower permeability;
- the depth from the surface (or distance from recharge source if direct infiltration is not the source of recharge); and
- the presence of fracture zones, cavities, or conduits such as tree roots, that can enhance rates/ volumes of infiltration or throughflow.

The most highly suitable habitats for stygofauna in the Pilbara are typically found in high storage/ high transmissivity aquifers (such as unconsolidated alluvium, calcrete, and Channel Iron Deposits or CID). These aquifers are characterised by an extensive network of interconnected voids which are in geological settings typically close to the surface. This network of interconnected voids provides large groundwater aquifers with rapid recharge, high oxygen levels, and plentiful sources of nutrients/ food (such as the roots of phreatophytic vegetation).

Stygofauna are also regularly found within fractured and weathered rock aquifers including Banded Iron Formations (BIF), basalt, and metamorphosed sedimentary or volcanic rocks, where zones of higher permeability have developed along fractures/ faults, geological contact zones, or due to secondary weathering of the upper profile. In these types of habitats, connectivity to the surface (*i.e.* the pathway for infiltration) is often complicated or restricted by less permeable zones within the host rock, or nearby impermeable layers such as intrusives, massive/ fresh rock, clays, or shales. Fractured/ weathered rock aquifers exhibit more variable interconnectivity between permeable zones within the host rock itself, and with different adjoining aquifers such as superficial aquifers in detrital zones higher in the profile (*e.g.* in valley fill, along drainage lines, and in sheetwash areas). In cases where there is a high degree of vertical connectivity between superficial detrital aquifers and deeper fractured rock aquifers, the former may facilitate wider local connectivity between patches of the latter, thus providing potential recharge pathways from the surface, and dispersal pathways for stygofauna species. Conversely, where superficial detrital aquifers and deeper fractured rock aquifers are separated by less permeable strata (aquitards/ aquicludes) or geological disconformities, the quality of habitat for stygofauna in the deeper fractured rock aquifer may be limited by a lack of dissolved oxygen and nutrients, and a lack of throughflow pathways facilitating dispersal.

In the Study Area, current habitat information (bore logs, geological mapping, diamond cores, and geological cross sections), hydrogeological reports, groundwater testing, and the results of stygofauna sampling indicate the presence of multiple stygofauna habitats within different strata. Table 3.2 provides details of the hydrogeological units present at the slotted interval in bores where stygofauna have been recorded.

The alluvial aquifers of Seven-Mile Creek (and its tributaries) form the most important and most highly prospective habitats for stygofauna, with high k and s values, and a direct connection to surface infiltration (particularly during flow events). Groundwater flows within these superficial alluvial aquifers may be affected by the presence of sills and dykes occurring within the drainage line especially to the north of the existing operations. However, floods and flow events are likely to facilitate wider habitat connectivity and provide a dispersal mechanism for most of the stygofauna species present throughout the wider local area or throughout the catchment. This is likely to be a reason why many common stygofauna species are shared between borefields connected by Seven-Mile Creek (such as the Town borefield and Southern Borefield), and even between creeks of the same catchment (*e.g.* Pirraburdoo Creek, Seven-Mile Creek, and Turee Creek East) (Biologic 2019). Nevertheless, not all stygofauna species occurring in such systems can be assumed to be widespread, as a few more dispersal-limited taxa are also known to occur.

Within the Study Area, fractured/ weathered rock aquifers are hosted within the mineralised Brockman Iron Formation (particularly at the existing operations), the fractured/ weathered Wittenoom Formation (north of the existing operations), the fractured Jeerinah Formation (at the Landfill bores), and the Wyloo/ McGrath Formation (Southern Borefield). Each of these fractured/ weathered rock aquifers may have its own physical and physicochemical characteristics that influence the extent and quality of stygofauna habitat, but in general these types of aquifers are more limited than the alluvial/ detrital aquifers. Permeability in these hydrogeological units is facilitated by fractures and weathered zones within the host rock. Thus, flow paths and the degree of interconnectivity can be more complex as they are influenced by the direction of geological strike, the presence of less permeable rock types nearby, faults and disconformities, and intrusives. Habitat quality for stygofauna may be depth dependent, as deeper fractured rock aquifers with more complex flow paths tend to feature lower dissolved oxygen (*i.e.* stagnant, anoxic, or anaerobic conditions) as depth from the surface increases.

Table 3.2: Hydrogeological habitat details at the depth of the slotted interval for bores where stygofauna were detected.

Borefield	Bores sampled (stygo detected)	Surface Geology	Screened aquifer	DTW	Stygofauna present (target species in bold)
Landfill	MB 3 MB15PAFL002 MB15PAFL003 MB16PAFL001	Colluvium Jeerinah Formation: pelite, metasandstone, chert, metabasaltic pillow lava and breccia; metadolerite sills	Colluvium, weathered dolerite (2-7m) Moderately to partially weathered dolerite. Some fresh dolerite. Calcite/ carbonate veins (15-20m)	**6-13 m**	Amphipoda, Cyclopoida, Harpacticoida, Ostracoda, Parabathynellidae
SMC North	MB 7, MB 8 MB 10, MB 13 MB 15 PZ06SMC0001	Alluvials: river gravels in a sand to silt matrix. Jeerinah Formation at the margins, as above.	Alluvials: sub-rounded river gravels, possibly of dolerite. Minor evidence of calcrete. Weathered dolerite at depth.	**6-13 m**	Amphipoda, Cyclopoida, Harpacticoida, Ostracoda Parabathynellidae, Oligochaeta
OPS (A)	MB17NLC006	Alluvials: river gravels in a sand to silt matrix.	Alluvials: sub-rounded river gravels, dolomite & hematite derived (2-7m)	**4 m**	**Bathynellidae `WAM-BATH001`**, Acari, Cyclopoida, Oligochaeta
OPS (B)	MB15NLC001 MB15NLC002	Alluvials: river gravels in a sand to silt matrix. Brockman Iron Formation (Joffre and Dales Gorge) at the margins.	Alluvials: sub-rounded river gravels, dolomite & hematite derived (2-7m) Joffre martite-hematite, weathered/ fractured shale bands, heavily weathered dolerite clay, shales.	**9 m**	**Bathynellidae `WAM-BATH001`**, Amphipoda, Cyclopoida, Parabathynellidae
OPS (C)	MB15NLC005 MB17NLC002 WB17NLC001 WB18NLC001	Brockman Iron Formation (Joffre and Dales Gorge) at the margins.	Dales Gorge Hematite-goethite, shale, chert.	**23-28 m**	**Bathynellidae GP2** (WB18 only), Acari, Amphipoda, Cyclopoida, Harpacticoida, Ostracoda
SBF (A)	MB17NLC001 MB154W003	Weeli Wolli Iron Formation and colluvium at the margins. Alluvium. colluvium and Mt Mc Grath Formation at the margins	Calcitic dolomite, hard, water bearing (72-90m) Deep alluvials, chert, hematite clasts (40-72m)	**26-29 m**	Cyclopoida, Oligochaeta, Ostracoda
SBF (B)	PMP2 PMO3, PMO3A PMP4, PMO4A	Alluvium and colluvium. Mt Mc Grath ferruginous sandstone, conglomerate, quartzite, shale, mudstone/ siltstone	(PMP2) Weeli Wolli IF, Beasley River Quartzite (PMO3/A) Duck Creek Dolomite, Breccia fault/ fracture zone (PMP4/O4A) Alluvials, Beasley River Quartzite	**9-16 m**	Acari, Amphipoda, Isopoda, Cyclopoida, Harpacticoida, Ostracoda, Parabathynellidae, Oligochaeta

Table 3.2 suggests multiple suitable aquifer types within each of the sampling areas – even in some cases multiple zones within a single deposit/ borefield (such as the existing operations and the SBF). Bores in Table 3.2 were divided up into similar hydrogeological settings based on similar groundwater depths and similar hydrogeological strata at the slotted interval. For example, in the existing operations area, zone (A) included bores located north of the McRae shales barrier, where water levels were within 4 m of the surface (note, in this case only MB17NLC006 is shown in the Table 3.2 as the other holes did not record stygofauna). Meanwhile in the existing operations area, water levels in zone (B) (MB15NLC001 and MB15NLC002, both slotted in the Joffre Member) were consistently 9 mbgl, while at the other bores (zone C) slotted in the Dales Gorge Member, groundwater was at 23-28 mbgl in spite of their close proximity to zones A and B.

