Rio Tinto

Brockman Syncline EIA Studies

Hazard Analysis and Risk Assessment for Dewatering Discharge to Boolgeeda Creek and Duck Creek

WRM
Wetland Research & Management

9 June 2020

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Frontispiece: Upper Duck Creek site DCU2, downstream of discharge outlet, October 2019.

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EXECUTIVE SUMMARY

Overview

This hazard analysis (HA) and aquatic ecosystem risk assessment relates to surplus dewatering discharge from the proposed Rio Tinto Iron Ore (RTIO) Brockman Syncline Iron Ore Project (the Proposal). The purpose of the HA is to identify analytes (parameters) in surplus discharge water that may pose a risk to aquatic ecosystems in downstream receiving environments of Boolgeeda Creek and/or Duck Creek.

The most recent site water balance indicates that the current approved surplus water discharge regimes to Boolgeeda Creek and Duck Creek will not need to change to support the Proposal. However, investigations are still in progress and these may indicate changes to the surplus water discharge regimes may be required.

As a preliminary risk assessment is required at an early stage of the Proposal, the HA uses available groundwater data for the Brockman Iron Formation (Sep. 2018 - Jun. 2019) and Marra Mamba Aquifer (Jun. 2016 - Mar. 2019) as indicative of dewater discharge quality. The HA compares the groundwater data from monitoring bores for the Proposal against site specific guideline values (SSGVs) previously developed for the Brockman 4 and Nammuldi-Silvergrass mines. The HA also takes into consideration historic and existing surface water quality data for Boolgeeda Creek and Duck Creek. In accordance with the National Water Quality Management Framework (ANZG 2018), water quality (physical and chemical stressors and toxicants) and several aquatic fauna receptors (hyporheic invertebrates, benthic macroinvertebrates and fish) are currently used to characterise and monitor ecosystem health. Zooplankton were also included in baseline surveys.

Potential Contaminants of Concern

The ecological values of creeklines within the development envelope and/or maximum predicted discharge extents were identified from annual aquatic ecosystem surveys conducted by WRM between November 2009 and November 2019.

It was concluded that dewatering discharge presents the following risks to aquatic fauna:

1. Moderate-high risk of habitat loss from,
    a. eutrophication due to nitrate and phosphorus enrichment, and
    b. sedimentation due to elevated TSS;
2. Low-moderate risk of habitat loss due to calcite precipitation;
3. Low-moderate risk of direct toxicity from nitrate and dissolved barium enrichment.

There is moderate certainty in the risk ratings for nitrate in groundwater, as although baseline groundwater data for the Proposal are limited to only 4 samples from WB16BSB0002 in the Marra Mamba Aquifer, the experience at existing below water table (BWT) mines Nammuldi-Silvergrass, Brockman 4 and Western Turner Syncline, is that groundwaters throughout the area are generally enriched in nitrate, relative to surface waters.

There is moderate certainty in the risk ratings for calcite precipitation, again based on experience at existing BWT mines Nammuldi-Silvergrass, Brockman 4 and Western Turner Syncline, where no significant calcite precipitation has been observed. However, because the final volumes to be discharged are yet to be confirmed, a low-moderate risk rating was assigned, rather than low or negligible risk.

There is low certainty in the risk rating for dissolved barium due to the limited baseline data for each bore and the variation in concentrations between bores, as well as the paucity of research on toxicity of dissolved barium to aquatic biota.

Based on long term monitoring at existing RTIO Pilbara BWT mines, and known local and regional species distributions, the consequences of the risks identified for the Proposal are expected to be localised to the discharge footprint and depend on the presence of receptors within this footprint:

- No change in conservation status of IUCN vulnerable species; copepod *Eodiaptomus lumholtzi*, Pilbara pin damselfly *Eurysticta coolawanyah*, and Pilbara emerald dragonfly (*Hemicordulia koomina*);
- No change in conservation status of the IUCN endangered fish species, Fortescue grunter *Leiopotherapon unicolor*;
- No change in conservation status of potential and likely short range endemics (SREs):
    - copepod cf. *Areacandona* sp.,
    - amphipods *Chydaekata* sp., *Maarka* sp., *Nedsia* sp., indeterminate juvenile Paramelitidae and Melitidae, and
    - isopods *Pygolabis* sp. and indeterminate juvenile Bathynellidae and Syncarida;
- Short-term loss of, or population reduction in, 10 - 20% of aquatic fauna (invertebrates and fish) from nitrate toxicity;
- Long-term loss of up to 70% of benthic and hyporheic invertebrate species in sections of the channel that become heavily armoured by calcite precipitation (noting that calcite precipitation has not occurred under the current discharge regime for Nammuldi-Silvergrass);
- Short-term shifts in benthic invertebrate and zooplankton species assemblage composition due to altered flow regime, *i.e.* still water (lentic) species replaced by flowing-water (lotic) species;
- Short-term increase in abundance of native fish, and some hyporheic (*e.g.* stygal amphipods) and benthic invertebrate species due to increased spatial extent of surface water and sub-surface flow.

The majority of aquatic fauna and (by association) aquatic ecosystem functioning is considered to be at low risk from increased magnitude or frequency of flow as this is expected to benefit the majority of species, by increasing the 'carrying capacity' of the naturally ephemeral creeks. Other than bed-armouring (considered to be of low-moderate risk), any responses to changes in water quality are also anticipated to be short-term, with fauna populations returning to 'baseline' condition on cessation of dewatering of surplus water discharge.

There is low risk that biodiversity or genetic diversity would be permanently reduced or lost at the local or regional level as a result of the Proposal. This is assuming no significant fragmentation of habitat by cumulative effects of groundwater drawdown for the Proposal and the proposed Fortescue Metals Group (FMG) Flying Fish and Eliwana mines immediately to the west. Due to the taxonomic uncertainty for stygal amphipods and isopods present in the hyporheos, it is not possible to determine species distributions at the regional scale and hence conservation status. While the genera and families are known from hyporheos and groundwater bores elsewhere in the Pilbara, genetic analysis is needed to confirm species taxonomy.

1. INTRODUCTION

1.1 Background

Rio Tinto Iron Ore (RTIO), on behalf of Hamersley Iron Pty Ltd, is proposing the development of the Brockman Syncline project (the Proposal). The Proposal is located approximately 60 km west-north west of Tom Price, in the upper Ashburton River catchment in the central Pilbara region of Western Australia (Figure 1). The Proposal expands on three existing RTIO operations:

- Nammuldi-Silvergrass,
- Brockman 2, and
- Brockman 4.

The Proposal includes the development of new, above and below water table deposits. The Proposal also includes discharge of surplus water from dewatering to Boolgeeda Creek and Duck Creek (Figures 2 & 3). The most recent site water balance indicates that the current approved surplus water discharge regimes to Boolgeeda Creek and Duck Creek will not need to change to support the Proposal. However, investigations are still in progress and these may indicate changes to the surplus water discharge regimes may be required. Surplus water discharge has been occurring intermittently for the past four years from the Brockman 4 Project into Boolgeeda Creek, and for the past six years from the Nammuldi-Silvergrass Project into Duck Creek.

The Environmental Protection Authority (EPA) have stated that dewatering resulting in groundwater drawdown and the discharge of surplus water has the potential to impact the environmental factor *Inland Waters*, and requires detailed assessments to determine the extent of the Proposal's direct and indirect impacts, and how the environmental issues could be managed (EPA Extract of Determination 28 August 2019). As part of the Environmental Impact Assessment (EIA) process, preliminary key environmental factors must be identified and assessed, and these form the EPA's basis for the decision of whether a Proposal's environmental impact is considered acceptable (EPA 2013).

Despite recent updates to the EPA's environmental factor *Inland Waters* (EPA 2018), there are still no prescriptive guidance statements at the state level on surface and groundwater quality. In the absence of technical guidance, Australia's National Water Quality Management Strategy (WQMS) provides authoritative guidance (*i.e.* a framework) on the management of water quality in Australia and New Zealand (ANZG 2018). ANZG (2018) replaces the 2000 *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000).

To protect the community values of waterways (aquatic ecosystems and cultural and spiritual values), the WQMF applies a weight of evidence (WoE) process to collect, analyse and evaluate a combination of different qualitative, semi-quantitative or quantitative lines of evidence (LoE) to make an overall assessment of water quality and its associated management. Measuring indicators from multiple LoE across the pressure-stressor-ecosystem receptor (PSER) causal pathway gives greater weight (or certainty) to assessment conclusions, and subsequent management decisions to meet water quality objectives, than basing evaluation on a single line of evidence. Therefore, and in accordance with the WQMF (ANZG 2018) water quality (physical and chemical stressors and toxicants) and several aquatic fauna receptors (hyporheic invertebrates, benthic macroinvertebrates and fish) are currently used to characterise and monitor ecosystem health condition. Location of aquatic fauna monitoring sites is shown in Figure 3.

Other water related studies have been undertaken to inform the EIA for the Proposal:

- Hydrogeological conceptualisation modelling;
- Surplus water discharge extent assessments (Boolgeeda Creek and Duck Creek);

- Aquatic Ecological Values Desk-top Review (WRM 2019d);
- Baseline Aquatic Ecosystem Field Survey - Dry Season (October) 2019 (WRM IN PREP).

In addition to these studies, RTIO engaged WRM to investigate the hazard and risk posed to aquatic ecosystems by dewater discharge to surface waters. This document presents a hazard analysis (HA) and risk assessment for Duck Creek and Boolgeeda Creek downstream of dewatering discharge locations. The HA and risk assessment are specific to the quality of groundwater in dewater discharge to surface creeklines.

1.2 Purpose

The purpose of this report is to provide a better understanding of the ecological risks and hazards associated with the discharge of groundwater from the Proposal to ephemeral creeks. It updates the previous HAs and risk assessments by WRM for Nammuldi-Silvergrass dewater discharge to Duck Creek (WRM 2014c,d), and Brockman 4 dewater discharge to Boolgeeda Creek (WRM 2018a). These were conducted post-commencement of dewatering discharge, on the premise that final concentrations of individual analytes will be influenced not only by the hydro-geochemistry of the aquifer(s) of origin, but also by the hydro-geochemistry of the receiving creeklines. The HAs were based on comparison to site specific guidelines value (SSGVs[1]), pre- and post-discharge monitoring data for water quality and aquatic fauna, and review of groundwater data indicative of aquifers to be dewatered. The SSGVs for Duck Creek (WRM 2014d) and Boolgeeda Creek (WRM 2018a) are based on the 80th percentile (and 20th percentile for pH and dissolved oxygen) values for combined baseline and reference data for the creeks, and ANZECC/ARMCANZ (2000) default guidelines. Reference data from adjacent and similar regional creeks were included as there are limited baseline data. The SSGVs are provided in Appendix 1 and 2.

As a preliminary risk assessment is required at an early stage of the Proposal, the current HA uses groundwater data as indicative of dewater discharge quality. The HA compares the groundwater data against the SSGVs and takes into consideration historic and existing surface water quality data for Duck and Boolgeeda creeks.

As for previous HAs, the current HA should be viewed as a dynamic process, and progressively reviewed as mining operations develop, and/or as new ecological effects data (laboratory ecotoxicity or field ecological survey data) become available. For example, data from any future aquatic fauna monitoring for the Proposal, should be used to ground-truth and refine both the risk assessment and existing SSGVs. Multiple lines of evidence need to be employed to assess the ecological impacts.

1.3 Limitations

There are a number of limitations to this report:

1. This assessment targets dewatering discharge to Boolgeeda Creek and Duck Creek from the Proposal below water table (BWT) deposits, and does not consider hydrocarbons or other potential contaminants in leachate or run-off originating from on-site.
2. Modelling the rates of downstream transport of contaminants was beyond the scope of the current study, as was modelling rates of sorption on naturally-occurring particulates, deposition, accumulation and potential re-release into the water column.

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[1] Under the new ANZG (2018) guidelines, the ANZECC/ARMCANZ (2000) term default trigger value (TV), is replaced by default guideline value (DGV), and the term site-specific trigger value (SSTV) is replaced by site-specific guideline value (SSGV). The ANZG (2018) terminology has been adopted for the current report.

3. Risk characterisation focuses on the aquatic fauna of the downstream receiving environments of Boolgeeda Creek and Duck Creek, and does not include riparian vegetation or terrestrial biota.
4. Laboratory ecotoxicity studies of chronic versus acute effects of contaminants on local aquatic fauna were outside the scope of the current study. Potential toxicity effects have been evaluated based on generic information from published toxicity guidelines (*i.e.* ANZG 2018, USEPA 2019, CCME 2019, and references therein), and a recent laboratory ecotoxicological study for nitrate commissioned for another RTIO Pilbara site (van Dam 2019). The degree to which increased bioavailability leads to increased toxicity in these environments is also unknown, though again generalisations are made based on available literature.
5. The relationship between external concentration of water- or soil-borne contaminants and internal dose in local aquatic biota is unknown. Similarly, the extent of biomagnification through trophic levels in local food webs is unknown; *e.g.* the extent to which fish accumulate toxic levels of metals through ingestion of macroinvertebrates or plants with elevated tissue metal concentrations. Preliminary investigations by WRM indicate background levels of some metals are naturally elevated in some fish species, irrespective of water concentration, suggesting different pathways for accumulation, such as *via* sediment or through food webs (*i.e.* diet) (WRM 2014a, 2017b). To date no further research on tissue metal concentrations has been conducted for local species.

