Woodie Woodie: Aquatic Ecology Baseline Study 2020/2021

PREPARED FOR CONSOLIDATED MINERALS PTY LTD | DECEMBER 2021

Stantec

Revision Schedule

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Executive Summary

Background and Objective

Consolidated Minerals Pty Ltd (ConsMin) owns and operates the Woodie Woodie Manganese Project (Woodie Woodie) located approximately 400 km southeast of Port Hedland in the Pilbara region of Western Australia. Mining currently takes place within several open satellite pits, some of which occurs below water table (BWT). Most surplus groundwater is discharged to Brumby Creek, an ephemeral creekline that traverses the area. ConsMin are seeking to expand their operations at Woodie Woodie, known as the Woodie Continued Operations Project (WCOP), with additional dewatering likely required, which will to lead to drawdown of groundwaters within the WCOP development envelope (the Development Envelope).

Given the potential for discharge and drawdown impacts on local receiving environments from the WCOP, Stantec Australia Pty Ltd (Stantec) were engaged by ConsMin to undertake an aquatic ecology baseline study of rivers and creeklines within, and adjacent to, the Development Envelope (the Study). The objective of the Study was to gain an understanding of existing aquatic ecology values of the Development Envelope and surrounds, to inform regulatory approvals, aligning with the Western Australian Environmental Protection Authority (EPA)'s Inland Waters environmental factor. The objective was addressed by summarising records of conservation significant taxa from the area via a desktop assessment, systematic sampling of water and sediment quality, aquatic biota and vertebrate fauna during dual phase (dry and wet season) field surveys, and completing an impact assessment of increased discharge and drawdown on receiving aquatic ecosystems and their biota, based on the desktop assessment and survey results.

A total of 12 sites were sampled during the field surveys, which took place in November 2020 (dry season) and May 2021 (wet season). Sampling comprised four sites within the existing discharge footprint, including two on Brumby Creek, and two on the Oakover River downstream (downstream discharge sites), four sites on the Oakover River upstream of the discharge (upstream reference sites), and four temporary pools on ephemeral creeklines within or adjacent to the Development Envelope (temporary pools). The latter did not hold surface water in the dry season. A range of ecological components were assessed at each site, including water and sediment quality, aquatic macrophytes, phytoplankton, diatoms, aquatic invertebrates, fish, waterbirds and other vertebrate fauna (reptiles and amphibians).

Key Findings

The rivers and creeklines sampled during the Study were found to support a diverse and abundant aquatic biota community. In total, nine aquatic macrophyte, 71 phytoplankton, 64 diatom, 170 aquatic invertebrate, seven fish and twelve waterbird taxa were recorded at the downstream discharge, upstream reference and temporary pool sites across the dry and wet seasons. During dry conditions, the permanent or semi-permanent pools on the Oakover River (both upstream and downstream of discharge), as well as the perennial reach of Brumby Creek influenced by the existing discharge, provide refuge for aquatic biota in an otherwise arid landscape. In the wet season, expansion of riverine pools following flooding, and associated increases in habitat availability and favorable water quality, leads to enhanced productivity of primary producers (algae and macrophytes) and increased diversity of aquatic invertebrates, supporting higher order consumers such as fish and waterbirds.

Sites influenced by the existing discharge were found to support comparable macrophyte, algal, invertebrate fish diversity, abundance and composition, to permanent reference sites upstream during the Study. This was associated with the perennial hydrological regime created by the discharge, as well as water quality characterised by relatively low salinity, turbidity and metals. In contrast, opportunistic, transient invertebrate taxa, and hardy and adaptable fish species (*Melanotaenia australis* and *Leiopotherapon unicolor*), were characteristic of temporary pools within and adjacent to the Development Envelope, while aquatic macrophytes and waterbirds were depauperate. This is mainly due to the short residence time of surface water, and relatively high turbidity, nutrients and metals concentrations, which likely increase as the hydroperiod progesses.

Conservation Significant Species

The majority of macrophyte, algal, invertebrate and vertebrate taxa recorded during the Study have broader distributions throughout the Pilbara, northern-Australia, or across Australia. Exceptions included the dragonfly *Hemicordulia koomina,* and the damselfly *Eurysticta coolawanyah*, which are endemic to the Pilbara region, and are listed as Vulnerable on the IUCN Red List of Threatened Species. *Eurysticta coolawanyah* was widely distributed in the local area, recorded from discharge, upstream reference and temporary pool sites, while *Hemicordulia koomina* was only recorded from one upstream reference site, reflecting the cryptic nature of this species.