The hydrogeological complexity of this area is affected by dykes and numerous geological disconformities which are likely to complicate the interconnectivity between bores despite spatial proximity. Nevertheless, the occurrence of approximately the same stygofauna species assemblage throughout these areas nevertheless suggests a mechanism facilitating stygofauna dispersal. Vertical connectivity with the overlying alluvial aquifers (particularly during floods and flow events in Seven-Mile Creek) could potentially function as such (refer section 3.4 below for further investigation in relation to water quality).

There is some suggestion that multiple habitat zones could also be a feature of the Southern Borefield, with bores in zone A showing groundwater at 26-29 mbgl (albeit in various hydrogeological settings), while bores in zone B (in the McGrath Formation), had water levels between 9-16 mbgl, and exhibited a much more diverse stygofauna assemblage (Table 3.2). Further investigation into this trend is complicated by inconsistencies in the drilling log data available for some of the older bores in this area, and the much greater spatial scale allowing for greater hydrogeological variability.

Owing to the similarity in habitats present and stygofauna collected between the SMC north and Landfill survey areas, and the similar range of groundwater depths measured at the time of survey, it is considered likely that these areas may be well-connected hydrogeologically. Section 3.4 provides further evidence supporting this theory from a water quality perspective.

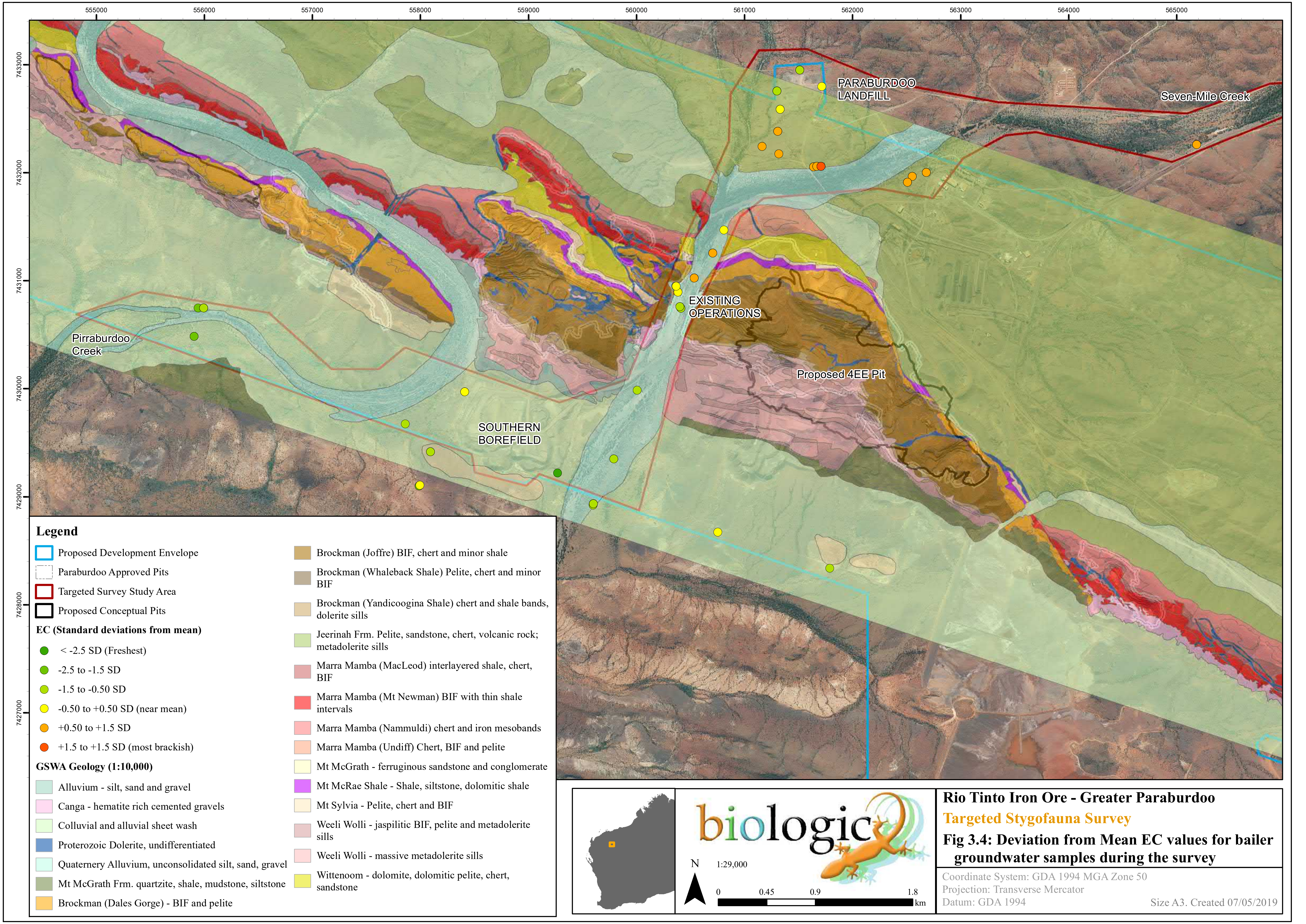
3.4 Water physicochemistry

Table 3.3 shows the groundwater physicochemical measurements taken during the survey. Overall, the groundwater conditions sampled during the survey were variably fresh to brackish fresh (mean EC 2224 µS/cm, SD 840 µS/cm), consistently neutral (mean pH 7.6, range 7.23-8.9), moderate to low dissolved oxygen (mean DO 1.5ppm SD 0.9ppm), and with highly variable redox values (mean ORP 21 mV, SD 105 mV, and 13 out of 38 sites registering negative ORP) (Table 3.3).

Table 3.3: Water physicochemical measurements observed during the targeted survey. Bores are listed in approximate order north to south. Red font indicates bores of similarly high EC/ salinity. Light grey shading indicates differences in depth to groundwater (not adjusted for topography).

Bore/ Site No.	Date	EOH (m)	DTW (m)	Temp. (°C)	EC (uS/cm)	Salinity (ppm)	Acidity (pH)	Redox (mV)	O_2 (ppm)	Turbidity; Odour	Aquifer notes
LFL											
MB15PAFL002	17/05/2019	26	13	28	1608	0.76	7.5	117.2	1.6	Very low; Fresh clean	LFL dolerite
MB15PAFL001	17/05/2019	25	13	27	2078	1.02	7.62	103.4	1.86	Very low; Stale	LFL dolerite
MB15PAFL003	17/05/2019	23	8	29.7	1704	0.78	7.39	96	1.09	Very low; Stale	LFL dolerite
MB 3	17/05/2019	11	7	29	2121	1	7.56	88.7	1.22	Very low; Fresh clean	LFL dolerite
MB16PAFL0001	17/05/2019	27	6	29.2	3291	1.58	8.39	77.8	1.34	Very low; Stale	LFL alluvial/ dolerite
MB16PAFL0002	17/05/2019	23	7	29.2	3375	1.62	7.87	-37.6	1.18	Very low; Slight sulphurous	LFL alluvial/ dolerite
MB16PAFL0003	17/05/2019	22	5	26.9	3090	1.57	7.61	121.1	1.46	Very low; Fresh clean	LFL alluvial/ dolerite
SMC-N											
PZ06SMC0001	17/05/2019	13	5	29.8	3165	1.49	7.37	95	1.53	Very low; Dead ant odour	SMC alluvial/ dolerite
MB 7	17/05/2019	6	4	26.7	3444	1.74	7.56	75.7	0.96	Medium; Fresh clean	SMC alluvial
MB 8	17/05/2019	8	4	26.4	3196	1.62	7.51	57.6	1	Medium; Fresh clean	SMC alluvial
MB 9	17/05/2019	6	4	27.3	3672	1.84	7.5	2.8	1.11	Low; Stale	SMC alluvial
MB 15	17/05/2019	9	6	28.5	2929	1.41	7.54	-146.6	1.11	Low; Slight sulphurous	SMC alluvial
MB 13	17/05/2019	7	5	29.9	3027	1.42	7.43	64.8	0.94	Low; Slight sulphurous	SMC alluvial
MB 10	17/05/2019	7	5	31.3	3190	1.46	7.48	75.4	1.24	Very low; Stale	SMC alluvial
OPS											
MB17NLC0006	16/05/2019	8	4	27.3	3261	1.63	7.58	-81.6	1.97	High; Clay/ dust odour	OPS (A) alluvial
MB17NLC0004	16/05/2019	78	4	27.4	2282	1.11	7.6	-20.2	1.59	Low; Clay/ dust odour	OPS (A) fractured
MB17NLC0005	16/05/2019	59	4	27.6	2519	1.23	7.67	-182.4	1.78	Very low; Major sulphurous	OPS (A) fractured
WB18NLC0001	16/05/2019	76	28	25.9	2998	1.53	7.61	72.3	2.01	Very low; Fresh clean	OPS (C) MTS/ WD
MB15NLC001	16/05/2019	48	9	29.6	2648	1.24	8.68	-77.7	1.41	Low, black sed.; Slight sulphurous	OPS (B) Joffre
MB15NLC005	16/05/2019	32	9	30.2	2562	1.18	8.97	-82.1	1.04	Low, black sed.; Decomposition	OPS (B) Joffre
MB15NLC002	16/05/2019	42	25	27	2506	1.23	7.81	97.8	1.18	Very low; Slight sulphurous	OPS (C) DG
WB17NLC0001	16/05/2019	41	25	27.3	1815	0.87	7.66	10.7	0.87	Low; Clay/ dust odour	OPS (C) DG
MB17NLC0002	16/05/2019	36	23	28.1	1878	0.89	7.82	93.6	0.9	Very low; Fresh clean	OPS (C) DG