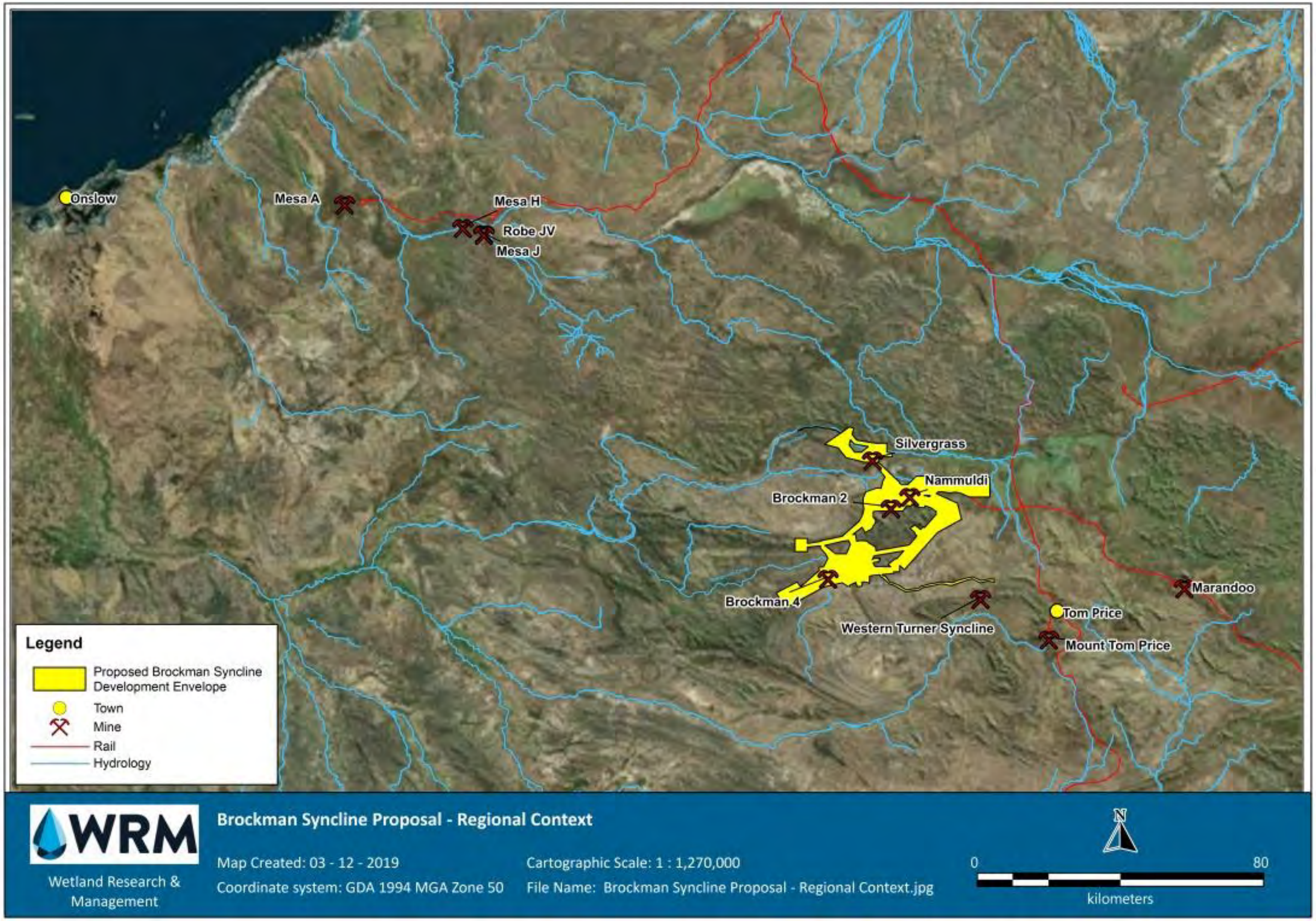

Figure 1. Brockman Syncline Proposal.

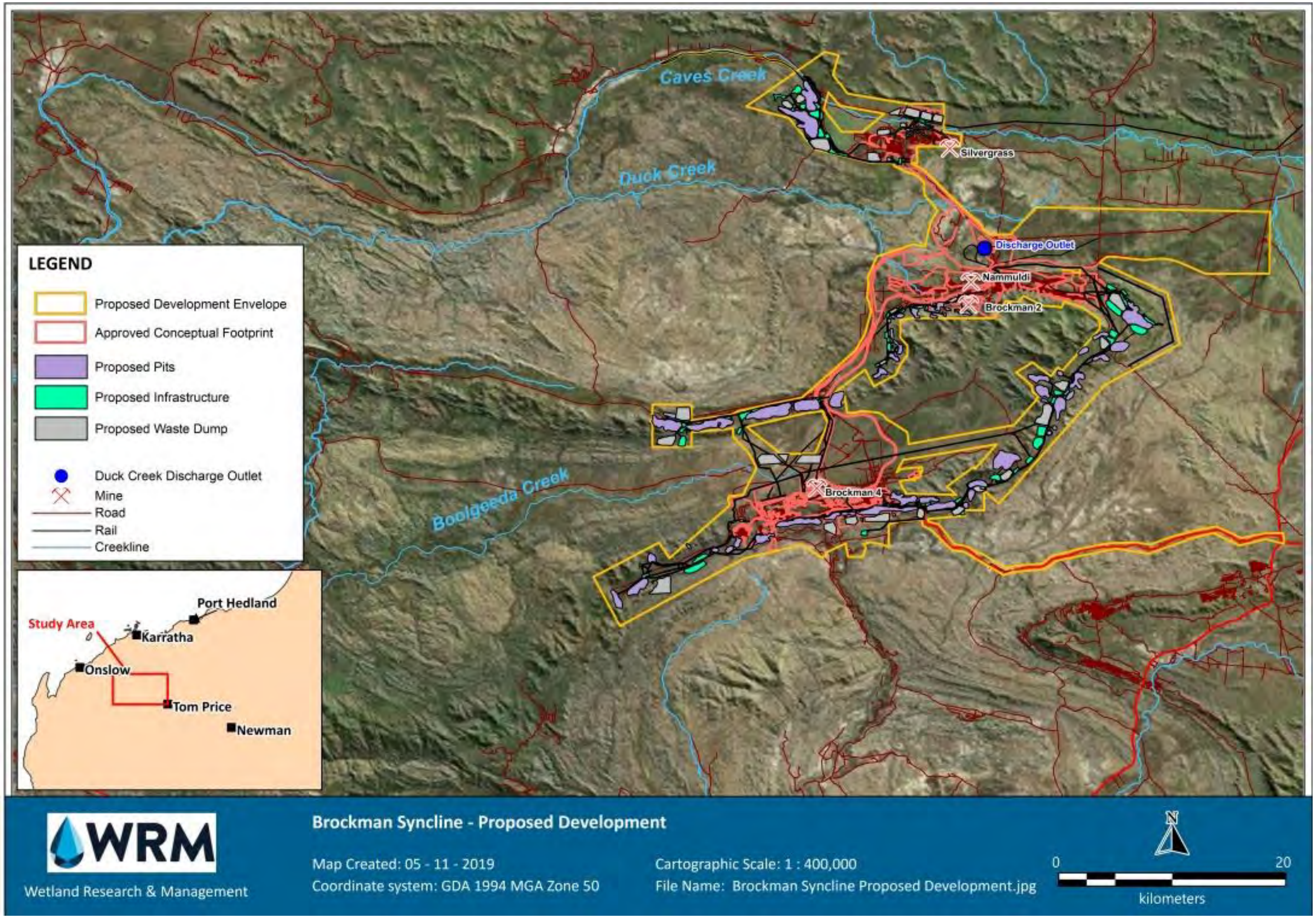

Figure 2. Brockman Syncline Development Envelope.

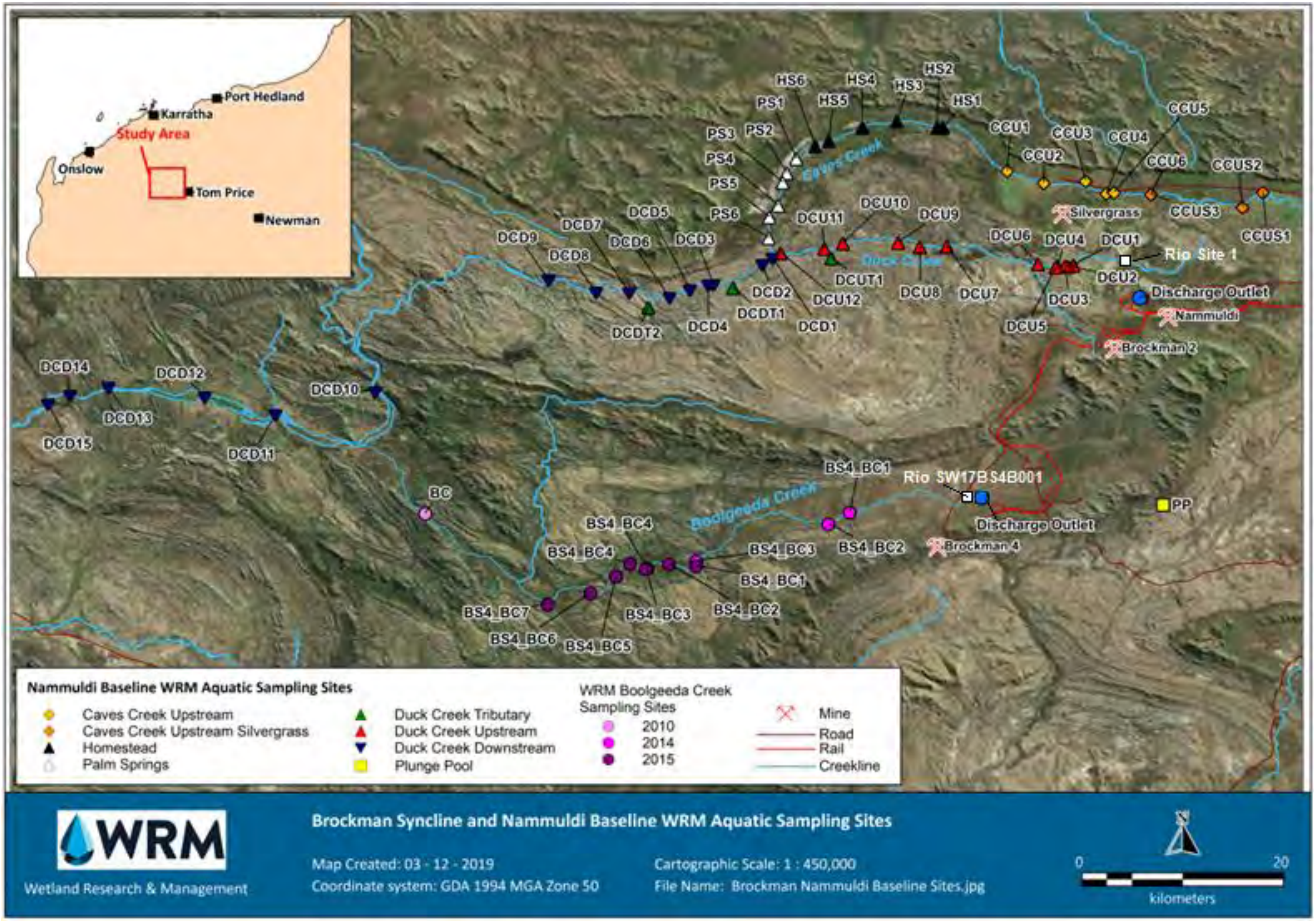

Figure 3. Aquatic ecosystem monitoring sites.

2. HAZARD IDENTIFICATION

2.1 Available Monitoring Data

2.1.1 Groundwater Quality

Groundwater in the Proposal area is highly compartmentalised, therefore, for the current report, available RTIO data for groundwater quality from the source aquifers were reviewed as a surrogate for discharge quality. This included data for 27 monitoring bores in the Brockman Iron Formation and seven bores in the Marra Mamba Aquifer were reviewed to determine what (if any) analytes elevated in groundwaters may be of concern if discharged to creeklines. All bores are at depths representative of the aquifers being dewatered/discharged. Bores and sampling dates are summarised in Table 1, and reviewed data provided in Appendix 3.

Groundwater data for other production and monitoring bores for Nammuldi-Silvergrass and Brockman 4 operations were reviewed for previous HAs and risk assessments. Results of these earlier assessments can be found in WRM (2014c,d) and WRM (2018a).

Table 1. Groundwater quality monitoring datasets.

Brockman Iron Formation			
Bore	**Sampling period**		**Total no. samples**
	Start	End	
MB11NAM001	16-02-2019	16-02-2019	1
MB12NAM017	16-02-2019	16-02-2019	1
MB12NAM018	16-02-2019	16-02-2019	1
MB12NAM019	16-02-2019	16-02-2019	1
MB15BS1E001	26-09-2018	09-06-2019	4
MB15BS1E002	26-09-2018	26-09-2018	2
MB17BS10001	26-09-2018	26-09-2018	2
MB17BS10002	27-09-2018	27-09-2018	2
MB17BS10003	27-09-2018	27-09-2018	2
MB17BS10004	27-09-2018	27-09-2018	2
MB17BS10005	26-09-2018	09-06-2019	5
MB17BS10006	26-09-2018	09-06-2019	5
MB17BS20002	15-02-2019	15-02-2019	1
MB17BS20003	16-02-2019	16-02-2019	1
MB17BS20004	16-02-2019	16-02-2019	1
MB17BS20005	15-02-2019	15-02-2019	1
MB17BS30001	27-09-2018	07-06-2019	5
MB17BS30005	27-09-2018	08-06-2019	5
MB17VIV0002	26-09-2018	26-09-2018	2
MB17VIV0003	26-09-2018	26-09-2018	2
MB17VIV0004	26-09-2018	26-09-2018	2
MB18BS30002	14-02-2019	07-06-2019	3
MB18BS30003	14-02-2019	07-06-2019	3
MB18BS4B0008	09-06-2019	09-06-2019	2
MB18BS4B0009	09-06-2019	09-06-2019	2
MB18BS4B0010	09-06-2019	09-06-2019	2
MB18BS4B0014	09-06-2019	09-06-2019	2

Marra Mamba Aquifer			
Bore	**Sampling period**		**Total no. samples**
	Start	End	
MB11NAM001	16-02-2019	16-02-2019	1
MB13SILV001	03-03-2019	03-03-2019	2
MB13SILV002	03-03-2019	03-03-2019	2
MB17NAM0001	15-02-2019	15-02-2019	1
MB18NAM0009	13-10-2018	15-10-2018	2
MB18NAM0010	14-10-2018	14-10-2018	1
WB16BS4B0002	27-06-2016	08-07-2018	4

2.1.2 Surface Water Quality

Available surface water quality datasets for creeklines and tributaries adjacent to (reference) and downstream (potential impact) of the current dewatering discharge points are summarised in Table 2. Raw data are provided in Appendix 3. Included are baseline and post-discharge data from WRM biannual sampling for Nammuldi-Silvergrass and Brockman 4, and RTIO monitoring data for creekline compliance sites on Duck Creek (Site 1) and Boolgeeda Creek (SW17BS4B001). Surface water sampling locations are shown in Figure 3.

Surface waters of Duck and Boolgeeda creeks downstream of the existing discharge outlets display similar seasonal water quality properties to each other, and to reference waterbodies in adjacent sub-catchments of upper Caves Creek, and the Beasley and Hardey rivers (WRM 2014d). Palm Springs sites (Figure 1) however, have considerably higher salinity, alkalinity and hardness values, compared to other waterbodies.

Table 2. Surface water quality monitoring datasets.