Additionally, database records suggest that the semi-permanent and permanent pools of the Oakover River downstream of the discharge intermittently support significant migratory waterbird species, including *Actitis hypoleucos* (common sandpiper), *Tringa glareola* (wood sandpiper), *Pandion cristatus* (osprey) and *Plegadis falcinellus* (glossy ibis). There are also records of *Liasis olivaceus barroni* (Pilbara olive python) and the migratory waterbird *Calidris canutus* (red knot) from temporary waterbodies within the Development Envelope. However, both taxa are only likely to visit these pools following inundation during the wet season.

<u>Ecological Values and Impact Assessment</u>

Based on the findings from the Study, the permanent and semi-permanent pools of the Oakover River upstream of the existing discharge were considered to be of **moderate to high** ecological value within the local area, primarily associated with the habitat and refuge these waterbodies provide in an otherwise arid landscape (higher value was associated with groundwater dependent pools of the upstream reference reach). Similarly, the reach of Brumby Creek and the riverine habitats of the Oakover River downstream of the existing discharge provide stable water quality and habitat during both the wet and dry seasons, albeit temporarily (for the life of operations), and were therefore also considered to be of **moderate to high** ecological value. Comparatively, the temporary pools within and adjacent to the Development Envelope, despite support a variety of transient and opportunistic aquatic biota, only hold surface water for a short period (weeks to months) and are subject to declining water quality towards the end of the hydroperiod, and therefore, were to be of **low to moderate** ecological value, within a local context.

Discharge modelling suggested that an additional 85 and 91 km of the Oakover River downstream of the existing discharge footprint, as well as a short section of Warri Warri Creek (eight to 10 km), may be influenced by the increase in discharge, although based on groundwater quality data from the area, only total nitrogen and nitrates were expected to be elevated in the discharge water. Creation of artificial perennial flows, increased habitat availability and colonisation of aquatic biota, and potential toxicity from nitrates, were considered the main potential impacts to receiving environments from the increase in discharge. Modelling of drawdown within the WCOP area showed that cones of depression are likely to be steep (up to 70 m) within the northern and central sections to 2028 and 2030, although limited drawdown (<1 m) expected to occur outside of the Development Envelope, due to the presence of numerous low permeability faults and geological units. Therefore, the reduction in hydroperiod or loss of temporary pools within the Development Envelope was considered to be the main potential impact of groundwater drawdown.

The subsequent impact assessment (**Table ES 2)** determined that the proposed increase in discharge from the WCOP will likely pose a ***low*** risk to aquatic biota (including conservation significant species). This was mainly due to the natural resilience of aquatic biota of the region to variation in hydrology and water quality (including nitrates), as demonstrated by the creation of habitat for aquatic biota within the existing discharge footprint. The addition of discharge water low in salinity, turbidity and metals may therefore benefit many aquatic biota and conservation significant species, by providing increased habitat and perennial flows for the life of discharge operations. The potential risk of groundwater drawdown to aquatic biota (including conservation significant species) was classified as ***negligible***, as temporary pools within the zone of drawdown are not linked to the underlying aquifer (with existing groundwater levels >80 m below the surface), and therefore, are unlikely to be impacted by changes to groundwater levels.

However, the risk determinations were ascertained based on the following assumptions, in relation to the proposed discharge and drawdown:

- The immediate receiving environments (Warri Warri Creek/Brumby Creek) have the adequate storage and flow capacity for the increased discharge volume;
- Any additional discharge outfall will be designed and positioned appropriately, to minimise erosion from the discharge within the river channel; and
- Drawdown will largely be constrained to within the east and west boundaries of the Development Envelope, due to the presence of low permeability faults and geological units, and will not impact the aquifers that support groundwater-dependent pools of the Oakover River.

Table ES 1: Summary of the ecological values of Upstream Reference, Downstream Discharge and Temporary Pool sites during the Study.