SMC-S											
PMO7	16/05/2019	57	51	29	1525	0.75	7.77	110	1.3	High; Fresh clean	SMC-S alluvials
SBF											
MB154W003	17/05/2019	67	26	31.4	2257	1.01	7.7	100.9	1.29	Very low; Fresh clean	SBF (A) alluvials
PMP4	15/05/2019	93	12	27.4	1381	0.65	8	160.1	6.09	Very low; Fresh clean	SBF (A) alluvials
PMO4	15/05/2019	93	10	28.6	615	0.28	8.31	137.1	1.87	Low; Stale	SBF (B) alluvial/ dolomite
PMO4A	15/05/2019	86	9	28.9	903	0.41	8.98	44.2	1.56	Very low; Fresh clean	SBF (B) alluvial/ dolomite
MB094W01	15/05/2019	36	25	30.7	165	0.89	7.55	-90.1	1.78	Very low; Slight sulphurous	SBF (B) shale
MB17NLC0001	16/05/2019	90	29	28.1	1487	0.7	7.82	148.3	2.45	Very low; Fresh clean	SBF (B) dolomite
MB17SB0001	17/05/2019	88	16	31.4	1798	0.8	7.82	-172.9	0.01	Very low; Major sulphurous	SBF (B) dolomite
PMO2A	15/05/2019	34	17	29.5	1504	0.69	8.6	-27.5	1.75	Very low; Stale	SBF (B) WWIF
PMP2	15/05/2019	54	16	29.8	1851	0.85	7.62	127.1	1.99	Very low; Stale	SBF (B) alluvial/ WWIF
PMO3	15/05/2019	86	16	30.9	1904	0.86	8.78	70.9	2.26	Very low; Stale	SBF (B) dolomite
PMO3A	15/05/2019	55	15	32.7	1087	0.46	7.4	-145.9	1.38	Very low; Mineral	SBF (B) dolomite
PMP3	15/05/2019	81	17	33.7	2072	0.89	7.23	105.1	1.39	Medium; Mineral	SBF (B) dolomite
TSF											
MB18TSF0003	16/05/2019	60	26	29.9	1576	0.72	7.44	-171.9	0.94	Very low; Major sulphurous	TSF
MB18TSF0004	16/05/2019	63	25	30.3	2214	1.01	7.36	-192.6	1.09	Very low; Major sulphurous	TSF



Rio Tinto Iron Ore - Greater Paraburdoo

Targeted Stygofauna Survey

Fig 3.4: Deviation from Mean EC values for bailer groundwater samples during the survey

While this range of conditions would be expected to be generally tolerable for stygofauna, the high variability of the groundwater measurements may potentially reflect multiple hydrogeological habitats within and between borefields/ sampling areas, as well as conditions within the bores themselves.

In some cases, poor results from stygofauna sampling could be related to poor water quality within the bores. For example, several of the bores slotted at great depth from surface and showed highly negative redox values, produced strong sulphurous odours and failed to record stygofauna, including MB17NLC0005, MB17SB0001, MB18TSF0003, and MB18TSF0004. However, certain other bores with negative redox values recorded stygofauna, including syncarids (MB15, MB15NLC001, MB15NLC005). However, these bores were slotted higher in the profile and occurred in different aquifers. It is also likely that other biological activity (*e.g.* frogs sheltering under the bore cap) could have reduced the redox values at MB15NLC001 and MB15NLC005.

The water quality data measured during pumping (Appendix 3) showed considerably lower oxygen and redox values at depth (ca. 45 mbgl), whereas samples taken 10-15 m higher in the profile showed higher oxygen and more moderate or positive redox values, indicating limited or slow water mixing within the vertical profile. In the SBF and existing operations area, pumping was undertaken at multiple depths to sample different strata. Bores at the LFL were much shallower, thus pumping was only undertaken at the end of hole. Most bores showed no sign of flow change or dewatering during the pumping, except PMP2 (reduced rate of flow at shallower depth 35 m), PMO3 (very reduced flow/ intermittent pumping at shallower depth 25 m), and MB15PAFL002 (dewatered after 5 minutes, with 2/3rds recovery over a 10 min period) (Appendix 3). These cases suggest lower inflows/ transmissivity from the surrounding aquifer than the other bores pumped, potentially due to fractured rock aquifers. It was interesting that all of these bores still recorded stygofauna, with PMP2 and MB15PAFL002 showing particularly rich assemblages.

The bores and sampling areas in Table 3.3 are approximately ordered from north to south, reflecting the surface water flow direction of Seven-Mile Creek. If groundwater flows were relatively simple and consistent with this direction, there would be clear gradients in terms of characteristics such as EC/ salinity and depth to groundwater between north and south; rather, the data reflect a much more complex hydrogeological environment.

The bores within the existing operations area reflected a highly variable and complex hydrogeological environment in terms of depth to groundwater and EC/ salinity, probably reflecting considerable hydrogeological compartmentalisation. Bores MB15NLC001 and MB15NLC005 recorded groundwater 9 mbgl and EC 2550-2650 µS/cm, while nearby bores MB15NLC002 and WB18NLC001 recorded groundwater 25-28 mbgl and a similar EC, in contrast to WB17NLC001 slightly further downstream (29 mbgl and 1815 µS/cm). Interestingly, many of these sites shared essentially the same stygofauna assemblage, including the target species Bathynellidae `WAM-BATH001`. For this reason, it is suspected that the current water levels and water quality characteristics in this area may have been affected by the interaction of groundwater drawdown, the very dry conditions observed during the survey, and the hydrogeological compartmentalisation of the habitat in the existing operations area. Owing to the high number of shared stygofauna species, it is likely that these aquifer compartments have been periodically connected over time, potentially via floods and associated groundwater rise within the overlying alluvial detrital zone.

Some water quality trends supporting this theory were apparent north of the McRae Shales barrier which currently limits groundwater drawdown. Sites sharing similar EC/ salinity and depth to groundwater values in the LFL, SMC north, and northern existing operations area (*i.e.* north of the McRae Shales) are marked in red font in Table 3.3. The distribution of these sites can be seen in Figure 3.4, as a series of orange and red points indicating relatively high EC values (+0.5 to +1.5 standard deviations from the overall mean EC), all of which appear to occur within the potentially connected detrital alluvial aquifers of SMC north (extending out to the southern LFL bores and northern existing operations area).

Notwithstanding that some of these bores are apparently slotted in fractured Jeerinah Formation aquifers (*e.g.* MB16PAFL0001, MB16PAFL0002, MB16PAFL0003, and PZ06SMC0001), the consistently shallow depth to water (4-6 m), and elevated EC/ salinity would be expected to indicate superficial detrital aquifers due to higher evapotranspiration and potential inflow of salts during surface flows. There were a few other sites with similar water depths in the LFL area (MB3 and MB15PAFL003), and in the northern existing operations (MB15NLC004 and 005), but these sites did not show similar elevated EC/salinity. Except for MB3, they were recorded as being slotted in deeper fractured rock aquifers, potentially less continuous with the overlying alluvial aquifers.