Creek	Site	*Baseline sampling period		Total no. samples	*Post-discharge sampling period		Total no. samples
		Start	End		Start	End	
Boolgeeda Ck	RTIO SW17BS4B001	--	--	0	May-2017	Aug-2017	4
	BS4-BC1	Apr-2014	Apr-2015	2	--	--	0
	BS4-BC2	Apr-2014	Apr-2015	2	--	--	0
	BS4-BC3	Apr-2014	Apr-2015	2	--	--	0
	BS4-BC4	Apr-2014	Apr-2015	2	--	--	0
	BS4-BC5	Apr-2015	Apr-2015	1	--	--	0
	BS4-BC6	Apr-2015	Apr-2015	1	--	--	0
	BS4-BC7	Apr-2015	Apr-2015	1	--	--	0
	BC	Oct-2010	Apr-2013	4	--	--	0
Duck Ck	RTIO Site 1	--	--	0	Oct-2013	May-2014	11
	DCU1	Apr-2011	Apr-2012	3	Apr-2014	Mar-2019	7
	DCU2	Apr-2011	Apr-2013	5	Mar-2015	Mar-2019	6
	DCU3	Apr-2011	Apr-2013	5	Apr-2016	Apr-2018	3
	DCU4	Nov-2009	Apr-2012	7	Mar-2015	Mar-2019	5
	DCU5	Nov-2009	Apr-2013	7	Apr-2016	Mar-2019	3
	DCU6	Nov-2009	Apr-2012	6	Apr-2014	Mar-2019	4
	DCU7	--	--	0	Apr-2014	Apr-2018	3
	DCU8	--	--	0	Apr-2014	Mar-2019	2
	DCU9	--	--	0	Apr-2014	Apr-2016	2
	DCU10	--	--	0	Apr-2014	Mar-2019	6
	DCU11	--	--	0	Apr-2014	Mar-2019	7
	DCU12	--	--	0	Apr-2014	Mar-2019	6
	DCD	--	--	0	Mar-2019	Mar-2019	1
	DCD1	Nov-2009	Apr-2012	6	Apr-2014	Mar-2019	6
	DCD2	Nov-2009	Apr-2012	5	Apr-2014	Apr-2018	5
	DCD3	Nov-2009	Apr-2012	6	Mar-2015	Apr-2018	4
	DCD4	Jun-2010	Nov-2012	6	--	--	0
	DCD5	Jun-2010	Nov-2012	6	Apr-2014	Mar-2019	2
	DCD6	Jun-2010	Nov-2012	6	Apr-2014	Apr-2014	1
	DCD7	Oct-2010	Apr-2013	6	Apr-2014	Mar-2019	6
	DCD8	Oct-2010	Apr-2013	6	Apr-2014	Apr-2014	1
	DCD9	Oct-2010	Apr-2013	6	Apr-2014	Mar-2015	2
	DCD10	Oct-2010	Apr-2013	5	Apr-2014	Mar-2015	2

Creek	Site	*Baseline sampling period		Total no. samples	*Post-discharge sampling period		Total no. samples
		Start	End		Start	End	
	DCD11	Oct-2010	Apr-2013	7	Apr-2014	Apr-2014	1
	DCD12	Oct-2010	Apr-2013	7	Apr-2014	Apr-2014	1
	DCD13	Apr-2011	Apr-2013	5	Apr-2014	Apr-2014	1
	DCD14	Apr-2011	Apr-2013	4	Apr-2014	Apr-2014	1
	DCD15	Apr-2011	Apr-2013	5	Apr-2014	Apr-2014	1
Duck Ck Trib.	DCUT1	Jun-2010	Nov-2012	6	Apr-2014	Mar-2019	5
	DCDT1	Apr-2010	Apr-2012	5	Apr-2014	Mar-2019	6
	DCDT2	Jun-2010	Nov-2012	6	Apr-2014	Mar-2019	6
Caves Ck	CCU1	Apr-2011	Apr-2012	2	--	--	0
	CCU2	Apr-2011	Apr-2013	3		--	0
	CCU3	Apr-2011	Apr-2013	3	--	--	0
	CCU4	Apr-2011	Apr-2013	3	--	--	0
	CCU5	Apr-2011	Apr-2011	1	--	--	0
	CCU6	Apr-2011	Apr-2013	3	--	--	0
	HS1	Nov-2009	Apr-2012	6	--	--	0
	HS2	Nov-2009	Apr-2012	6	--	--	0
	HS3	Nov-2009	Apr-2012	4	--	--	0
	HS4	Apr-2011	Apr-2012	2	--	--	0
	HS5	Nov-2009	Apr-2012	3	--	--	0
	HS6	Nov-2009	Apr-2012	6	--	--	0
Palm Springs	PS1	Nov-2009	Apr-2012	6	Mar-2019	Mar-2019	1
	PS2	Nov-2009	Apr-2012	5	Mar-2019	Mar-2019	1
	PS3	Nov-2009	Apr-2012	6	Apr-2014	Apr-2018	5
	PS4	Nov-2009	Apr-2012	6	Apr-2016	Apr-2018	3
	PS5	Nov-2009	Apr-2012	6	Apr-2014	Mar-2019	4
	PS6	Nov-2009	Apr-2012	6	Apr-2014	Mar-2017	4

*Not all sites were sampled in all years, dependent on antecedent rainfall and/or dewatering discharge volumes, some sites were dry, including RTIO compliance monitoring sites.

2.1.3 Aquatic Biota

Aquatic fauna and faunal habitats likely to be affected by changes in water quality and/or flow regime were identified from:

- published stress/toxicity thresholds for fauna (ANZG 2018, CCME 2019, USEPA 2019),
- recent ecotoxicity investigations for nitrate (van Dam 2019),
- known local and regional distributions determined from the Aquatic Ecological Values Desktop Review (WRM 2019d), and
- WRM biannual aquatic biota sampling for Brockman 4 and Nammuldi-Silvergrass, pre- and post-discharge.

Concurrent with water quality sampling (Table 2), WRM survey hyporheic[2] invertebrates, macroinvertebrates and fish, as part of aquatic ecosystem monitoring programs for the existing mines. Lower trophic orders, *i.e.* phytoplankton and zooplankton, are not currently monitored, but were included in the baseline surveys. Under current post-discharge monitoring programs, if an adverse response is

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[2] Hyporheic invertebrates – invertebrates restricted to the hyporheos or hyporheic zone which is the zone of saturated sediments adjacent to and beneath creeks and rivers where there is often intermixing of ground and surface.

detected in higher trophic levels (macroinvertebrates, fish), then targeted sampling for phytoplankton and zooplankton may be re-instigated in the future. Comparative analysis of all data using univariate (*e.g.* Spearman rank correlation, ANOVA) and multivariate (PRIMER/PERMANOVA) techniques is used to assess responses in fauna and water quality relative to baseline and in context of dewatering discharge. Results are submitted in WRM annual monitoring reports to Rio Tinto.

WRM have undertaken 14 rounds of aquatic baseline and post-discharge surveys (four dry season and ten wet season) of Caves, Duck and Boolgeeda creeklines over the past decade (since dry season 2009), and sampled Plunge Pool during the wet season (March) of 2019 (WRM 2019b). Other baseline surveys specific to the Proposal were conducted by WRM in October 2019 however, other than species lists for fish, processing of data is not yet complete. A final technical report will be provided to RTIO in April 2020.

2.2 Stressors and Toxicants of Potential Concern in Groundwater

Values for ground and surface water monitoring data that exceed SSGVs are highlighted in Appendix 3.

2.2.1 Brockman Iron Formation

Exceedances were recorded for the following groundwater analytes in the Brockman Iron Formation:

- stressors - conductivity (EC), pH, total dissolved solids (TDS), total phosphorus (P-total), total suspended solids (TSS), and
- toxicants - dissolved barium (Ba), boron (B), chromium (Cr), copper (Cu), and iron (Fe).

Exceedances for EC, pH, TDS, B, Cr, Cu and Fe were only slightly higher than SSGVs (or lower for pH), and still well within the baseline range for Duck Creek and reference range for Boolgeeda Creek, noting there are few baseline data for Boolgeeda Creek. It is therefore considered there is low risk to aquatic ecosystems as a result of dewater discharge water quality exceeding SSGVs for these analytes, at current reported levels for Brockman Iron Formation bores.

However, exceedances for P-total (all bores), TSS (all bores) and possibly Ba (MB17BS10002) were considered to pose moderate to high risk to aquatic ecosystems, based on the greater magnitude and frequency of exceedance of SSGVs and the baseline/reference ranges for the creeks.

There is only a single sample value for Ba concentration in MB17BS10002 (1.87 mg/L Ba, 27-09-2018). This value is almost 20x the SSGVs (0.09 mg/L, 0.1 mg/L), and at least one order of magnitude greater than concentrations recorded for all other bores in both the Brockman Iron Formation (range 0.009 - 0.185 mg/L) and Marra Mamba Aquifer (range 0.021 - 0.078 mg/L). As such, the value for Ba in MB17BS10002 may be anomalous, but further sampling is required to confirm this.

Relatively high P-total concentrations were recorded for 14 of the 27 bores. The median value for combined data (0.03 mg/L P-total) was higher than the SSGV for the creeks (0.02 mg/L), while the maximum (1.43 mg/L) was ~70x higher.

TSS values were very high for 22 bores (median 96 mg/L, max 10,200 mg/L), compared with both the SSGV for baseflow in the creeks (5 mg/L) and with the reference maximum (91 mg/L), noting there are no baseline data for the creeks.

No monitoring data were available for nitrogen concentrations in the Brockman Iron Formation, and limits of reporting (LORs) for dissolved selenium (Se), silver (Ag) and vanadium (V) were too high to compare against SSGVs or ANZG (2018) DGVs. Given nitrate concentrations in groundwaters across the region are known to be naturally higher than in surface waters, it is probable that nitrate in groundwater in the Brockman Iron Formation exceeds concentrations in surface waters of Duck and Boolgeeda Creek (WRM 2014b,c,d, 2016a,b, 2018, 2019c, 2020).

Potential indicators of calcite precipitation (pH, alkalinity, EC, TDS, Ca, HCO_3, SiO_2) were mostly well within the baseline/reference range for the creeks. The exception was silica (total SiO_2) for which there are no data for groundwaters. The Langelier Saturation Index (LSI) was also used as an approximate indicator of calcium carbonate saturation in groundwater. As temperature data were not available, temperature was assumed equivalent to median of reference data for the creeks (*i.e*. 26°C). Calculated LSI values ranged from -2.7 to 1.0 (median 0.2), indicating groundwater is mostly under- to slightly over-saturated in calcium carbonate (Appendix 3). This suggests discharge of groundwater poses low to moderate risk of calcite precipitation if discharged to the creeks.

2.2.2 Marra Mamba Aquifer

Exceedances were recorded for the following groundwater analytes in the Marra Mamba Aquifer:

- stressors – P-total, TSS, and
- toxicants – nitrate ($N\text{-}NO_3$), and dissolved B, Fe, and nickel (Ni).

Exceedances for P-total, B, Fe and Ni, were only slightly higher than SSGVs and still well within the baseline range for Duck Creek and reference range for Boolgeeda Creek (Appendix 3). Therefore, it is considered there is low risk to aquatic ecosystems as a result of dewater discharge water quality exceeding SSGVs for these analytes, at current reported levels for Marra Mamba bores.

Exceedances for nitrogen (WB16BS4B0002) and TSS (MB17NAM0001, MB17NAM0009 MB17NAM0010) were considered to pose moderate-high risk to aquatic ecosystems, based on the greater magnitude and frequency of exceedance of SSGVs and baseline/reference ranges for the creeks.

Nitrogen (as $N\text{-}NO_3$, $N\text{-}NO_X$, N-total) data are only available for WB16BS4B0002. There are no nitrogen data for other bores. In all four samples for WB16BS4B0002, nitrate was the dominant form of nitrogen present, with a range in values of 1.59 - 3.64 $N\text{-}NO_3$ (7.0 - 16.1 mg/L NO_3)[3]. Nitrate concentrations were up to 6x the eutrophication SSGV and 1.4x the toxicity SSGV for the creeks (Appendix 1).

TSS data are only available for four of bores, with high values recorded for three; MB17NAM0001 (36 mg/L), MB17NAM0009 (540 mg/L) and MB17NAM0010 (30 mg/L). These concentrations are considerably higher the SSGV (5 mg/L), again noting there are no baseline data for the creeks.

LORs for Se, Ag and V were too high to compare against SSGVs or ANZG (2018) DGVs.

Potential indicators of calcite precipitation (pH, alkalinity, EC, TDS, Ca, HCO_3, SiO_2) were mostly well within the baseline/reference range for the creeks. The exception was silica (total SiO_2) which was elevated in WB16BS4B0002. Elevated concentrations were approximately 2x - 3x the SSGV for total SiO_2 (27 mg/L), however the SSGV is based on limited reference data ($n = 8$) and may not represent the typical concentrations in surface waters. Calculated LSI values ranged from -0.3 to 0.8 (median 0.7), indicating groundwater is generally slightly over-saturated in calcium carbonate (Appendix 3). This suggests groundwater from the Marra Mamba Aquifer poses low to moderate risk of calcite precipitation if discharged to the creeks.

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[3] To convert $N\text{-}NO_3$ (mg/L) to NO_3 (mg/L), multiply the value for $N\text{-}NO_3$ by 4.43.

3. AQUATIC ECOSYSTEM RECEPTORS

3.1 Wetland Habitats

3.1.1 Boolgeeda Creek

Boolgeeda Creek is a highly ephemeral system that flows westward from the Proposal for approximately 74 km before joining Duck Creek. Based on field observation, surface water expression generally persists for days to weeks following rainfall events. Only one deep longer-term (semi-permanent) pool is known from Boolgeeda Creek (site BC), located approximately 9.6 km upstream of the confluence with Duck Creek (Figure 4). While this pool persists over the dry season during wetter years, it dries completely during drought years (see WRM 2019d). When inundated, the ephemeral pools on Boolgeeda Creek support relatively high diversity of aquatic invertebrate species, compared to the semi-permanent pool at BC, and compared to ephemeral and semi-permanent/permanent pools on Duck Creek and many other Pilbara systems monitored by WRM (*i.e*. Caves, Coondiner, Kalgan, Weeli Wolli and Marillana creeks, and the Beasley, Hardy and upper Fortescue rivers) (see WRM 2015, 2016b, 2019a). Most of these species are common and widespread throughout the Pilbara. Fewer taxa of conservation and/or scientific interest are known from surface waters and hyporheic zone of Boolgeeda Creek, compared to Duck Creek, likely because of the shorter hydroperiod of Boolgeeda Creek (sections 3.2 and 3.3). The number of fish species that frequent the ephemeral pools (3 species) is also low compared to BC (7 species) and semi-permanent/permanent pools on Duck Creek (8 species), but comparable to other ephemeral pools in the Pilbara (WRM 2015, 2016b, 2019a).