Reach / Waterbody	Hydrology / Habitat	Water Quality	Sediment Quality	Primary Producers	2nd and 3rd Order Consumers	Conservation Significant Taxa (Desktop and Baseline Study)	Ecological Value
Upstream Reference	• Large permanent, spring-fed riverine pools • Semi-permanent riverine pools, which are expansive in the wet season, and contract substantially during the dry season.	• Fresh water (EC < 5,000 µS/cm), neutral to alkaline pH, generally low metals levels. • Elevated nutrient concentrations due to groundwater influence (spring-fed pools) • Salinity, nutrients and turbidity increase at semi-permanent pools during the dry season due to evapoconcentration and cattle impacts	• Low salinity, nutrients and metals levels • Salinity and nutrients increase at semi-permanent pools during the dry season due to evapoconcentration • Some naturally elevated metals at spring-fed pools (e.g. nickel and chromium)	• Eight aquatic macrophytes, 54 phytoplankton, 43 diatoms, all with Pilbara wide/cosmopolitan distribution • Increased diatom productivity during the wet season and semi-permanent pools expand and water quality increases	• 130 invertebrate taxa, seven fish species and five waterbirds • Increased richness and abundance of aquatic invertebrates during the wet season, associated with greater habitat availability and higher overall productivity	• *Hemicorulia koomina* (dragonfly) (IUCN Vulnerable) • *Nososticta pilbara* (damselfly) (BC Act P2) – record likely erroneous	**Moderate to High**
Downstream Discharge (Brumby Creek)	• Flows perennially due to discharge • Historically ephemeral creekline, • Perennial regime, and overall productivity expected to decrease following cessation of discharge	• Fresh water (EC < 5,000 µS/cm), alkaline pH, generally low metals levels • Elevated nitrogen concentrations due to discharge of enriched groundwater • Seasonally homogenous water quality	• Low salinity and metals levels • Elevated total nitrogen (BCD2 in the dry season), related to elevated concentrations in discharge water	• Eight aquatic macrophytes, 34 phytoplankton, 28 diatoms, all with Pilbara wide/cosmopolitan distribution • Diverse macrophyte assemblage associated with water permanency and morphological heterogeneity, with deep pools, shallow backwaters and areas of flow	• 75 invertebrate taxa, six fish species and one waterbird • Consistent aquatic invertebrate diversity between seasons, due to homogenous conditions created by discharge • Invertebrate assemblage at BCD2 comparable to permanent spring ORU1 on the Oakover River, reflecting perennial flow regime	• *Eurysticta coolawanyah* (damselfly) (IUCN Vulnerable)	**Moderate**
Downstream Discharge (Oakover River)	• Large permanent riverine pools maintained by discharge • Limited change in pool size or depth between seasons due to discharge influence	• Fresh water (EC < 5,000 µS/cm), alkaline pH, generally low nutrient and metals levels • Relatively consistent water quality between seasons, due to discharge maintaining pool size and depth over the dry season	• Low salinity and metals levels • Higher nutrient concentrations during the wet season, likely due to catchment inflows and distribution of nutrients following flooding	• Seven aquatic macrophytes, 33 phytoplankton, 30 diatoms, all with Pilbara wide/cosmopolitan distribution • Increased diatom productivity during the wet season and semi-permanent pools expand and water quality increases	• 67 invertebrate taxa, five fish species and nine waterbirds • High waterbird diversity at ORD2, with this site supplying a permanent water and food source, with a large, rocky cliff face, providing shelter and nesting habitat	• *Actitis hypoleucos* (common sandpiper) (Migratory) • *Tringa glareola* (wood sandpiper) (Migratory) • *Plegadis falcinellus* (glossy ibis) (Migratory) • *Pandion cristatus* (osprey) (Migratory)	**Moderate to High -**
Temporary Pools	• Small, ephemeral pools, typically located at the base of small rocky gorges • Hydrology influenced exclusively by rainfall • Short hydroperiod; only hold water for a period of weeks to months during the wet season	• Fresh water (EC < 5,000 µS/cm), alkaline pH, generally low nutrient and metals levels • Elevated turbidity, nutrients and some metals at some sites associated with impacts from unrestricted livestock access and evapoconcentration	• Generally low salinity and metals levels • Elevated total nitrogen and total phosphorous levels, likely related to the breakdown of animal waste from unrestricted livestock access, along with evaopconcentration effects	• One aquatic macrophyte, 28 phytoplankton, 19 diatoms, all with Pilbara wide/cosmopolitan distribution • Low diversity of macrophytes and diatoms related to ephemeral regime • High abundance of phytoplankton recorded, associated with large numbers of the colonial green alga *Pediastrum* sp. and the dinoflagellate *Peridinium* sp.	• 51 invertebrate taxa, four fish species, two waterbirds • Invertebrate assemblages comprising transient and opportunistic taxa, able to rapidly colonise waterbodies following inundation • Fish fauna comprising species with high dispersal capabilities and tolerance of a wide range of environmental conditions (e.g. *Melanotaenia australis* and *Leioptherapon unicolor*).	• *Liasis olivaceus barroni* (Pilbara olive python) (BC Act and EPBC Act Vulnerable) • *Eurysticta coolawanyah* (damselfly) (IUCN Vulnerable) • *Calidris canutus* (red knot) (BC Act and EPBC Act Endangered)	**Low to Moderate**