4. DISCUSSION AND ASSESSMENT

4.1 Limitations to knowledge

There were several important contextual factors affecting the results of the targeted survey and the current state of knowledge, which may have influenced the perceived risks to the target taxa from the proposed development:

1. Rarity of the fauna/ difficulties in detecting wider occurrences – this is a general limitation to subterranean fauna surveys exemplified by the detection of 3 species parabathynellid species only during the targeted survey, despite multiple previous visits to the same bores. Given the taxonomy and ecology of the region's bathynellid fauna is also still in development, it is difficult to infer how much the current findings reflect the rarity of the taxa (or difficulties in detecting them) vs their potentially restricted distributions within certain habitats/ areas.
2. Very dry wet season 2018-2019 – during the current survey groundwater levels were at an almost historic low, having been through an extended dry period since the last flow event in Seven-Mile Creek in 2017 (RTIO 2019). This may have temporarily reduced the potential wider occurrence of the target fauna or concentrated the fauna into patchier areas remaining saturated despite the low groundwater levels.
3. Current disturbance – in addition to the unseasonably dry conditions, the groundwater levels and stygofauna assemblages observed during the survey may also have been affected by the existing groundwater impacts/ drawdown from 4E/4W mining operations (within the SMC south and existing operations aquifers). The Paraburdoo operations also currently discharge water into the SMC north detrital aquifer, which may artificially supplement groundwater levels north of the McRae shales barrier in the SMC north area and the northern existing operations (RTIO 2019). Further groundwater drawdown likely occurs in the northern (town) borefield as a result of abstraction for potable water, although it is uncertain to what extent this may affect groundwater levels in SMC north.
4. Uncertainties regarding extent of impacts – to date there has not been any modelling of potential groundwater drawdown within the alluvial aquifers of Seven-Mile Creek and its tributaries north of the existing operations, including at the Landfill and SMC north. The connectivity and flow paths within these units are poorly understood, due to the complex hydrogeology, vertical interactions, and the presence of faults, intrusive dykes/ sills, and geological disconformities. Parts of SMC north are less well-studied owing to the relatively low numbers and patchy locations of suitable bores/ drilling in this area (particularly areas beyond the development envelope).

4.2 Habitat connectivity and species distributions

The most recent research into the Bathynellidae of the Pilbara region (Perina *et al.* 2018, 2019a, 2019b) has indicated that this group is more likely than other stygofauna found within the region to exhibit short-range endemism. This is due to the group's poor dispersal abilities and its ancient colonisation of subterranean habitats, driving isolated speciation over long geological time scales that pre-date current surface catchments/ drainage patterns. Nevertheless, some present bathynellid taxa are known from comparatively recent alluvial/ hyporheic habitats as well as deeper fractured rock aquifers, as is the case in the current survey. Therefore, while it is likely that the two bathynellid species found within the Study Area represent SRE taxa and are unlikely to occur widely in the local and regional area beyond the Study Area, there is a potential that they may occur slightly more widely than currently recorded, particularly in the alluvial aquifers of the SMC north area, which appear to be highly connected to the existing operations.

Owing to the poorer dispersal capabilities of bathynellid taxa and the restricted distributions found throughout described species in the group, the individual distributions of most other stygofauna species would be considered poor surrogates for the distribution of bathynellid taxa occurring in the same habitat. Nevertheless, current and previous sampling has shown that the stygofauna assemblage from the existing operations is well represented beyond the existing operations, particularly to the north at the Landfill bores and SMC north, while some more widely dispersed species also occur at the SBF and Northern/ Town Borefield (Biologic 2019).

While this may be an unsatisfactory substitute for evidence of the target species occurring beyond the existing operations, it provides a strong indication of hydraulic connectivity (probably within the alluvial aquifers, which is supported by water quality similarities shown in Table 3.3) providing a means for stygofauna dispersal between compartmentalised groundwater habitats along Seven-Mile Creek. It also supports the hypothesis that the fractured rock aquifers of the existing operations area are unlikely to be an evolutionarily discrete unit (connected to other habitable zones by floods and surface flows), and it is likely that the stygofauna occurring in such habitats should also occur elsewhere within the interconnected system of alluvial and fractured rock aquifers along Seven-Mile Creek.

4.3 Risk assessment

The targeted survey has found two undescribed bathynellid species in the existing operations area; Bathynellidae `sp. WAM-BATH001`, and Bathynellidae `sp. GP2` (Appendix 1). Bathynellidae sp. `WAM-BATH001` is known from bores MB15NLC001 and MB15NLC005 (in the Joffre Member), WB17NLC0001 (in Dales Gorge), and MB15NLC006 in superficial alluvial aquifers north of the McRae Shales barrier which form a northern limit to the fractured rock aquifers in the existing operations. Meanwhile, Bathynellidae `sp. GP2` is a singleton (and may represent a different genus) known only from bore WB18NLC0001, slotted in the Mt Sylvia and Wittenoom Formations within the existing operations.

Existing mining operations have affected the existing operation’s fractured rock aquifers, by lowering groundwater levels and reducing the habitat available for stygofauna (Figure 4.1, ‘2018’ current scenario), and possibly affecting water quality (Table 3.3). Despite this, the persistence of stygofauna assemblages in the existing operations area indicate that these impacts have not been serious to date. Nevertheless, it is likely that over time, this area will become less suitable for stygofauna due to increased impacts of groundwater drawdown and mining for the development of the proposed 4EE Pit (Figure 4.1, ‘proposed’ scenario).

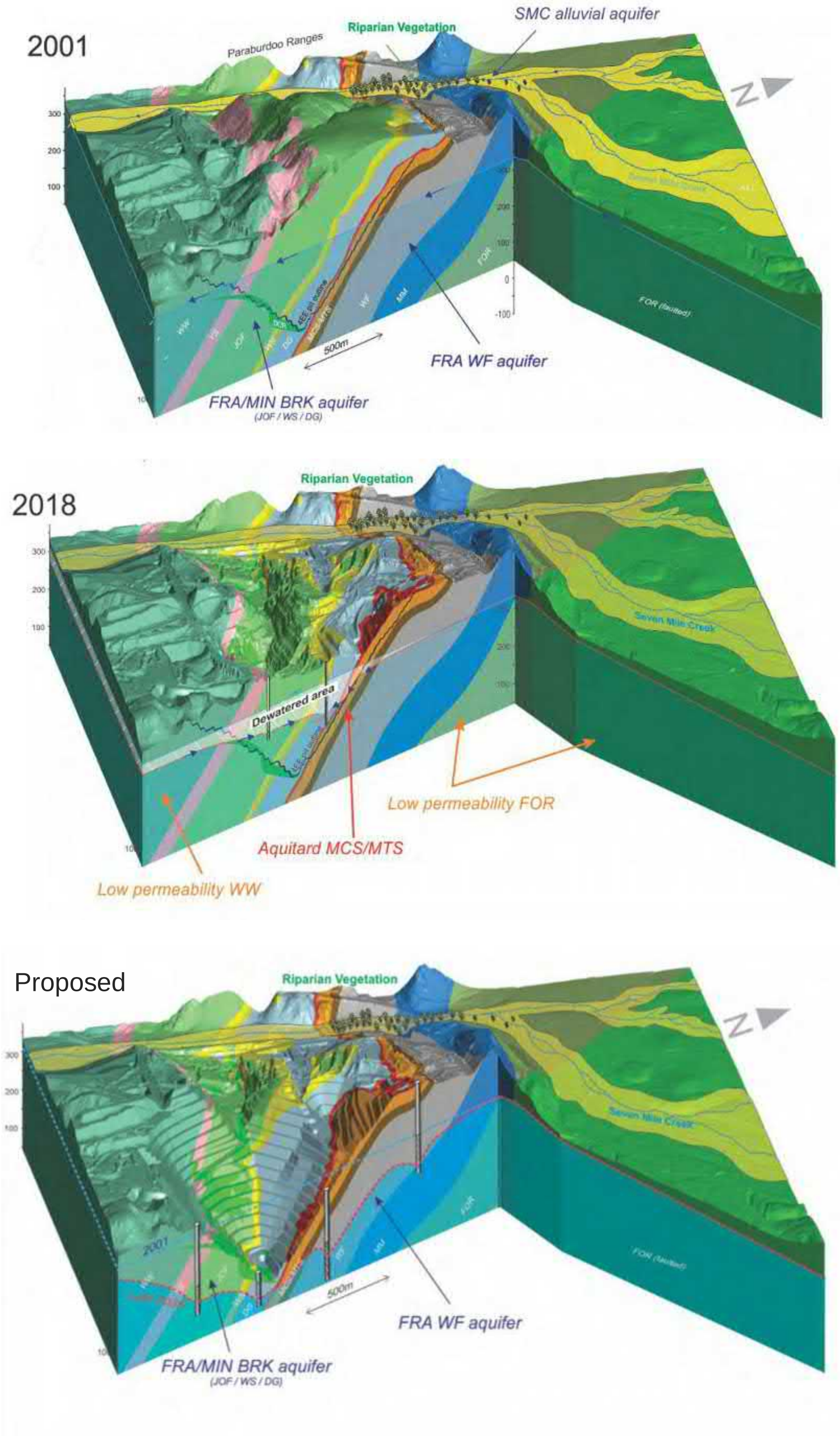


Figure 4.1: Cross sections of pre-mining, current development (2018), and likely impacts from proposed development of 4EE pit in the area of the existing operations and SMC north.