3.1.2 Duck Creek

Several suspected semi-permanent to permanent clear river pools persist along Duck Creek and in at least one of the unnamed tributaries (Figure 4). These pools are situated on bedrock structures that impede groundwater flow, or against cliffs where high-flow events have scoured deep pools (Pinder *et al.* 2010). The pools are known to persist (albeit reduced) during drought periods (WRM 2019d). Ephemeral pools also form along Duck Creek following significant wet season rainfall, establishing connectivity between the more persistent waterholes and aiding dispersal of epigean and hyporheic species throughout the system.

The ephemeral pools on Duck Creek support similar diversity of zooplankton, macroinvertebrate and fish species to the semi-permanent/permanent pools on Duck Creek, and to nearby Caves Creek, Beasley River and upper Ashburton River (see WRM 2015, 2016b, 2019a). Most taxa of conservation and/or scientific interest recorded from the semi-permanent/permanent pools on Duck Creek, are also known from the ephemeral pools (see section 3.2 and 3.3, and Table 3). The more permanent pools support refugia for a greater diversity of fauna during dry periods, which are then able to colonise the ephemeral waterbodies following inundation events.

3.2 Aquatic Invertebrates

More than 200 zooplankton species, 80 hyporheic species, and 300 macroinvertebrate species have been recorded from within, and adjacent to, the Proposal during WRM aquatic ecosystem surveys from November 2009 to November 2019. This includes:

- Three conservation listed species:
    - Pilbara pin damselfly *Eurysticta coolawanyah* (**IUCN Vulnerable**);
    - Pilbara emerald dragonfly *Hemicordulia koomina* (**IUCN Vulnerable**);

  - calanoid copepod *Eodiaptomus lumholtzi* (**IUCN Vulnerable**);
- Eight stygal taxa of conservation interest, being potential short-range endemics (SREs):
  - amphipods *Chydaekata* sp., *Maarka* sp., *Nedsia* sp., Melitidae sp., and isopod *Pygolabis* sp. that are likely SREs;
  - indeterminate Paramelitidae amphipod and Syncarida specimens that are potential SREs;
  - the ostracod cf. *Areacandona* sp. (juvenile specimen) that is a potential SRE;
- Five zooplankton species (rotifers) potentially new to science (Table 3).

Distributions of taxa of conservation and/or scientific interest are summarised in Table 3. All taxa collected from within the development envelope and/or predicted dewatering discharge extent are also known to occur, or are likely to occur, at locations outside the Proposal area.

The IUCN conservation listings for the damselfly *E. coolawanyah* and dragonfly *H. koomina* have only recently been upgraded from Near Threatened to Vulnerable (Dow 2019a,b), because the perceived 'risk of extinction' has increased as a result of continuing habitat loss due to dams, water abstraction and severe weather associated with climate change. Both species have been recorded from numerous ephemeral and semi-permanent pools along Duck Creek and Boolgeeda Creek, and are known to occur widely across the Pilbara (Table 3).

The IUCN listing for the copepod *E. lumholtzi* is based on a 1996 assessment and is in need of updating (IUCN 2019). This species is now known to occur in ephemeral and permanent pools at numerous locations across the Pilbara, including sites along Duck Creek, Caves Creek, Mindy Mindy Creek, Coondiner Creek, Kalgan Creek, Weeli Wolli Creek, Koodaideri Springs, Fortescue River and the Cane River, as well as Papua New Guinea (WRM unpub. data).

Some stygal specimens could not be positively identified to lower taxonomic level owing either to inadvertent damage during field collection, or immature life stage, *i.e.* Paramelitidae, Melitidae, Syncarida, and the ostracod cf. *Areacandona* sp. Others require genetic analysis to determine taxonomic affinities with congeners known from nearby and regional locations, and confirm short-range endemism, *i.e*. *Chydaekata* sp., *Maarka* sp., *Nedsia* sp., *Pygolabis* sp., and Bathynellidae sp. Morphological differentiation amongst species is difficult, and it is possible geographical distribution has a large influence on endemicity, dependent on aquifer connectivity.

The rotifer species that are potentially new to science belong to known genera with Australia-wide or world-wide distributions (*Hexarthra* sp. A n. sp., *Lecane* ?*eylesii*, *Eosphora* nr *najas* n. sp., *Proales* n. sp., cf. *Resticula* n. sp.). The fact they have only recently been discovered is probably due to the paucity of historical surveys for Australian freshwater zooplankton, rather than restricted distributions. Four are known to occur outside the development envelope and outside the predicted discharge extent (Table 3). Two of these are known only from ephemeral pools on Duck Creek, though it is probable both species have a broader distribution (Dr R. Shiel, University of Adelaide, pers. comm.): *Eosphora* nr *najas* n. sp. (DCD10, DCD14, DCUT1) and *Proales* n. sp. (DCD10). *Proales* n. sp. is the only species currently only known only from one location within the predicted discharge zone.

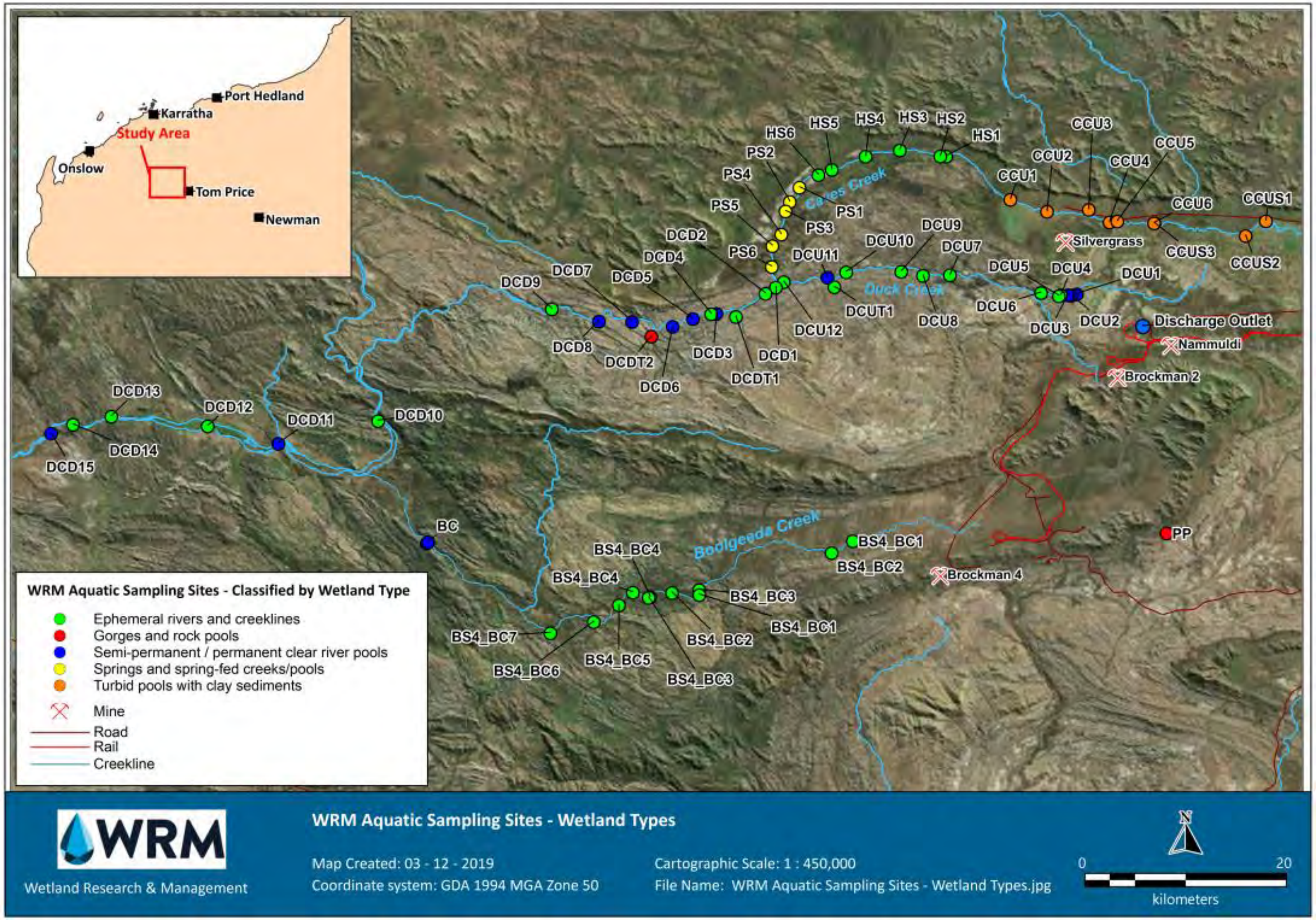

Figure 4. Wetland types within the vicinity of the Proposal (from WRM 2019d).

Table 3. Significant aquatic fauna species recorded from the Proposal area.

Species	**Distribution within the maximum predicted dewatering discharge extent**	**Distribution outside of discharge extent and elsewhere**	**Significance**	**Conservation listed**
ZOOPLANKTON				
ROTIFERA				
Hexarthra sp. A n. sp.	Duck Creek - DCU1, DCU3 to 6	Duck Creek reference tributary (DCUT1). Llikely occurs elsewhere.	Potentially new species.	No
Lecane ?eylesii	None known	Caves Creek (HS4). Likely occurs elsewhere.	New record for Australia. Morphologically different.	No
Eosphora nr *najas* n. sp.	Duck Creek - DCD10	Duck Creek reference tributary (DCUT1), and downstream of maximum predicted discharge extent (DCD14). Likely occurs elsewhere.	Potentially new species.	No
Proales n. sp.	Duck Creek - DCD10	None known but likely occurs elsewhere.	Potentially new species.	No
cf. *Resticula* n. sp.	Duck Creek - DCD3	Caves Creek (HS3, HS5). Likely occurs elsewhere.	Potentially new species.	No
COPEPODA				
Eodiaptomus lumholtzi	Duck Creek - DCU3, DCU6, DCD4 to 10, DCD11.	Duck Creek reference tributary (DCDT1), and downstream of maximum predicted discharge extent (DCD12, DCD15); Caves Creek (CCU1 to 5, HS5 to 6); Coondiner, Kalgan, Mindy Mindy, Weeli Wolli, and Koodaideri Spring creeks, Cane River and Papua New Guinea (WRM unpub. dat.), also two localities in Lake Woods, Northern Territory; and in Collinson's, Ayr and Saltern lagoons, Valley of Lagoons, west of Ingham, Qld (IUCN 2019).	Based on 1996 assessment that the species is rarely recorded and no longer occurs in type locality (IUCN 2019). Listing is need of updating.	**IUCN** **Vulnerable**
STYGAL CRUSTACEA				
OSTRACODA				
cf. *Areacandona* sp. [juvenile]	None known	Duck Creek reference tributary (DCDT1), Palm Springs, Robe River, Weeli Wolli Creek and Marillana Creek catchments. Many species confined to single localities associated with one or two surface sub-catchments of tributaries flowing into major rivers.	Potential SRE	No
AMPHIPODA				
Chydaekata sp. (Paramelitidae)	None known	Palm Springs (PS3, PS4, PS6). Likely occurs elsewhere. Genetic analysis required to confirm species-level identification. Genus known from Marillana, Weeli Wolli, Mindy Mindy and Kalgan Creeks, with distinct lineages in separate catchments (see Finston *et al.* 2007, 2008).	Likely SRE	No

Species	Distribution within the maximum predicted dewatering discharge extent	Distribution outside of discharge extent and elsewhere	Significance	Conservation listed
Maarka sp. (Paramelitidae)	Duck Creek - DCD11	Uncertain but likely occurs elsewhere. Genetic analysis required to confirm species-level identification. Recently described genus known only from upper Fortescue River catchment (Ethel Creek, Roy Hill, Weeli Wolli Creek, Marillana Creek, Coondewanna, Iron Valley) (Finston *et al.* 2011).	Likely SRE	No
Paramelitidae spp.	Duck Creek - DCU1, DCU3 to 6, DCDU8, DCD2 to 8, DCD11	Duck Creek (DCD12 to 13); Caves Creek (HS2); Palm Springs (PS1 to 6); Beasley River (BR1). Elsewhere uncertain. Genetic analysis required to confirm species-level identification. Possibly belongs to genus *Pilbarus* known from Caves Creek (Biota 2010a, Finston *et al*. 2011) and FMG Eliwana bores (Biologic 2007). Paramelitid amphipods occur widely, but individual species may have restricted distributions.	Potential SRE	No
Nedsia sp. (Eriopisidae)	Duck Creek - DCD8, DCD11	Duck Creek (DCD 12 to 13); Palm Springs (PS4); Beasley River (BR1). Elsewhere uncertain. Genetic analysis required to confirm species-level identification. Genus known from Nammuldi and Silvergrass reference bores, bores at Homestead and Caves Creek, Palm Springs, FMG Eliwana bores Bungaroo Ck, Robe River, Cape Range, and Barrow Island catchments. *Nedsia* species appear to show high degree of short-range endemism (see Biota 2006, 2010a,b, 2019, Bennelongia 2013).	Likely SRE	No
Melitidae sp.	Duck Creek - DCD4 to 10, DCD11; Boolgeeda Creek - BC	Duck Creek - downstream of maximum predicted discharge extent (DCD14), Palm Springs. Elsewhere uncertain. Taxonomy poorly understood. Genetic analysis required to confirm species-level identification (Halse *et al.* 2014).	Likely SRE	No
ISOPODA				
Pygolabis sp. (Tainisopidae)	Duck Creek - DCD11; Boolgeeda Creek - BC	Uncertain. Species identification not possible due to damage or immaturity of specimens, but species of *Pygolabis* tend to be restricted to individual creeklines in Fortescue, Ashburton or Robe catchments (Finston *et al.* 2009). Genus known from Homestead and Silvergrass West bores (Biota 2010a).	Likely SRE	No
SYNCARIDA				
Syncarida sp. (including Bathynellidae sp.)	Duck Creek - DCU4, DCU6, DCU10, DCD11; Boolgeeda Creek - BS4_BC1, BC3, BC5, BC7	Duck Creek - downstream of maximum predicted discharge extent (DCD12). Elsewhere uncertain. Genetic analysis required to confirm species-level identification. Syncarida occur widely, but species may have restricted distributions (Bennelongia 2014, WRM 2017a)	Potential SRE	No
INSECTA				

Species	Distribution within the maximum predicted dewatering discharge extent	Distribution outside of discharge extent and elsewhere	Significance	Conservation listed
Eurysticta coolawanyah (Pilbara pin damselfly)	Duck Creek - DCU1 to 12, DCD1 to 9, DCD11; Boolgeeda Creek - BS4_BC1, BC3	Duck Creek (DCD12, DCD15) and reference tributaries (DCDT1, DCDT2, DCUT1); Caves Creek (HS1 to 6); Palm Springs. Pilbara endemic known from multiple locations across the Pilbara (*e.g*. Beasley River, Coondiner Creek, Mindy Mindy, Kalgan, Marillana and Weeli Wolli creeks, Hamersley Gorge, Fortescue Falls, Millstream, Skull Springs, Bamboo Springs, Nyeetbury Spring, Robe River) (Pinder *et al*. 2010, WM unpub. dat.). Maximum known distribution extent is 7,937 km^2.	Vulnerable because of continuing decline in area, extent and/or quality of habitat due to dams and water abstraction (DOW 2019).	**IUCN** **Vulnerable**
Hemicordulia koomina (Pilbara emerald dragonfly)	Duck Creek - DCU2, DCU10 to 12, DCD1 to 10, DCD11; Boolgeeda Creek - BS4_BC1	Duck Creek (DCD13); Caves Creek (CCU4, HS1 to 5); Palm Springs (PS1). Pilbara endemic; known from multiple locations across the Pilbara (*e.g.* Beasley River, Hardy River, Coondiner, Mindy Creek, Kalgan, Mungarathoona, Marillana and Weeli Wolli creeks, Hamersley Gorge, Fortescue Falls, Millstream, Nanutarra Pools, Skull Springs, Bamboo Springs, Nyeetbury Spring) (Pinder *et al*. 2010, WM unpub. dat.). Maximum known distribution extent is 6,504 km^2.	Vulnerable because of continuing decline in area, extent and/or quality of habitat due to dams and water abstraction (DOW 2019).	**IUCN** **Vulnerable**
VERTEBRATA - FISH				
Leiopotherapon aheneus (Fortescue grunter)	Duck Creek – numerous ephemeral and semi-permanent/permanent pools; Boolgeeda Creek – BC and numerous ephemeral pools	Duck Creek – downstream of predicted discharge extent; widespread in Caves Creek, Palm Springs, and Ashburton, Fortescue (below Fortescue March) and Robe River catchments. Maximum estimated extent of occurrence is 37,155 km^2.	Threatened by habitat loss due to overgrazing, water abstraction, and introduced species (Morgan 2019)	**IUCN Endangered;** **Parks and Wildlife Priority 4**

3.3 Fish

During most recent sampling within the proposed dewatering discharge extent, 2,269 fish were captured from Duck Creek (October 2019), and 820 fish were captured from Boolgeeda Creek (April 2014 and April 2015). Fish diversity and abundance in Duck Creek, and in the semi-permanent pool (BC) on Boolgeeda Creek, is high compared to other ephemeral and seasonal Pilbara systems. Eight[4] of the thirteen freshwater fish species known from the Pilbara have been recorded from the Proposal area during WRM surveys from November 2009 to November 2019. These species include:

- Fortescue grunter *Leiopotherapon aheneus* (**IUCN Endangered**),
- spangled perch *Leiopotherapon unicolor*,
- Pilbara tandan (eel-tailed catfish) *Neosilurus* sp. (possibly an undescribed species),
- western rainbowfish *Melanotaenia australis*,
- barred grunter *Amniataba percoides*,
- bony bream *Nematalosa erebi*,
- flathead goby *Glossogobius giurus*, and
- lesser salmon catfish *Neoarius graeffei.*

Seven of the eight freshwater fish species are widespread throughout the ephemeral and semi-permanent/permanent pools on Duck Creek, and occur in the semi-permanent pool, BC, on Boolgeeda Creek. The exception is the lesser salmon catfish, which has only previously been recorded in pools downstream of the Duck Creek confluence with Caves Creek. Adult specimens of the salmon-tail catfish (*N. graeffei*) have been recorded from large, deep pools predominantly at DCD11, but also at DCD7, DCD8 and DCD15, suggesting these pools are indeed semi-permanent to permanent water holes which hold water for extended periods of time. Only four of the eight species are known to frequent the ephemeral pools along Boolgeeda Creek; western rainbowfish, spangled perch, Pilbara tandan and Fortescue Grunter. Shallow water depth, short hydroperiod and limited surface flow connection between these ephemeral pools are likely the main factors restricting colonisation by other fish species.

The Fortescue grunter is the only species listed for conservation significance. The listing has recently been upgraded to '**Endangered**' by the International Union for Conservation of Nature (IUCN; Morgan 2019), and as a Priority 4 Species on the Department of Parks and Wildlife Priority Fauna List (Parks & Wildlife 2019). The recent listing as Endangered is based on the following threats: degradation of habitat by over-grazing, introduced species, changed hydrological regimes, changed fire frequencies, an increased water extraction for mining (Carwardine *et al.* 2014), and recent introductions of redclaw crayfish (*Cherax quadricarinatus*) and sailfin mollies (*Poecilia latipinna*) to the Fortescue River which will have unknown impacts on the habitat (Thorburn 2018, Pinder *et al*. 2019). This species has a restricted distribution within the Pilbara Region of Western Australia and is only known from the Fortescue, Robe and Ashburton river systems (Allen *et al.* 2002). It is a highly mobile species and is present in all major creeklines within, and adjacent to, the Proposal, *i.e*. Duck Creek, Caves Creek, Boolgeeda Creek, Beasley River, Hardey River and Ashburton River.

Of scientific interest is the occurrence of hybrid terapontid (grunter) specimens throughout Duck Creek, Caves Creek, Boolgeeda Creek, and nearby Beasley and Hardy rivers. DNA analysis is yet to be undertaken to positively identify which species are hybridising, but they are likely to be two of the three known grunter species occurring in the system; spangled perch, Fortescue grunter and/or barred grunter. Such hybridisation has been widely recorded for the Pilbara (Morgan & Gill 2006, Morgan *et al*. 2009, WRM unpub. dat.). Morgan and Gill (2006) suggest that hybridisation between fish species is not uncommon.

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[4] Terapontid hybrid grunters were recorded separately from other grunters, thereby forming an indeterminate ninth species which are yet be formally described.

4. EXPOSURE CHARACTERISATION

Exposure characterisation assumed all aquatic fauna within the discharge footprint would be equally exposed to all stressors and toxicants of concern in surface waters. Due to the high level of uncertainty, influencing factors such as dilution, complexation, precipitation, between-species differences in tolerance, rate of accumulation, and dietary exposure pathways were not taken into consideration. Exposures in sediment were not evaluated because final concentrations are a result of long-term deposition and no data on current sediment concentrations were available. Nor has allowance been made for possible longitudinal gradients in stressors or toxicants along Duck or Boolgeeda Creek. Instead it was assumed that exposure concentrations within the entire discharge footprint are the same as recorded for groundwater monitoring bores (*i.e*. likely worst-case scenario).

5. RISK TO AQUATIC ECOSYSTEM RECEPTORS

5.1 Change in Water Quality

5.1.1 Inorganic Nitrate

Based on the hazard identification in section 2.2, elevated nitrate concentration in dewatering discharge was considered to present the following risks to aquatic ecosystems:

- **moderate-high risk** of habitat loss through eutrophication, and
- **low-moderate risk** of direct toxicity.

The limited groundwater monitoring data for nitrate (2 samples for WB16BS4B0002) suggest nitrate loads, as well as concentrations, may be significantly increased under constant discharge scenarios.

Nitrogen-enriched groundwaters that discharge to creekline pools can result in eutrophication by fuelling nuisance algal and macrophyte growth (*e.g. Typha*). These in turn may physically smother other life forms, as well as deplete oxygen from the water column due to increased biological oxygen demand during microbial decomposition, leading to anoxia (zero dissolved oxygen) or hypoxia (< 20% dissolved oxygen).

There are also natural long-term pools on lower Duck Creek which may form significant ‘sinks’ for nitrate (or other contaminants) in dewatering discharge, when loads are flushed and deposited further downstream during rainfall events. These sinks can in turn become sources if loads exceed the assimilative capacity of the system. Such pools are unlikely to form along Boolgeeda Creek if discharge volumes remain low and intermittent. For both creeks, risk of eutrophication is highest during periods when natural flow is at its lowest (*e.g*. dry season) and dewatering discharge constitutes most of the surface water present in channel pools. During the wet season, risk of eutrophication will be low-moderate as rainfall will dilute nitrate concentrations, thereby limiting excessive algal and microbial growth, while higher water velocities would break apart and flush algal colonies downstream.

From a management perspective, elevated nitrogen concentrations in the creeks are of greater importance than concentrations at the discharge point(s), as the former better represent final exposure concentrations for aquatic biota in the creeks. At the Nammuldi-Silvergrass compliance point on Duck Creek, nitrate (median 2.3 mg/L N-NO_3, max. 31 mg/L N-NO_3) already exceeds the eutrophication SSGV (0.04 mg/L as N-NO_3), and occasionally exceeds the toxicity SSGV (2.5 mg/L as N-NO_3) as a result of the current periodic dewater discharge regime (WRM 2019c). WRM annual (wet season) monitoring data show concentrations reduce to background levels approximately 7 km downstream. Field surveys (2009

- 2018) have detected no significant[5] deleterious effect on aquatic fauna (hyporheos, macroinvertebrates, fish) that can be attributed to Nammuldi-Silvergrass dewatering discharge (WRM 2019a).

Thus, although nitrogen levels already exceed the SSGVs, the SSGVs were calculated from field concentrations and do not necessarily reflect threshold concentrations at which eutrophication, or chronic or acute toxicity effects are likely to be observed. Similarly, ANZG (2018) DGVs were developed primarily for water bodies other than those in the arid and semi-arid tropics. Based on ANZG (2018) DGVs for 90% and 80% species protection, *i.e*. 3.1 mg/L and 5.4 mg/L, respectively, continual discharge of groundwater with nitrate concentrations equivalent to those measured for the Marra Mamba Aquifer (3.52 - 3.64 mg/L N-NO_3, WB16BS4B0002), may potentially result in loss of between 10% and 20% of species from direct toxicity. However, the acceptable or 'normal' range common to water bodies of the Pilbara remains poorly understood and consequently, the DGVs should be applied with caution.

The two major considerations for the Proposal are, i) final discharge volumes and nitrate loadings compared to current dewatering regimes for Nammuldi-Silvergrass and Brockman 4, and ii) potential for more long-term pools to be maintained by surface and sub-surface flow, forming 'sinks' for nitrates or other contaminants in the creeks.

WRM have previously investigated the relationship between nitrate and Pilbara macroinvertebrate species richness for RTIO Yandi (WRM 2020), in order to better assess nitrate risk to aquatic biota. A weight of evidence approach was used, by comparing known field distributions from WRM regional surveys across the Pilbara with results from a recent laboratory ecotoxicological study commissioned by RTIO (van Dam 2019). Pilbara macroinvertebrate data (species richness) from multiple sites across the western and eastern Pilbara, including reference and mine exposed sites, exhibiting a range of nitrate concentrations, were plotted against corresponding nitrate concentration to ascertain if there is a threshold above which diversity sharply declines. The plot in Figure 5 uses all available baseline and monitoring data for RTIO Nammuldi-Silvergrass, Yandi, HD1, HD4, Western Turner Syncline, Marandoo, Mesa H, Mesa B/C, and Pilbara Regional programs, as well as data from the Parks and Wildlife Pilbara Biological Survey (PBS) (Pinder *et al*. 2010). This large dataset takes into account the tolerances of common and widespread macroinvertebrates of the Pilbara bioregion, allowing interpretation of whether the functional integrity of the downstream receiving environment is likely to be compromised as a result of discharge water quality. Figure 6 shows the subset of data specific to Duck Creek, and to Marillana and Weeli Wolli creeks sampled for the Yandi project area. The rationale for using macroinvertebrates is that adverse effects to lower order taxa (*e.g.* zooplankton) within aquatic food webs, are expected to manifest as change in higher order taxa such as macroinvertebrates. In addition, macroinvertebrate species richness displays far less spatial and temporal variation than zooplankton and fish species richness, and as such, relationships with water quality are more readily interpretable.

Figures 5 and 6 indicate species richness is highest at sites with N-NO3 concentrations < 2.5 mg/L. However, there are relatively few data for sites where N-NO_3 exceeds 2.5 mg/L, other than those on Marillana Creek downstream of DO9/DO9A, which are also affected by changes in flow. In Duck Creek, species richness ranged from 12 to 64 for N-NO_3 ≤ 2.5 mg/L (n = 163), compared to 47 for N-NO_3 > 2.5 mg/L (n = 1, DCDT2). In Marillana Creek, species richness ranged from 11 to 73 for N-NO_3 ≤ 2.5 mg/L (n = 114), compared to a range of 27 to 46 for N-NO_3 > 2.5 mg/L (n = 13). In Weeli Wolli Creek, species richness ranged from 18 to 75 for N-NO_3 ≤ 2.5 mg/L (n = 208), compared to a range of 30 to 40 for N-NO_3 > 2.5 mg/L (n = 3). This suggests a potential decline in peak species richness by up to 40% if concentrations were to remain constantly high, acknowledging the limitations in the data. The paucity of data for reference sites with naturally high nitrate concentration, makes it difficult to distinguish change due to high nitrate in dewatering discharge, from change due to other factors such as flow. In Figures 5 and 6 it can be seen that most sites have low nitrate concentrations (< 2.5 mg/L) and support both high and low

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[5] Based on analysis of species richness and abundance data using univariate (Spearman rank correlation, ANOVA) and multivariate (nMDS ordination, PERMANOVA, DistLM) techniques (WRM 2018b, 2019a).

macroinvertebrate species richness. This variability likely reflects the influence of other factors at those sites when sampled, for example, degree of drying/evapoconcentration, time of sampling after rainfall, system reset following cyclones, or disturbance from cattle. However, available data for sites with higher nitrate concentrations (> 2.5 mg/L) are mostly limited to one reference site on a tributary of Duck Creek (DCDT2), and mine-exposed Marillana and Weeli Wolli Creek sites, which appear to support only relatively low species richness when nitrate concentrations are high.