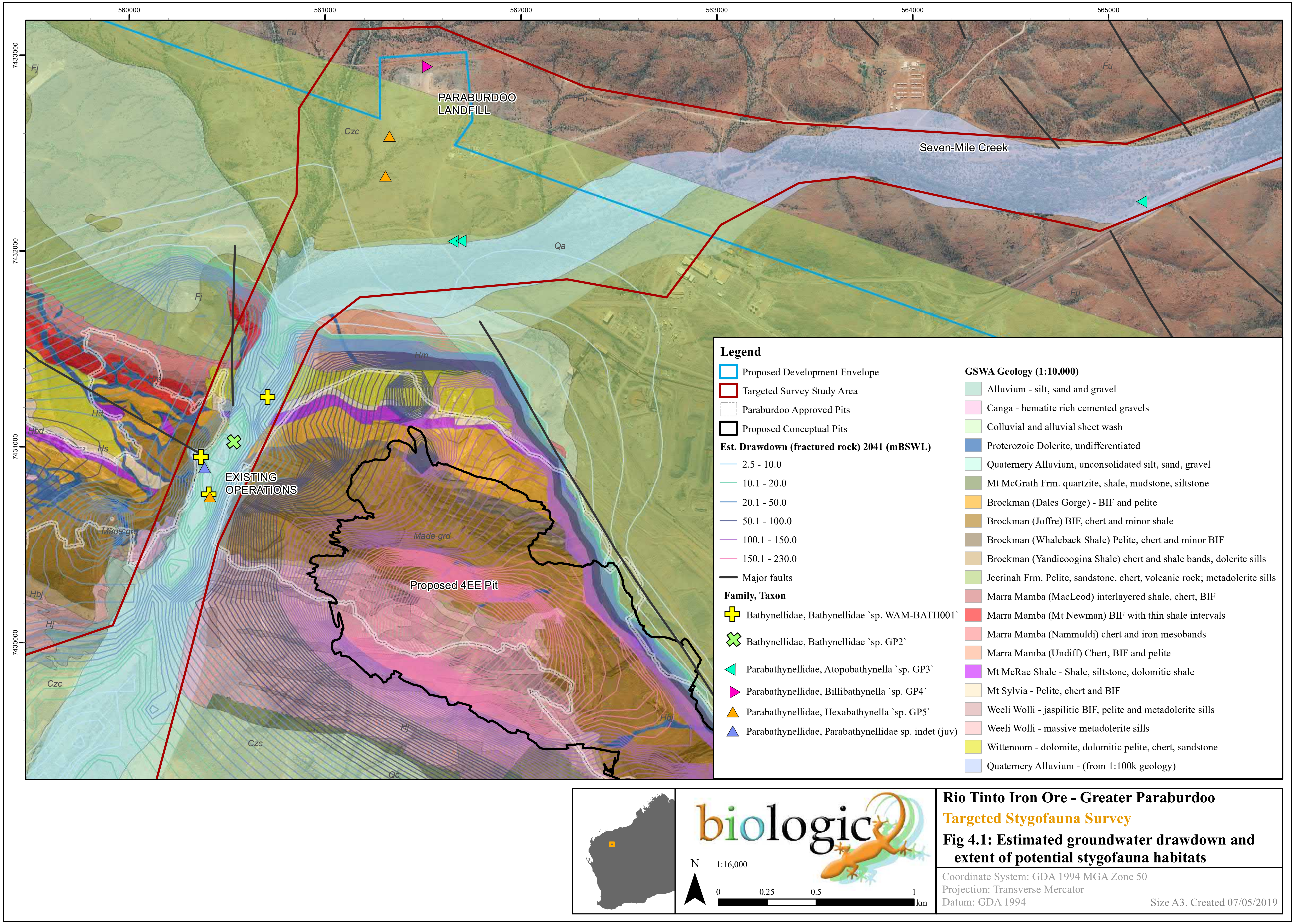
The proposed mining development at 4EE requires the dewatering of the Brockman, Weeli Wolli, and Wittenoom Formations in the vicinity of the existing operations to ensure safe mining conditions (RTIO 2019). Under the proposed mining development scenario, in dry season conditions the fractured rock aquifers and the overlying alluvial aquifers in the existing operations area will be completely dewatered. In wet season conditions, surface flows in Seven-Mile Creek may periodically replenish groundwater in the existing operations, but the residence time in this habitat will likely be minimal, due to throughflows into other connected formations affected by groundwater drawdown.

Groundwater drawdown will also extend into the fractured rock habitats in SMC north (Wittenoom Dolomite and Jeerinah Formation) and the Landfill area (Jeerinah Formation) to a more limited degree (Figure 4.2). This is likely to cause drawdown to propagate through the alluvial groundwater habitats of SMC north in dry conditions (Figure 4.2, 4.3), although the full extent of the potential drawdown within this layer has not been modelled due to the complexities of flow pathways throughout the alluvial aquifer.

For the two target species (Bathynellidae` sp. WAM-BATH001` and Bathynellidae `sp. GP2`) the risks from the proposed development of 4EE pit and associated groundwater drawdown are considered high. This risk assessment is based upon the following key factors:

- The two bathynellid species are known only from bores within the existing operations despite a reasonable survey effort to detect them more widely within connected and potentially connected habitats.
    - However, the current results are affected by the aforementioned limitations and knowledge gaps, therefore it is still possible that both species could occur more widely than is currently recognised, particularly within the alluvial aquifers in the SMC north area, due to the high degree of hydraulic connectivity with the aquifers of the existing operations area.
- The propagation of groundwater drawdown in the superficial alluvial aquifers in the SMC north area may be limited by sills/ intrusives occurring throughout the drainage line, which may result in patches of viable habitat remaining saturated from periodic surface inflows along Seven-Mile Creek.
    - However, no modelling of the location and extent of these upstream sills/ intrusives, alluvial geometry or predicted drawdown in the alluvials is currently available to inform an assessment of how much habitat may remain saturated. This inference cannot currently be relied upon as evidence of suitable, out of impact habitats for stygofauna species potentially affected by drawdown from the proposed development.

This assessment is based on information available at the time of writing and may be subject to change following the receipt of any additional or revised information regarding stygofauna taxonomy, subterranean habitats, and/or proposed impact areas.