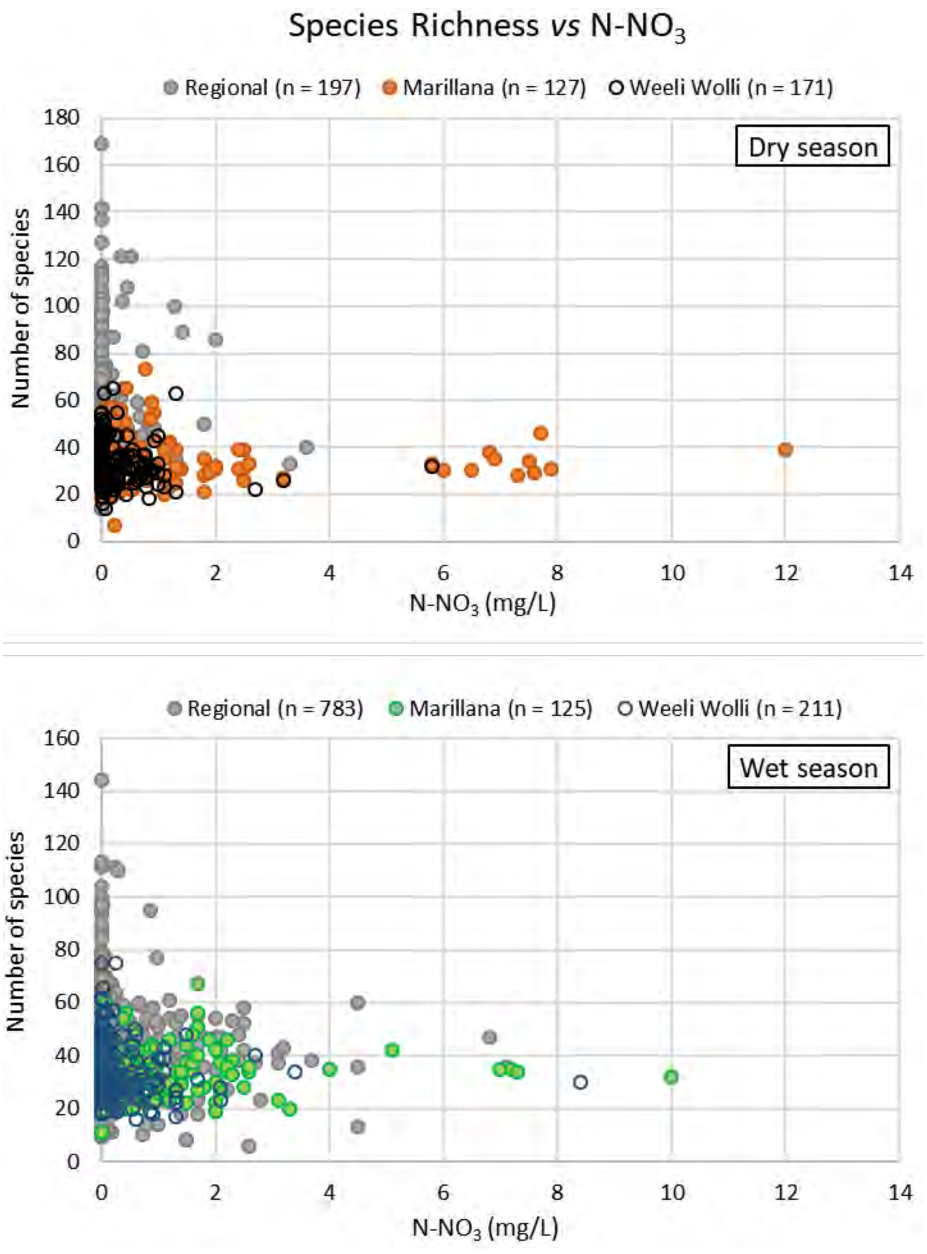

Figure 5. Relationship between macroinvertebrate species richness and nitrate concentration. Data are combined data from WRM dry and wet season aquatic ecosystem surveys of Marillana, Weeli Wolli and Pilbara regional creeks (2008 - 2019), and Parks and Wildlife PBS (2003 - 2006)[6]; (n = number of samples).

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[6] Note claypan and salt marsh sites were excluded as they are not representative of habitats along Marillana and Weeli Wolli Creek.

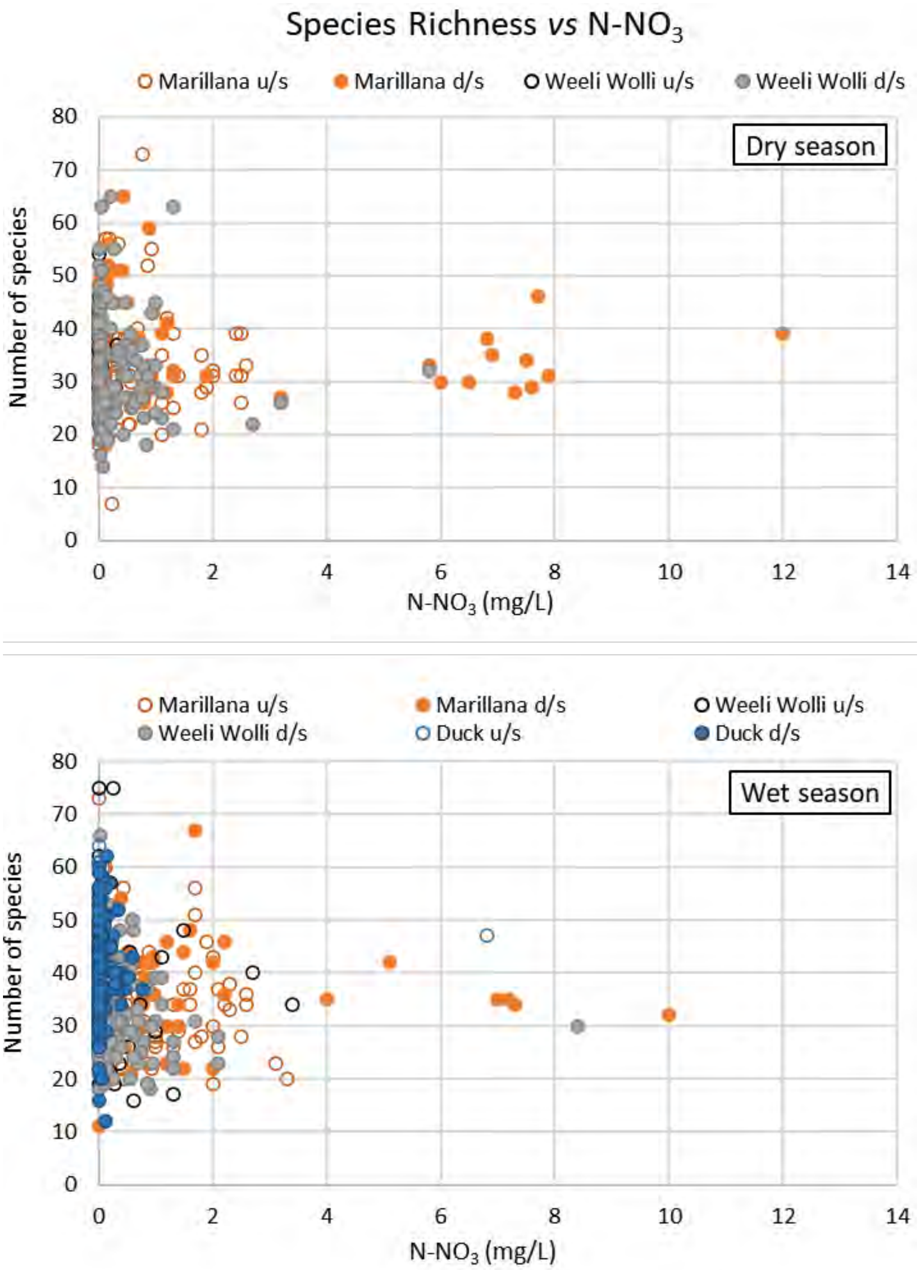

Figure 6. Relationship between macroinvertebrate species richness and nitrate concentration for Duck, Marillana, and Weeli Wolli Creek sites. Data are a subset of data shown in Figure 6, and include Duck (2010-2018), Marillana (2008-2019) and Weeli Wolli (2008-2019) Creek sites sampled for Nammuldi, Yandi and HD1 projects, respectively, upstream (u/s) and downstream (d/s) of dewatering discharge outlets. Note, no dry season data are available for Duck Creek.

Nitrate ecotoxicity studies have been undertaken for other RTIO Pilbara projects (ESA 2019a,b, van Dam 2019). van Dam (2019) derived “indicative” nitrate GVs based on ecotoxicity tests for two local microalgal species (*Chlorella* sp., *Oocystis solitaria*). and results from previous ESA (2019a,b) test reports for three local invertebrate species (*Ceriodaphnia dubia*, *Simocephalus heilongjiangensis*, *Hydra viridissimma*). The GVs were not intended for use as SSGVs, but to allow comparison to current ANZG (2018) DGVs and compare local species toxicity to that of other species. Tests were conducted at a water hardness of around 450 mg/L (as $CaCO_3$) and water temperatures of 23 to 27°C, to better simulate ambient conditions in local creeks, citing that water hardness may have an ameliorating effect on toxicity for some species (Hickey 2013). van Dam (2019) states that because only five species were tested and sample sizes were small, the dataset falls short of the minimum requirement for deriving SSGVs (Warne *et al.* 2018), and therefore the GVs are indicative only, with high uncertainty.

The indicative GVs (Table 4) are higher than the ANZG (2018) DGVs for 99%, 95%, 90% and 80% species protection (1.1 mg/L, 2.1 mg/L, 3.1 mg/L and 5.4 mg/L, respectively), and higher than the current (2014) toxicity SSTV (2.5 mg/L), which is designed to protect 95% of existing species.

Table 4. van Dam (2019) indicative site-specific guideline values for nitrate.

% species protection	Nitrate (mg/L N-NO_3)	
	Animal species' IC10 toxicity data and microalgal species' $EC10_{stim}$ data	All species IC10 toxicity data
99%	16 (9.7 – 50) [a]	2.7 (1.1 – 215)
95%	25 (21 – 52)	14 (6.8 – 217)
90%	32 (28 – 53)	30 (14 – 562)
80%	40 (36 – 71)	66 (27 – 778)

[a] Values in parentheses represent lower and upper 95% confidence intervals.

Despite the high uncertainty in the indicative GVs, together with the field distribution data, they suggest the current toxicity SSGV for Nammuldi-Silvergrass may be overly conservative. As it is not possible to entirely separate the effects of high nitrate concentration from changes in flow, a conservative approach is recommended. van Dam (2019) notes that the test results may indicate the current proposed ANZG (2018) DGVs for nitrate are conservative for Pilbara species, and recommends that a "site-adapted GV" could be warranted (calculated from combining the local data with datasets used to derive New Zealand GVs on which current ANZG (2018) DGVs are based).

The magnitude of any increases in nitrate in surface waters will be limited by the final volumes of surplus dewater discharged, the assimilative capacity of the creek, and dilution and flushing by seasonal rainfall.

At Yandi, dewatering discharge is considerably more enriched in nitrate (median 7.8 mg/L N-NO_3, 2017 - 2019) than in Nammuldi-Silvergrass dewatering discharge. Though median (2017 - 2019) nitrate concentrations in the surface waters remain lower than concentrations in discharge waters, there is some evidence to suggest the assimilation capacity of Marillana Creek may have declined. Field studies by Honours student, Dallas Campbell (Murdoch University) in 2018, found attenuation of nitrate to be lower in Marillana Creek compared to regional reference Bamboo Springs, which has naturally elevated nitrate concentrations, though not as elevated as dewatering discharge. Under flowing water conditions, a decrease in nitrate concentration was detected over a 2 km distance downstream of DO9/9A (from ave. 1.71 mg/L, to ave. 1.03 mg/L N-NO_X), however this decrease was not statistically significant (D. Campbell, unpub. dat.). In contrast, at Bamboo Spring, a statistically significant reduction in nitrate concentration was recorded over a 200 m distance (1.1 mg/L to 0.005 mg/L N-NO_X) downstream of the spring source. The apparently greater assimilative capacity for nitrate in the natural spring is likely due to longer residence times (lower flow rates/discharge) and greater turnover of aquatic and riparian plant detritus to drive denitrification processes. In the channel downstream of DO9/9A, the increased nitrogen load from dewater discharge was also found to be associated with a dominance of microbial material, increased total nitrogen content in aquatic plants (up to 20x higher), increased rates of periphyton growth, increased gross primary production (GPP), and increased frequency of de-oxygenation events (D. Campbell, unpub. dat.); all of which are indicators of eutrophication.

In summary, WRM field distributional data (2008 - 2019) and van Dam (2019) ecotoxicity tests suggest local species may have a greater tolerance to elevated nitrate than represented by the current toxicity SSGV, which is based on default guidelines. However, this requires further research. In addition, we cannot rule out potential eutrophication effects because of uncertainty in the final volumes and quality of surplus dewater to be discharged, the assimilation capacity, and how the system will respond to future nitrate loading. Consequently, it is considered there is moderate to high risk to aquatic ecosystems from eutrophication, and low to moderate risk of direct toxicity, as a result of dewater discharge water quality exceeding SSGVs, at current reported levels for groundwater.

5.1.2 Total Phosphorus

Based on median concentrations in Brockman Iron Formation bores, total phosphorus (P-total) in dewatering discharge was considered to present the following risk to aquatic ecosystems:

- **moderate-high risk** of habitat loss through eutrophication.

In addition, the maximum P-total concentration in the bores (1.43 mg/L) is 10x higher than previously assessed for the existing Brockman 4 discharge outlet (max. 0.14 mg/L P-total, DP15BS4001) and 100x higher than at the Nammuldi-Silvergrass discharge outlet (WRM 2014c, 2018a). Though concentrations in the creeklines downstream of existing discharge outlets have remained low (WRM 2018a, 2019a), this may not be the case if phosphorus loads increase under future scenarios.

In oxygenated conditions, phosphorus in freshwaters readily sorbs to, or complexes with, oxides, carbonates, organic matter and clays. This would be expected to reduce the availability of phosphorus for uptake by algae and aquatic plants, once discharged to the creeks. However, the elevated nitrate further increases the potential for eutrophication if uptake capacity for phosphorus is also exceeded.

5.1.3 Total Suspended Solids

Based on concentrations in most Brockman Iron Formation bores and four Marra Mamba bores, suspended solids in dewatering discharge present the following risk to aquatic ecosystems:

- **moderate-high risk** of habitat loss.

Naturally high concentrations of total suspended solids (TSS) often occur in Pilbara creeks following rainfall events. However, frequently or atypically high levels can affect community dynamics by smothering benthic plants and animals, clogging gills, and reducing light transmission. Suspended solids can also act as sinks or sources of contaminants, though interaction pathways and effects are poorly understood for the mixtures of particulates that constitute TSS (Dunlop et *al*. 2008, Chapman *et al*. 2017).

5.1.4 Dissolved Barium

Based on the one high value recorded for MB17BS10002 (1.87 mg/L Ba), dissolved barium presents the following risk to aquatic ecosystems:

- **low to moderate risk** of direct toxicity.