Rio Tinto Iron Ore - Greater Paraburdoo

Targeted Stygofauna Survey

Fig 4.1: Estimated groundwater drawdown and extent of potential stygofauna habitats

Coordinate System: GDA 1994 MGA Zone 50
Projection: Transverse Mercator
Datum: GDA 1994

Size A3. Created 07/05/2019

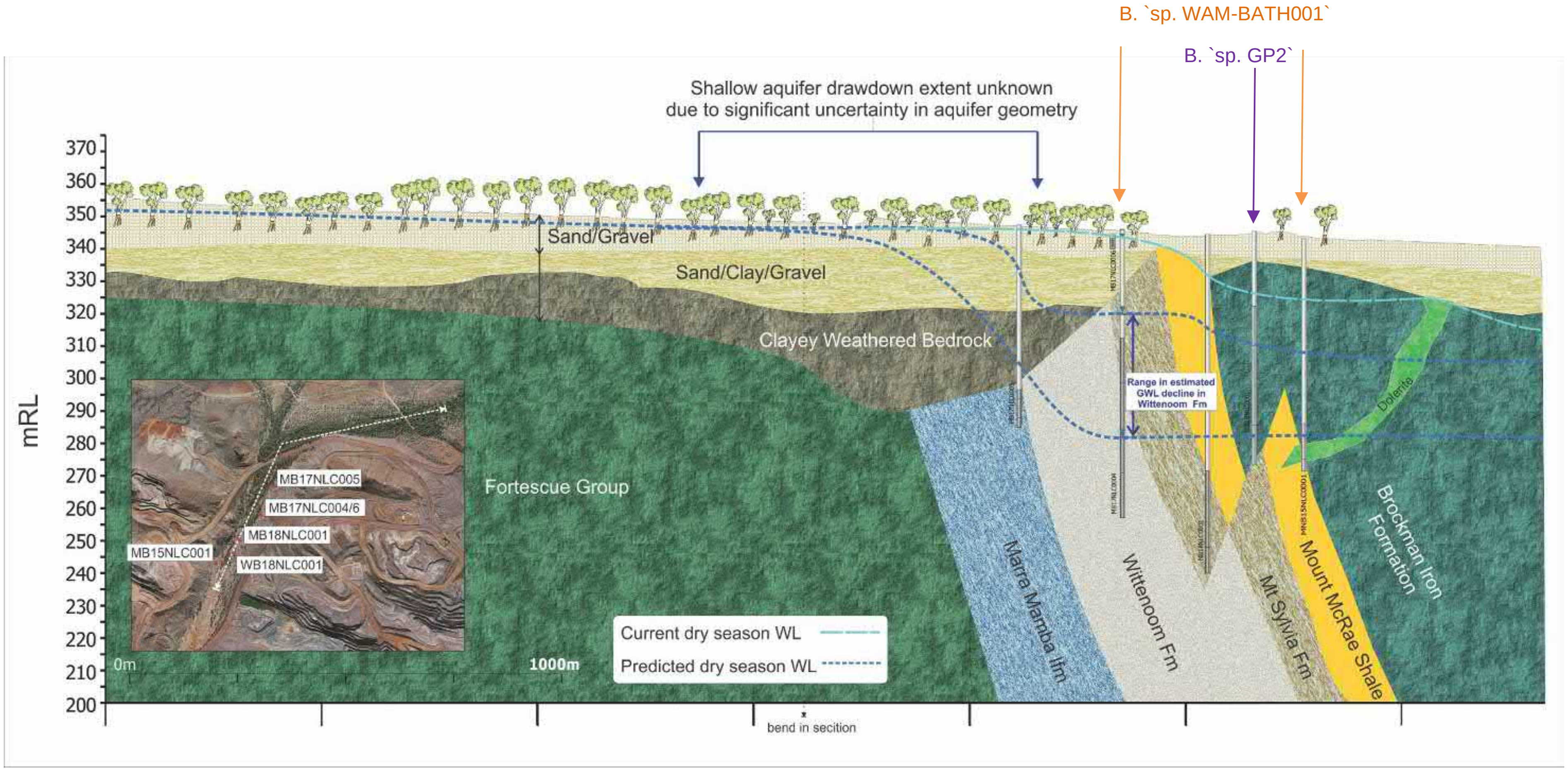


Figure 4.3: Long section of the existing operations and SMC north area showing interactions between superficial alluvial aquifers and deeper fractured rock aquifers, and estimated groundwater drawdown from the proposed development.

5. KEY FINDINGS

The targeted stygofauna survey sampled 38 sites by net hauling and pumping, to investigate the potential wider occurrence of bathynellid syncarids previously collected from highly compartmentalised fractured rock aquifers of the existing operations area, which are likely to be increasingly impacted by proposed mining and groundwater drawdown at 4EE. The survey detected two undescribed bathynellid species, representing Potential SRE stygobites:

- Bathynellidae sp. \`WAM-BATH001\` (*i.e.* the original target species), now known from three bores in fractured/ weathered rock aquifers in the existing operations area, and from the superficial alluvial aquifer of Seven-Mile Creek to the immediate north; and
- Bathynellidae sp. GP2, a new species and putative new genus, known from the fractured Mt Sylvia and Wittenoom Dolomite Formations within the existing operations.

The results of stygofauna habitat assessment, geological and hydrogeological modelling, water physicochemistry measurements, and stygofauna sampling to date have found that the alluvial/ detrital aquifers of Seven-Mile Creek and its tributaries are likely to be the most important habitats for stygofauna in the Study Area. The alluvial aquifers are likely to provide a degree of connectivity (particularly during floods) between deeper, fractured rock aquifers occurring along Seven-Mile Creek, potentially providing a dispersal mechanism for stygofauna species.

Under the proposed mining of 4EE pit, the fractured rock aquifers and the overlying alluvial aquifers in the existing operations will be completely dewatered, while more moderate levels of groundwater drawdown will affect the local extent of fractured rock aquifers in Seven-Mile Creek north and the Landfill area. Owing to hydraulic connectivity, the superficial alluvial aquifers in this area will also be affected, although the extent and magnitude of drawdown in these aquifers is not modelled due to complicated flow paths and the likely presence of impermeable rock barriers within Seven-Mile Creek.

The proposed impacts are regarded as a high risk to the two Bathynellid species known only from the existing operations area to date, due to the following factors:

- Sampling to date has failed to detect these species beyond the aquifer habitats likely to be impacted by the proposed dewatering/ groundwater drawdown;
- There is a reasonable likelihood that these species may occur more widely than currently recognised within the local extent of alluvial/ detrital aquifers in Seven-Mile Creek to the north (based on hydrogeological connectivity and the locally wider occurrence of most other stygofauna species within the same assemblage),
- However, due to the uncertainties around the extent and magnitude of groundwater drawdown throughout the alluvial/ detrital aquifers of Seven-Mile Creek, it is not certain what proportion of this habitat can be considered out of impact, and therefore this does not moderate the perceived risk to the target species.

These findings may be subject to change following the receipt of additional or revised information regarding fauna taxonomy, subterranean habitats, and/or proposed impact areas.

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7. APPENDICES

Appendix 1 – Morphological comparisons of Bathynellidae (G. Perina)

GREATER PARABURDOO BATHYNELLIDAE MORPHOLOGICAL IDENTIFICATIONS

21/08/2019

The morphology of the following Bathynellidae specimens was analysed:

BES#	Bore code	spmn #	Notes
6932	MB15NLC0001	7	3 females, 4 males
7570	MB17NLC007	2	1 male, 1 female
6908	WB18NLC0001	1	female

Specimens from BES6932 and BES7570 shared distinctive morphological characters such as: absence of epipod on thoracopod I, four setae on exopod of thoracopods I to VII, and furcal rami with five spines: first spine almost twice as long as third one, 3rd spine >2nd>4th- dorsal spine.

The specimen from BES6908 presents instead: epipod on thoracopod I, five setae on exopod of thoracopods II to VII and four setae on exopod of thoracopod I. Furcal rami with five spines: the dorsal spine is the shortest, $1^{st}>3^{rd}>4^{th}>2^{nd}$. Therefore; based on this set of characters it is my professional opinion that this specimen represents a different species (and most likely a different genus) to the other specimens collected from bores MB15NLC0001 and MB17NLC007.

Based on current knowledge of Bathynellidae in the Pilbara region (Perina *et al.*, 2019a; Perina *et al.*, 2018; Perina *et al.*, 2019b), the two taxa collected from Paraburdoo represent new undescribed species (and most likely new genera). Chances that these taxa are confined to the aquifer system in the Greater Paraburdoo area (and therefore considered SREs) are highly likely, as Bathynellidae are confined to the interstitial/subterranean environment, and have low dispersal abilities (Coineau & Camacho, 2013).

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Appendix 2 – Molecular genetic (DNA) analysis of Bathynellidae

INTRODUCTION

Rio Tinto Iron Ore Pty Ltd (Rio Tinto) commissioned Biologic Environmental Survey Pty Ltd (Biologic) to carry out molecular analysis (DNA barcoding) upon bathynellid specimens collected during the Greater Paraburdoo Targeted Stygofauna Survey (the Survey). The objectives of the molecular analysis project were to:

- Successfully extract and sequence DNA from 10 bathynellid specimens collected during the Survey;
- Determine whether the specimens collected during the Survey belonged to the same or different genetic lineages representing putative ‘species’; and
- Determine whether the specimens collected during the survey belonged to the same, or different putative ‘species’ as was previously recorded and sequenced during the baseline survey (Biologic 2019) *i.e. Bathynella* sp. \`WAM-BATH001\`.