It must be emphasised that there is low certainty in the risk rating for dissolved barium due to the limited baseline data for each bore and the variation in concentrations between bores. In addition, barium is readily adsorped to clay particles and suspended organic matter, forms soluble salts with chloride and nitrate, and insoluble salts with sulfate, carbonate and phosphate that precipitate out of the water column. Hence the concentration of dissolved barium is typically low in natural surface waters of the Pilbara (*i.e*. 80%ile 0.1 mg/L, max. 1.0 mg/L, WRM unpub. dat.).

There are currently no national guidelines for barium in freshwaters, owing to the paucity of research on toxic effects to aquatic biota. The most recent ecotoxicity study is that by Golding *et al.* (2018) for two species representative of Australian freshwater species; the alga *Chlorella* sp. 12 and the water flea (micro-crustacean) *Ceriodaphnia dubia*. A chronic EC10 of 1.7 mg/L was derived for dissolved barium, based on a predicted EC10 derived from acute EC50/10 data for the most sensitive species, the water flea.

However, additional chronic toxicity data are required to derive guidelines for dissolved and precipitated barium (*e.g*. barium sulfate) to protect freshwater biota (Golding *et al*. 2018).

The EC10 of 1.7 mg/L is slightly lower than the value for groundwater in MB17BS10002. Concentrations at existing discharge outlets (DP and DP15BS4001) and in the creeklines are far lower (typically < 0.1 mg/L) (WRM 2014c, 2018a,b, 2019a). In the absence of a more definitive guideline, it was assumed chronic toxicity effects may be observed at dissolved concentrations > 1.7 mg/L.

5.2 Calcite Precipitation and Bed Armouring

Based on calculated LSIs and experience at other mine sites, it is considered there is:

- **low to moderate** risk to aquatic fauna habitats from bed armouring bed armouring and infilling of riffles and pools along Duck and Boolgeeda Creek due to calcite precipitation from discharge waters.

A trend toward higher (more positive) LSI values was previously reported for the Brockman 4 discharge outlet and RTIO monitoring site SW17BS4B001 in downstream Boolgeeda Creek (WRM 2018a). Nammuldi-Silvergrass dewatering discharge also appears saturated in calcium carbonate. Visual inspection and handling of mineral substrate at fauna sampling sites close to the discharge outlets on Duck and Boolgeeda Creek, indicate no observable creek bed armouring or loss of instream habitat from calcification (WRM 2019a). Although discharge waters appear to be saturated in calcium carbonate, the intermittent discharge regimes and cessation of surface flows through upper Duck and Boolgeeda Creek, for extended period of time during the dry season each year, remains sufficient to prevent early onset of calcification effects (WRM 2019a).

Higher LSI values alone are also not conclusive evidence that calcite precipitation will occur. It is recommended that, in the first instance, the channel be visually inspected for calcite deposits, and if confirmed, expert assistance (*e.g.* CSIRO) should be sought to determine the rate of deposition.

If indicators of calcite precipitation (pH, alkalinity, EC, TDS, Ca, HCO_3, SiO_2, temperature) remain at or close to 80%ile values of the reference dataset, then risk of precipitation and bed armouring on discharge to the surface is considered to be low. Groundwater data showed these parameters were mostly below SSGVs for surface waters. The exception was silica (reactive SiO_2) which was elevated in WB16BS4B0002.

If extensive calcite precipitation were to occur, it could eventually lead to localised armouring of the creek bed, creating in-stream habitat analogous to bedrock in terms of reduced habitat heterogeneity and reduced aquatic species diversity in the effected reaches (WRM 2018b, 2019e). Armouring may take several years to develop, but once it begins, the spatial extent can increase rapidly (WRM 2018b). The rate and volume of dewatering discharge will determine the area affected, and if the final discharge regime for the Proposal is similar to the existing regime for Nammuldi-Silvergrass, then the risk is considered to be negligible.

6. CONSEQUENCE ANALYSIS

6.1 Aquatic Invertebrates

Most species recorded are known to occur widely outside the development envelope and predicted discharge extent, and therefore, any adverse effects from the Proposal will be at a local-scale only. No changes to current conservation listings would be expected as a result of the Proposal. This includes the three species formally listed as vulnerable; the pelagic copepod *Eodiaptomus lumholtzi*, the Pilbara pin damselfly *Eurysticta coolawanyah*, and the Pilbara emerald dragonfly *Hemicordulia koomina.*

All three listed species occur widely across the Pilbara, in ephemeral as well as permanent pools. For each, the known extent of distribution within pools in the Proposal area, constitutes less than 10% of known extent outside the Proposal area. It is not likely that any one pool within the Proposal area is critical habitat for these species. However, many of the known locations outside the Proposal area are within zones of groundwater drawdown and/or mine dewatering discharge (*i.e*. Caves, Marillana, Weeli Wolli, Kalgan and Mungarathoona creeks, Beasley, Hardey and Robe rivers, and Millstream), or tourism (*i.e*. Hamersley Gorge, Fortescue Falls, Skull Springs, Bamboo Springs, Nyeetbury Spring).

In addition, a comprehensive study of major Pilbara rivers (Fortescue, Yule, De Grey) by the Department of Conservation Biodiversity and Attractions (then DEC), concluded catchments cannot be considered surrogates for one another for the purposes of conservation of pool invertebrate faunas (Pinder & Leung 2009). The same is likely true for pools within the Ashburton River catchment, suggesting that so long as a variety of pool habitats is maintained across the upper, as well as lower, Ashburton catchment, the existing invertebrate fauna as a whole, will be maintained (Pinder & Leung 2009).

The new rotifer *Proales* n. sp. (family Proalidae), is the only species currently known from a single ephemeral pool on Duck Creek (DCD10) within the predicted maximum dewatering discharge. It is highly probable *Proales* n. sp. has a broader distribution, but until it is collected elsewhere, it is considered at a higher level of risk due to its current rarity and low occurrence. Therefore, loss of *Proales* n. sp. from DCD10 would constitute a 100% loss of known distribution, and the species would be considered endangered.

Life histories and survival strategies of aquatic species are intrinsically linked to water quality, and seasonality and predictability of flow regimes. However, current knowledge of the tolerances of Pilbara aquatic invertebrates is not sufficient to accurately predict the level of impact changes in water quality and/or unseasonal flows may have. Adverse water quality and eutrophication present a greater risk to aquatic invertebrates than to fish, as fish are more mobile and capable of traversing greater distances in a relatively short period of time, thus more readily avoiding poorer water quality.

Because Duck and Boolgeeda creek have a naturally unpredictable, episodic flow regime, it is likely many invertebrates would adapt to a periodic discharge regime, as appears to be the case for the existing discharge regime for Nammuldi-Silvergrass. Under a periodic discharge regime, resultant intermittent flows and drying pools are more similar to the natural conditions in the creek, except that there may be some periods of unseasonal flow relative to the natural hydrology.

Altered hydroperiod can alter reproductive cycles in invertebrates adapted to periodic or seasonal flows. Continuous discharge is likely to lead to a loss of 'seasonal' cues, allowing a single invertebrate assemblage to inhabit all areas of the creek year-round. Conversely longer flow duration and greater year-round connectivity between ground and surface waters will favour species that prefer perennial flow.

If continual discharge were to occur over the dry season, this may lead to early emergence of some species that may then not be able to successfully complete their life-cycle. Even if longer flow duration disadvantages invertebrates with specific drought-resistant strategies, it should only affect species within the discharge footprint. It is unlikely that any species would be lost from the creek entirely, as these taxa are expected to be present in ephemeral and seasonally flowing reaches outside the area of discharge influence, and in adjacent tributary creeks of the Ashburton catchment. After mine-closure, these invertebrates would be expected to re-colonise *via* natural dispersal following rain events (*e.g*. downstream drift, aerial invasion by winged adult stages *etc*.).

Increased hydroperiod due to dewatering will increase the carrying capacity for surface water and hyporheic invertebrates by inundating a greater surface area of the channel for longer duration, providing greater areal extent of existing habitats as well as potentially creating new habitats (*e.g*. small riffle habitats supporting lotic species). It is expected that over the long-term, this increase in habitat diversity will lead to increased taxa richness and abundance in Duck and Boolgeeda Creek, but altered species assemblage composition. For example, abundance of stygal amphipods has greatly increased over time in the hyporheos in Duck Creek (WRM 2019a), and in sections of Weeli Wolli Creek not affected by calcite armouring (WRM 2019e). This is considered due to increased duration and volume of surface and sub-surface flows, with greater year-round connectivity between ground and surface waters and a subsequent increase in spatial extent of hyporheic habitats.

The sandy gravels of the alluvium within the Duck, Boolgeeda, Palm Springs and lower Caves Creek channels provides habitat for a diverse hyporheos, including a number of stygal species, none of which are likely restricted to the development envelope or the predicted maximum discharge extent. In contrast, the bed substrates of upper Caves Creek (CCU sites) are predominately clay, which is less conductive (*i.e.* lower hydraulic conductivity), and lack the interstitial spaces needed by many hyporheic species for colonisation.

Some stygal amphipod and isopod species were collected from multiple sites on Duck Creek, Palm Springs and Boolgeeda Creek, suggesting they are part of a larger community that extends throughout the two valleys. There is growing awareness of the importance of hyporheic zones to continuity of stygofauna habitat and gene flow (Hancock & Boulton 2008, Cook *et al*. 2012, Stantec 2017, Moore *et al.* 2018) as well as refugia for many surface water species during dry periods. In general, Pilbara stygofauna species richness is greatest where the water-table is closer to the ground surface (Mokany *et al*. 2018).

Should the habitats along Duck and Boolgeeda Creek be affected by eutrophication (*via* nutrient infiltration), siltation or groundwater drawdown associated with the Proposal, then any species loss is expected to be highly localised, given their known and expected wider distributions within hyporheic zones of the Duck Creek, Palm Springs and lower Caves Creek sub-catchments. This is assuming no significant fragmentation of habitat by cumulative effects of groundwater drawdown for the Proposal and the proposed Fortescue Metals Group (FMG) Flying Fish and Eliwana mines immediately to the west. Due to the taxonomic uncertainty for stygal amphipods and isopods, it is not possible to determine species distributions at the regional scale and hence conservation status. While the genera and families are known from hyporheos and groundwater bores elsewhere in the Pilbara, genetic analysis is needed to confirm species taxonomy.

6.2 Fish

Baseline studies suggest there is strong and widespread recruitment in fish populations in Duck and Boolgeeda Creek following good wet season rainfall (WRM 2016). Depending on discharge extent, and assuming no adverse change in water quality, dewatering discharge to the creeks may increase the carrying capacity of the system for fish. If this were to occur, then it is expected the abundance of all fish species, including the endangered Fortescue Grunter, would increase. In addition, any larger, deeper pools that may form due to discharge will sustain larger-sized fish. These values however, will return to pre-impact conditions once discharge ceases.

Should eutrophication or calcite armouring reduce habitat availability for Fortescue grunter, risk to regional populations would still be low, given the widespread occurrence of Fortescue grunter in regional creeks and rivers outside the influence of the Proposal. Any impact to populations in Duck and Boolgeeda Creek would be short-term, as fish could readily recolonise from the numerous permanent pools on lower Duck Creek and the Ashburton River, once conditions improved. The known extent of distribution within pools in the Proposal area, constitutes less than 10% of known extent outside the Proposal area. However, the geographic range is highly fragmented and, as for the invertebrates, many of the known locations outside the Proposal area are within zones of groundwater drawdown and/or mine dewatering discharge.

Risk of loss of genetic diversity due to the Proposal is also considered to be low. There is nothing to suggest that populations of the various fish species present in Duck and Boolgeeda Creek are genetically distinct from populations in other adjoining tributaries of the Ashburton River. Boolgeeda Creek would periodically connect to Duck Creek and the Ashburton River following high rainfall events. As such, there are unlikely to be long-term barriers to gene flow that would result in genetically distinct sub-species that might be lost under continual discharge.

As a more natural ephemeral flow regime returns on cessation of dewatering, available in-stream habitats in Boolgeeda Creek may become homogeneous if extensive bed armouring were to develop and persist.

7. CONCLUSIONS

Dewatering discharge from the Proposal presents the following risk to aquatic fauna (zooplankton, hyporheos, macroinvertebrates and fish):

1. Moderate-high risk of habitat loss from,
   a. eutrophication due to nitrate and phosphorus enrichment, and
   b. sedimentation due to elevated TSS;
2. Low-moderate risk of habitat loss due to calcite precipitation;
3. Low-moderate risk of direct toxicity from nitrate and dissolved barium enrichment.

Risks posed by dewatering discharge for the Proposal are the same as those previously identified for existing Nammuldi-Silvergrass and Brockman 4 dewatering discharge operations.

Key uncertainties are, i) final concentrations of contaminants and loadings to the creek(s) under higher dewatering discharge scenarios, and possible sinks, ii) bioavailability of dissolved barium, and iii) longitudinal extent and persistence of any calcite-armouring.

There is moderate certainty in the risk rating for nitrate, as although baseline data are limited, the experience at existing BWT mines Nammuldi-Silvergrass, Brockman 4 and Western Turner Syncline, is that groundwaters throughout the area are generally enriched in nitrate relative to surface waters.

There is low certainty in the risk rating for dissolved barium for the Proposal, due to the limited baseline data for each monitoring bore, and the paucity of research on toxicity of dissolved barium to aquatic biota.

Concentrations of any contaminant at, or downstream of, discharge outlets will likely be diluted by wet season rainfall, but this assumes rainfall is sufficient to flush creeklines and reduce concentrations below ecosystem thresholds for assimilation. If discharge volumes are similar to current low and intermittent discharge volumes at Nammuldi-Silvergrass and Brockman 4, then all identified risks will likely be negligible-low.

Based on long term monitoring at existing RTIO Pilbara BWT mines, and known local and regional species distributions, the consequences of the risks identified for the Proposal are expected to be localised to the discharge footprint and depend on the presence of receptors within this footprint:

- No change in conservation status of IUCN vulnerable species; copepod *Eodiaptomus lumholtzi*, Pilbara pin damselfly *Eurysticta coolawanyah*, and Pilbara emerald dragonfly (*Hemicordulia koomina*);
- No change in conservation status of the IUCN endangered fish species, Fortescue grunter *Leiopotherapon unicolor*;
- No change in conservation status of potential and likely SREs:
  - copepod cf. *Areacandona* sp.,
  - amphipods *Chydaekata* sp., *Maarka* sp., *Nedsia* sp., indeterminate juvenile Paramelitidae and Melitidae, and
  - isopods *Pygolabis* sp. and indeterminate juvenile Bathynellidae and Syncarida;
- Short-term loss of, or population reduction in, 10 - 20% of aquatic fauna (invertebrates and fish) from nitrate toxicity;
- Long-term loss of up to 70% of benthic and hyporheic invertebrate species in sections of the channel that become heavily armoured by calcite precipitation (noting that calcite precipitation has not occurred under the current discharge regime for Nammuldi-Silvergrass);

- Short-term shifts in benthic invertebrate and zooplankton species assemblage composition due to altered flow regime, *i.e.* still water (lentic) species replaced by flowing-water (lotic) species;
- Short-term increase in abundance of native fish, and some hyporheic (*e.g*. stygal amphipods) and benthic invertebrate species due to increased spatial extent of surface water and sub-surface flow.

It is anticipated that there will be a statistically measurable response in most faunal indicators (species richness, abundance and composition) across all trophic levels (zooplankton, hyporheos, macroinvertebrates and fish). The majority of responses are anticipated to be short-term, returning to baseline condition on cessation of surplus water discharge.

In general, the aquatic invertebrate species diversity of the broader Brockman region, and in particular the Proposal development envelope area and predicted dewatering discharge zones, is considered to be high. This fact, combined with the growing extent of resource development across the Pilbara (mining in particular), means that consideration should also be given to the cumulative effect on regional aquatic habitats. Especially so for the conservation listed species and the diverse stygal community.

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APPENDICES

Appendix 1 Duck Creek SSGVs

SSGVs for Nammuldi-Silvergrass dewatering discharge to Duck Creek, compared with ANZG (2018) DGVs for 95% species protection, and 80%ile values (and 20%ile values for DO and pH) for local and similar regional creeks.

Percentile values shown for Nammuldi-Silver Creeks are from baseline data for sites BC, CCU1-6, DCD1-15, DCDT1-2, DCU1-6, DCUT1, HS1-6, sampled biannually November 2009 - April 2013.

SSGVs are for dewatering discharge to Duck Creek only, and not designed to be applied to Palm Springs or lower reaches of Caves Creek between Palm Springs and the confluence with Duck Creek.

All values are mg/L unless otherwise indicated; np = not provided; nr = not recorded.

Chemical		**ANZG (2018)**	**Nammuldi-Silvergrass Creeks**	**Palm Springs**	**Pilbara Regional Creeks**	**Nammuldi-Silvergrass + Regional Creeks**	**SSGV**
		95% DGV	**80%ile**	**80%ile**	**80%ile**	**80%ile**	
METALS, METALLOIDS, NON-METALLIC INORGANICS							
Al (pH>6.5)	T	0.055	0.008	<0.005	0.017	0.015	**0.055**
Alkalinity (as $CaCO_3$)		np	389	445	315	352	**--**
As (III)	T	0.024	nr	nr	nr	nr	**--**
As (V)	T	0.013	nr	nr	nr	nr	**--**
As-total	T, A	np	0.001	0.001	<0.001	<0.001	**0.013**
B	T	0.37	0.7	1.60	0.3	0.40	***0.4**
Ba	T	np	0.08	0.05	0.1	0.09	***0.09**
Ca	E	np	85	89	56	69	**--**
Cd	T, H	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	**0.0002**
Cl (chloride)		np	572	851	182	326	**--**
Chlorine-total	T	0.003	nr	nr	nr	nr	**--**
Co	T	np	0.0004	<0.0001	0.0013	0.0005	***0.0005**
CO_3		np	30	24	6	16	**--**
Cr (III)	T	np	nr	nr	nr	nr	**--**
Cr (VI)	T	0.001	nr	nr	nr	nr	**--**
Cr-total	T, C	np	<0.0005	<0.0005	<0.0005	<0.0005	**0.001**
Cu	T	0.0014	0.0022	0.0012	0.0016	0.0019	***0.0019**
DO-field (% sat)		85 - 120	57 -103	58 - 121	70 - 110	64 - 108	***64 - 120**
EC (µS/cm)	E	20 - 900	2992	4064	1340	1830	***1830**
Fe	T, F	0.3	0.04	0.03	0.08	0.06	**0.3**
Hardness (as $CaCO_3$)		np	856	996	468	590	**--**
HCO_3		np	455	532	378	404	**--**
Hg-inorganic	T, B	0.00006	nr	nr	nr	nr	**0.0001**
K		np	15	32	10	11	**--**
Mg	E	np	152	191	67	94	**--**
Mn	T	1.9	0.07	0.02	0.05	0.06	**1.9**
Mo	T, M	np	0.002	0.002	<0.001	0.001	***0.001**
Na		np	327	454	119	187	**--**
Ni	T, H	0.011	0.001	<0.001	<0.001	<0.001	**0.011**
N-NH_3	T	0.9	0.018	0.008	0.01	0.01	**0.90**
N-NH_4 (eutrophication)		0.01	nr	nr	nr	nr	**0.01**
N-NO_X (eutrophication)		0.03	0.01	0.008	0.08	0.04	***0.04**
NO_3	T, N	9.3	nr	nr	0.6	0.6	**11**

Chemical		**ANZG (2018)**	**Nammuldi-Silvergrass Creeks**	**Palm Springs**	**Pilbara Regional Creeks**	**Nammuldi-Silvergrass + Regional Creeks**	**SSGV**
		95% DGV	**80%ile**	**80%ile**	**80%ile**	**80%ile**	
N-total (eutrophication)		0.3	0.6	0.24	0.5	0.6	***0.6**
Pb	T, H	0.0034	<0.0001	<0.0001	0.0001	0.0001	**0.0034**
pH-field (pH units)		6 - 8	7.8 - 8.6	7.7 - 8.4	7.5 - 8.5	7.6 - 8.5	***7.6 - 8.5**
P-SR (eutrophication)		0.005	<0.01	<0.01	<0.01	<0.01	***0.01**
P-total (eutrophication)		0.01	0.03	0.01	0.02	0.02	***0.02**
S		np	110	140	29	66	**--**
Se-total	T, B	0.005	<0.001	0.001	<0.001	<0.001	**0.005**
Si		np	nr	nr	12	12	**--**
SiO_2		np	nr	nr	27	27	**--**
$S\text{-}SO_4$	E	np	347	432	74	170	**--**
TDS-calc		np	1680	2200	760	1100	***1100**
Temp-field (°C)		np	29.1	30.2	29.3	29.2	***29.2**
TSS		np	nr	nr	5	5	***5**
Turbidity (NTU)		2 -15	nr	nr	3	3	**15**
U	T	np	0.003	0.004	0.001	0.002	***0.002**
V	T	np	0.007	0.005	0.003	0.005	***0.005**
Zn	T, H	0.008	0.004	0.023	0.005	0.017	***0.017**

Notes:

* SSGV derived from 80%ile (and 20%ile for pH & DO) of combined baseline and reference data.

A. SSGV for As-total is equivalent to 95% species protection level DGV for As (V). For monitoring, if As-total concentration is >0.013 mg/L, then re-sample and analyse for metal species (*i.e.* As V and As III) concentrations and compare against default ANZECC/ARMCANZ triggers.

B. DGV for 99% species protection recommended due to the ability of these metals to bioaccumulate. However, laboratory analysis of mercury for routine screening is only achievable to 0.0001 mg/L Hg-inorganic or 0.00005 mg/L Hg-total; the latter by persulfate digestion on low salinity samples.

C. SSGV for Cr-total equivalent to 95% species protection level DGV for Cr (VI). For monitoring, if Cr-total concentration is >0.001, then re-sample and analyse for metal species (*i.e.* Cr VI and C rIII) concentrations and compare against default DGVs.

E. Conductivity (EC) and associated ions (*e.g.* Ca, Mg, $S\text{-}SO_4$) will vary depending on flow; values higher than the SSGV may occur naturally during the dry season if water levels are reduced due to evapo-concentration.

F. DGV for Fe is low reliability value.

H. SSGV should be modified for water hardness at the time of sampling using the default algorithms provided by ANZG (2018).

N. SSGV for NO_3 is based on previous interim New Zealand NOF standards value (MfE 2014) derived by Hickey (2013). ANZG (2018) now recommend "Grading" values for nitrate (as $N\text{-}NO_3$) toxicity. DGV value shown for nitrate is for NO_3, converted from ANZG (2018) value for $N\text{-}NO_3$ multiply by 4.43.

T. Toxicant.

Appendix 2 Boolgeeda Creek SSGVs

SSGVs for Brockman 4 dewatering discharge to Boolgeeda Creek, compared with ANZG (2018) DGVs for 95% species protection, and 80%ile values (and 20%ile values for DO and pH) for Boolgeeda and similar regional creeks.

Percentile values shown for Boolgeeda Creek are from baseline data for sites BS4-BC1 to BS4-BC7, sampled in April 2014 and April 2015.

SSGVs are for dewatering discharge to Boolgeeda Creek only, and not designed to be applied to Duck Creek.

All values are mg/L unless otherwise indicated; np = not provided; nr = not recorded.

Chemical		**ANZG (2018)**	**Boolgeeda Creek**	**Pilbara Regional Creeks**	**Boolgeeda + Regional Creeks**	**SSGV**
		95%	**80%ile**	**80%ile**	**80%ile**	
METALS, METALLOIDS, NON-METALLIC INORGANICS						
Al (pH>6.5)	T	0.055	0.032	0.015	0.015	**0.055**
Alkalinity (as $CaCO_3$)	T	np	157	351	354	**--**
As (III)	T	0.024	nr	nr	nr	**--**
As (V)	T	0.013	nr	nr	nr	**--**
As-total	T, A	np	<0.001	<0.001	<0.001	**0.013**
B	T	0.37	0.26	0.39	0.4	***0.4**
Ba	T	np	0.04	0.1	0.1	***0.1**
Ca	E	np	25	69	67	**--**
Cd	T, H	0.0002	<0.0001	<0.0001	<0.0001	**0.0002**
Cl (chloride)		np	148	313	314	**--**
Co	T	np	<0.0001	<0.0001	<0.001	***0.001**
CO_3		np	0.5	13	13	**np**
Cr (III)	T	np	nr	nr	nr	**--**
Cr (VI)	T	0.001	nr	<0.0005	<0.0005	**--**
Cr-total	T, C	np	<0.0005	<0.0005	<0.0005	**0.001**
Cu	T	0.0014	0.0004	0.0019	0.0018	***0.0018**
DO-field (% sat)		85 - 120	66 - 125	60 - 108	70 - 108	**70 - 120**
EC (µS/cm)		20 - 900	822	1774	1790	***1790**
Fe	T, F	0.3	0.06	0.07	0.07	**0.3**
Hardness (as $CaCO_3$)		np	160	572	560	**--**
HCO_3		np	191	406	408	**--**
Hg-inorganic	T, B	0.00006	nr	nr	<0.00005	**0.0001**
K		np	9	11	11	**--**
Mg	E	np	25	93	92	**--**
Mn	T	1.9	0.02	0.06	0.06	**1.9**
Mo	T, M	np	<0.001	0.001	0.001	***0.001**
Na		np	90	183	186	**--**
Ni	T, H	0.011	<0.001	<0.001	<0.001	**0.011**
$N\text{-}NH_3$	T	0.9	<0.01	0.01	0.01	**0.9**
$N\text{-}NH_4$ (eutrophication)		0.01	nr	nr	nr	**0.01**
$N\text{-}NO_x$ (eutrophication)		0.03	0.34	0.04	0.04	***0.04**
$N\text{-}NO_3$	T	2.1	0.34	0.04	0.04	**2.4**
N-total (eutrophication)		0.3	0.5	0.6	0.6	***0.6**
Pb	T, H	0.0034	<0.0001	<0.0001	0.0001	**0.0034**

Chemical	**ANZG (2018)**	**Boolgeeda Creek**	**Pilbara Regional Creeks**	**Boolgeeda + Regional Creeks**	**SSGV**
	95%	**80%ile**	**80%ile**	**80%ile**	
pH-field (pH units)	6 - 8	7.6 - 8.3	7.6 - 8.5	7.5 - 8.5	**7.5 - 8.5**
P-SR (eutrophication)	0.005	nr	<0.01	<0.01	***0.01**
P-total (eutrophication)	0.01	0.02	0.02	0.02	***0.02**
S	np	16	62	61	**--**
Se-total T, B	0.005	<0.001	<0.001	<0.01	**0.005**
Si	np	nr	12	12	**--**
SiO_2	np	nr	27	27	**--**
$S\text{-}SO_4$ E	np	50	164	163	**--**
TDS-calc	np	450	1100	1100	***1100**
Temp-field (°C)	np	30.2	29.2	29.0	***29**
TSS	np	nr	5	5	***5**
Turbidity (NTU)	2-15	nr	3	3.3	**15**
U T	np	0.0004	0.0018	0.002	***0.002**
V T	np	0.0018	0.004	0.004	***0.004**
Zn T	0.008	0.005	0.019	0.019	***0.019**

Notes:

* SSGV derived from 80%ile (and 20%ile for pH & DO) of combined baseline and reference data.

A. SSGV for As-total is equivalent to 95% species protection level DGV for As (V). For monitoring, if As-total concentration is >0.013 mg/L, then re-sample and analyse for metal species (*i.e.* As V and As III) concentrations and compare against default ANZECC/ARMCANZ triggers.

B. DGV for 99% species protection recommended due to the ability of these metals to bioaccumulate. However, laboratory analysis of mercury for routine screening is only achievable to 0.0001 mg/L Hg-inorganic or 0.00005 mg/L Hg-total; the latter by persulfate digestion on low salinity samples.

C. SSGV for Cr-total equivalent to 95% species protection level DGV for Cr (VI). For monitoring, if Cr-total concentration is >0.001, then re-sample and analyse for metal species (*i.e.* Cr VI and Cr III) concentrations and compare against default DGVs.

E. Conductivity (EC) and associated ions (*e.g.* Ca, Mg, $S\text{-}SO_4$) will vary depending on flow; values higher than the SSGV may occur naturally during the dry season if water levels are reduced due to evapo-concentration.

F. DGV for Fe is low reliability value.

H. SSGV should be modified for water hardness at the time of sampling using the default algorithms provided by ANZG (2018).

N. SSGV for NO_3 is based on previous interim New Zealand NOF standards value (MfE 2014) derived by Hickey (2013). ANZG (2018) now recommend “Grading” values for nitrate (as $N\text{-}NO_3$) toxicity. DGV value shown is new ANZG (2018) DGV for $N\text{-}NO_3$ as a toxicant.

T. Toxicant.

Appendix 3 Groundwater and Surface Water Quality Data

See embedded excel file, below: *Appendix 3 EIA Studies-HA-WQ Data 18-05-20.xlsx*

Appendix 3 EIS
Studies-HA-WQ Dat