This report presents the methods and results of the molecular analysis and provides justification for the delineation of putative ‘species’ from genetic lineages where possible, based on established thresholds of genetic divergence between sister species of the same or similar taxa.

METHODS

Ten specimens of Bathynellidae were identified during parataxonomic sorting of 752 subterranean fauna specimens from the Survey. Morphological identifications were conducted by Giulia Perina, the pre-eminent specialist taxonomist for the group, by slide mounting the specimens. Prior to the creation of permanent slides, a dissected portion of each specimen was placed into ATL buffer for DNA extraction using a commercially available extraction kit (QIAGEN DN-easy).

DNA extraction was undertaken using Folmer PCR primers LCO1490 and HCO2198 (Folmer *et al.*, 1994). These primers were the same as those used during the previous DNA analysis of baseline survey specimens at the Western Australian Museum (Appendix 3 in Biologic 2019). Sample DNA was amplified using Polymerase Chain Reaction (PCR) at the Cytochrome Oxidase I (COI) gene, the standard DNA barcoding region for animals (Herbert *et al.*, 2003).

A mitochondrial gene locus, mt 16S, was also amplified to supplement the information derived from COI, as recommended by Giulia Perina from her recent work on Pilbara Bathynellidae (Perina *et al.*, 2018). The gene 16S is specifically used in phylogenetic analysis for species delineation, as mitochondrial genes are often more evolutionarily conserved than nuclear genes (Zhang & Hewitt, 1996). The amplification of 16S was carried out using Bathynellidae-specific PCR Primers developed by Giulia's research; 16SBathy-21F and 16SBathy-453R (Perina *et al.*, 2018). Sequencing was carried out by the Australian Genomic Research Facility (AGRF) Perth node.

DNA extraction, PCR, and sequence data were managed using GENEIOUS software version 10.1.2 (Kearse *et al.*, 2012). Sequences were compared to *Bathynella* 'WAM-BATH001' sequences provided by Rio Tinto as well as additional sequences obtained from GenBank (Cullen, 2018). A Rio Tinto Paraburdoo Isopoda COI sequence was chosen as an outgroup to act as a comparison sequence for all the bathynellid sequences.

RESULTS AND DISCUSSION

Of the 10 specimens collected during the Survey, five specimens produced viable DNA for sequencing. Five successful sequences were obtained at the CO1 gene and four at the 16S gene (Table A1).

Pairwise comparisons revealed that the five sequences each differed by less than 0.01% (COI). This very low level of genetic divergence is indicative of a single genetic lineage, representing a single species of Bathynellidae.

Table A1: Bathynellidae samples sequenced from the targeted survey

BES No.	Bore code	Collection date	Notes	DNA CO1	DNA 16S	COI dissimilarity to WAM-BATH001 (%)
6908	WB18NLC0001	19/05/2019	female, morphologically different (GP2)	N	N	
7570a	MB15NLC0001	16/05/2019	female	Y	Y	0.004 - 0.007
7570b	MB15NLC0001	16/05/2019	male, brittle	N	N	
6932a	MB17NLC006	16/05/2019	female	Y	Y	0.004 - 0.007
6932b	MB17NLC006	16/05/2019	female	Y	Y	0.01 - 0.006
6932c	MB17NLC006	16/05/2019	female	Y	Y	0.004 - 0.007
6932d	MB17NLC006	16/05/2019	male	N	N	
6932e	MB17NLC006	16/05/2019	male	N	N	
6932f	MB17NLC006	16/05/2019	male	Y	N	0.004 - 0.007
6932g	MB17NLC006	16/05/2019	male	N	N	

The sequences were then aligned against available sequences on GenBank and Rio Tinto genetic databases using BLAST (Basic Local Alignment Search Tool) Analysis (Altschul *et al.*, 1990).

BLAST analysis found that the sequences from the Survey were somewhat similar to other Pilbara Bathynellidae sequences available on GenBank at 16S (these comprising mainly material from Giulia Perina's research). The level of divergence at 16S was relatively high (20-22%), indicating a different genetic lineage/ species.

Conversely, at CO1, the sequences from the Survey did not match anything on Genbank from the family Bathynellidae, including Giulia Perina's COI sequences, which had been derived using different primers (Perina *et al*., 2018), thus resulting in a different sized fragment of the gene. This highlights the need to use the same COI primers (or at least multiple loci) when comparing sequences of similar taxa, as was observed for comparisons against the Rio Tinto genetic database.

BLASTing against the Rio Tinto genetic database at COI showed that the five sequences from the Survey were > 0.01% divergent from *Bathynella* 'WAM-BATH001' collected during the baseline survey (Biologic 2019). This very low level of genetic divergence is indicative of a single genetic lineage, representing a single species of Bathynellidae (*i.e. Bathynella* 'WAM-BATH001').

Giulia Perina's morphological work indicated that one specimen from the targeted survey (BES6908, Table 3.1) was regarded as potentially morphologically different – unfortunately this was unable to be confirmed by the current analysis as the specimen failed to sequence.

CONCLUSION

Of a total of 10 specimens collected during the Targeted Survey, DNA from five bathynellid specimens was successfully extracted and sequenced (at COI and 16S).

All five specimens collected during the Survey belonged to the same genetic lineage, at a very low level of genetic divergence (<0.01%), representing a single species of Bathynellidae.

All five bathynellid specimens were found to belong to the same genetic lineage/ same species as the previously sequenced *Bathynella* 'WAM-BATH001', collected from the same area during the baseline survey.

Notwithstanding the possibility that one specimen that was not successfully sequenced may represent a morphologically different taxon, the remaining Bathynellidae specimens from the Targeted Survey and the baseline survey are considered likely to represent a single species, *Bathynella* 'WAM-BATH001'.

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Appendix 3 – Water quality data from pumping

Water quality measurements made before (bailer), during, and after pump sampling.

Type	Date	Depth (m)	Temp. (°C)	EC (uS/cm)	Salinity (ppm)	Acidity (pH)	Redox (mV)	Dissolved Oxygen	Turbidity; Odour	Sampling notes
MB15PAFL002 (LFL)										
Bailer	17/05/2019	15	28	1608	0.76	7.5	117.2	1.6 ppm; 20.6 %	Very low; Fresh clean	PVC, stygofauna observed
Pump 1	18/05/2019	25	30.4	1772	0.8	7.3	28.9	1.16 ppm; 15.4 %	High; Fresh clean	Grey sediment. Pumped at 1L/s for 5mins, dewatered.
Pump 2	18/05/2019	25	30.3	1761	0.8	7.16	78.6	1.02 ppm; 13.6 %	High; Stale	WQ taken after 5min (dewatered)
Pump 3	18/05/2019	25	30.5	1740	0.78	7.28	56.9	1.97 ppm; 26.2 %	High; Stale	Waited 10 min for recharge. Pumped at 1L/s for 3:30mins, dewatered.
COMMENT: DTW 12m. Dewatering of bore at moderate pumping rate, suggests fractured rock aquifer, limited inflow. Grey sediments suggest weathered/ fractured dolerite. Salinity/EC similar to MB15PAFL0003.										
MB15PAFL003 (LFL)										
Bailer	17/05/2019	9	29.7	1704	0.78	7.39	96	1.09 ppm; 14.2 %	Very low; Stale	PVC bore
Pump 1	18/05/2019	22	30.9	1903	0.85	7.41	30.8	1.49 ppm; 19 %	Low; Stale	Slight white sediment (clear after 2 min). Pumped at 1L/s for 15mins.
Pump 2	18/05/2019	22	31	1740	0.78	7.09	71	1.51 ppm; 20.6 %	Very low; Fresh clean	WQ taken after 15min. Clear. 1L/s for 15mins.
Pump 3	18/05/2019	22	31.1	1730	0.77	7.13	64.2	1.68 ppm; 22.8 %	Very low; Fresh clean	WQ taken after 30min. Clear, 1L/s
COMMENT: DTW 7m. Shallow DTW, clean clear sample, with no limit to inflow suggests alluvial or highly transmissive fractured rock aquifer. Salinity/EC similar to MB15PAFL0002.										
MB16PAFL0001 (LFL)										
Bailer	17/05/2019	8	29.2	3291	1.58	8.39	77.8	1.34 ppm; 17.1 %	Very low; Stale	PVC bore
Pump 1	18/05/2019	26	30.3	3552	1.67	7.53	94.4	1.66 ppm; 20.9 %	Very low; Fresh clean	Clear. 1L/s, 15 min.
Pump 2	18/05/2019	26	30.6	3580	1.68	7.37	88.3	1.51 ppm; 20.3 %	Very low; Fresh clean	WQ taken after 15min. Clear. 1L/s for 15mins.
Pump 3	18/05/2019	26	30.5	3585	1.68	7.38	99.5	1.45 ppm; 19.6 %	Very low; Fresh clean	WQ taken after 30min. Clear, 1L/s
COMMENT: DTW 6m. Shallow DTW, clean clear sample, with no limit to inflow suggests alluvial or highly transmissive fractured rock aquifer. Salinity/ EC similar to MB16PAFL0003.										
MB16PAFL0003 (LFL)										
Bailer	17/05/2019	7	26.9	3090	1.57	7.61	121.1	1.46 ppm; 18.3 %	Very low; Fresh clean	PVC bore

Type	Date	Depth (m)	Temp. (°C)	EC (uS/cm)	Salinity (ppm)	Acidity (pH)	Redox (mV)	Dissolved Oxygen	Turbidity; Odour	Sampling notes
Pump 1	18/05/2019	21	28.1	3291	1.61	7.58	123.2	0.91 ppm; 11.6 %	Very low; Fresh clean	Clear. 1L/s, 15 min.
Pump 2	18/05/2019	21	27.9	3348	1.64	7.67	120	1.13 ppm; 14.6 %	Very low; Fresh clean	WQ taken after 15min. Clear. 1L/s for 15mins.
Pump 3	18/05/2019	21	27.9	3354	1.65	7.65	100.1	1.1 ppm; 14.1 %	Very low; Fresh clean	WQ taken after 30min. Clear, 1L/s
COMMENT: DTW 5m. Shallow DTW, clean clear sample, with no limit to inflow suggests alluvial or highly transmissive fractured rock aquifer. Salinity/EC similar to MB16PAFL0001.										
PMO3 (SBF)										
Bailer	15/05/2019		30.9	1904	0.86	8.78	70.9	226 ppm; 30.4 %	Very low; Stale	Rusty steel bore
Pump 1	18/05/2019	45	31.5	1803	0.8	7.6	85	0.99 ppm; 13.7 %	Very low; Mineral	Deep sample. Slight red sediment (clear after 1 min). Pumped at 1L/s for 15mins.
Pump 2	18/05/2019	45	31.7	1851	0.82	7.35	24.7	0.67 ppm; 9.2 %	Very low; Mineral	Deep sample. WQ taken after 15min. Clear. 1L/s for 15mins.
Pump 3	18/05/2019	25	31.9	1913	0.84	8.02	26.7	0.63 ppm; 8.7 %	High, Mineral	Shallower depth. Pump slowed, intermittent after 3min.
Pump 4	18/05/2019	25	31.8	1843	0.81	7.41	29.7	0.58 ppm; 79 %	Low; Fresh clean	Shallower depth. Pumping stopped for 10 mins to recharge. Pump slowed, intermittent after 4min.
COMMENT: DTW 16m. Moderate DTW, clean clear sample, bore stressed at moderate pumping rate, suggests fractured rock aquifer, limited inflow. Red sediments may be due to rust/ alluvium. Salinity/EC similar to PMP2.										
PMP2 (SBF)										
Bailer	15/05/2019	18	29.8	1851	0.85	7.62	127.1	1.99 ppm; 19.8 %	Very low; Stale	Fibreglass bore
Pump 1	19/05/2019	45	29.8	1841	0.84	7.71	139.2	0.88 ppm; 11.6 %	Very low; Fresh clean	Deep sample. Slight beige sediment. Pumped at 1L/s for 15mins.
Pump 2	19/05/2019	45	30	1852	0.85	7.64	117.6	0.62 ppm; 8.1 %	Low; Stale	Deep sample. WQ taken after 15mins.
Pump 3	19/05/2019	35	30	1849	0.84	7.56	93.9	1.07 ppm; 14 %	High; Fresh clean	Shallower. Pump slower, 0.7L/sec. Brown sediments after 7 min
Pump 4	19/05/2019	35	30.2	1857	0.84	7.5	107.8	0.66 ppm; 8.8 %	High; Stale	Shallower. Pump slower. WQ taken after15 min
COMMENT: DTW 16m. Pumping at shallow depth showed brown sediments, bore stressed at moderate pumping rate - suggests fractured rock aquifer or silty alluvials. Salinity/EC similar to PMO3.										
PMP4 (SBF)										
Bailer	15/05/2019		27.4	1381	0.65	8	160.1	6.09 ppm; 77.3 %	Very low; Fresh clean	Fibreglass bore
Pump 1	18/05/2019	45	28.3	1407	0.66	7.45	96.6	0.01 ppm; 0.1 %	Very low; Fresh clean	Deep sample. Clear. Pumped at 1L/s for 15mins.

Type	Date	Depth (m)	Temp. (°C)	EC (uS/cm)	Salinity (ppm)	Acidity (pH)	Redox (mV)	Dissolved Oxygen	Turbidity; Odour	Sampling notes
Pump 2	18/05/2019	45	28.3	1403	0.66	7.21	124.5	0.01 ppm; 0.1 %	Very low; Fresh clean	Deep sample. WQ taken after 15mins.
Pump 3	18/05/2019	20	28.3	1392	0.65	7.22	121.9	1.91 ppm; 24.5%	Very low; Fresh clean	Shallower. Clear. Pumped at 1L/s for 15mins.
Pump 4	18/05/2019	20	28.4	1404	0.66	7.25	125.4	0.01 ppm; 0.1 %	Very low; Fresh clean	Shallower. WQ taken after15 min
COMMENT: DTW 12m. Clean/ clear sample, no slowdown of pumping rate, suggests highly transmissive fractured/ weathered rock aquifer or alluvial aquifer. Salinity/EC lower than PMP2/ PMO3 – may be different groundwater.										
WB17NLC0001 (OPS)										
Bailer	16/05/2019		27.3	1815	0.87	7.66	10.7	0.87 ppm; 11 %		New steel bore
Pump 1	19/05/2019	45	28.1	1894	0.9	7.49	-4.5	0.69 ppm; 8.9 %	High; Fresh clean	Deep sample. Red/brown sediment. Pumped at 1L/s for 15mins.
Pump 2	19/05/2019	45	28.2	1891	0.89	7.49	5.2	0.6 ppm; 7.7 %	High; Fresh clean	Deep sample. WQ taken after 15mins.
Pump 3	19/05/2019	35	28.4	1927	0.91	7.33	-35.6	0.51 ppm; 6.6 %	Very high; Mineral	Shallower sample. Red/brown sediment. Pumped at 1L/s for 5mins.
COMMENT: DTW 25m. Moderate DTW, red sediments, no change in pumping rate, suggests highly transmissive fractured rock aquifer/ alluvial aquifer. Red sediments may be due to rust/ alluvium. Salinity/EC much lower than WB18NLC0001 – different groundwater.										
WB18NLC0001 (OPS)										
Bailer	16/05/2019	30	25.9	2998	1.53	7.61	72.3	2.01 ppm; 25 %	Very low; Fresh clean	New steel bore
Pump 1	19/05/2019	45	26.2	3012	1.52	7.39	30.9	0.82 ppm; 10.1 %	Medium; Fresh clean	Deep sample. Red/brown sediment. Pumped at 1L/s for 15mins.
Pump 2	19/05/2019	45	26.2	3010	1.52	1.52	47.6	0.01 ppm; 0.1 %	Medium; Fresh clean	Deep sample. WQ taken after 15mins.
Pump 3	19/05/2019	35	26.3	3013	1.53	7.39	-27.7	0.61 ppm; 7.7 %	Very high; Mineral	Shallower sample. Red/brown sediment. Pumped at 1L/s for 15mins.
Pump 4	19/05/2019	35	26.4	3015	1.52	7.35	-1.6	0.6 ppm; 7.5 %	High; Fresh clean	Shallower. WQ taken after15 min
COMMENT: DTW 28m. Moderate DTW, red sediments, no change in pumping rate, suggests highly transmissive fractured rock aquifer/ alluvial aquifer. Red sediments may be due to rust/ alluvium. Salinity/EC much higher than WB17NLC0001 – different groundwater.										

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