Table ES 2: Summary of threatening processes and potential impacts to receiving environments associated with the WCOP.

Threatening Process	Receiving Environments	Conservation Significant Taxa Records Within Receiving Environments	Potential Impacts	Risk to Aquatic Biota, Justification and Key Assumptions
Discharge of excess groundwater to creeklines	• Ephemeral section of Warri Warri Creek prior to Brumby Creek confluence • Reach of Brumby Creek subject to current discharge • Oakover River within and downstream of current discharge extent	• *Eurysticta coolawanyah* (Pilbara pin damselfly) (IUCN Vulnerable) • *Actitis hypoleucos* (common sandpiper) (BC and EPBC Act Migratory) • *Pandion cristatus* (osprey) (BC and EPBC Act Migratory) • *Tringa glareola* (wood sandpiper) (BC and EPBC Act Migratory) • *Plegadis falcinellus* (glossy ibis) (BC and EPBC Act Migratory)	• Creation of perennial, albeit temporary (for the life of operations) flows, leading to a decrease in seasonal variation in hydrology, water quality and ecological processes • Increases in habitat availability and colonisation by aquatic biota • Increased algal/cyanobacterial growth (blooms), and/or direct toxicity to aquatic biota, due to elevated TN and nitrates	***Low*** • Aquatic ecosystems and biota likely naturally resilient to changes in hydrology, including increased, perennial flows during discharge operations, and declining flows upon cessation of discharge • Waterbodies subject to existing discharge (e.g. Brumby Creek, Oakover River downstream) host diverse and productive aquatic biota assemblages • Pilbara aquatic biota are likely inherently resilient to elevated TN and nitrate concentrations • Elevated TN and nitrate are likely to be localised within the immediate receiving environment of discharge • Appropriate outfall design will prevent physical impacts to creeklines • The immediate receiving environments have the adequate storage and flow capacity for the increased discharge volume
Groundwater drawdown from mine pit dewatering	• Temporary pools on ephemeral creeklines (Mungarathuna Creek, Warri Warri Creek) traversing the Development Envelope	• *Liasis olivaceus barroni* (Pilbara olive python) (BC and EPBC Act Vulnerable) • *Eurysticta coolawanyah* (Pilbara pin damselfly) (IUCN Vulnerable) • *Calidris canutus* (red knot) (BC and EPBC Act Endangered)	• Reduction or loss of pools within the predicted zone of groundwater drawdown	***Negligible*** • Groundwaters of the Development Envelope are already subject to historic drawdown • Ephemeral creeklines/temporary pools within the drawdown zone are not groundwater dependent and are unlikely to be affected by further declines in groundwater levels • Temporary pools within the Development Envelope are considered to be of low to moderate ecological value, in comparison to the nearby permanent/semi-permanent pools of the Oakover River • Drawdown will largely be constrained to within the east and west boundaries of the Development Envelope, due to the presence of low permeability faults and geological units,

Low: impact on a localised or temporary scale, with no irreversible damage to the aquatic ecosystem expected.
Negligible: No impact expected to aquatic ecosystem.

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1 Introduction

1.1 Background and Objectives

ConsMin owns and operates the Woodie Woodie Manganese Project (Woodie Woodie) located approximately 400 km southeast of Port Hedland in the Pilbara region of Western Australia (**Figure 1-1**). Woodie Woodie consists of 26 mining leases, 17 general purpose leases and one miscellaneous licence, with the capacity to process up to 5,000,000 tonnes of manganese ore per year (ConsMin 2020b). Mining takes place within several open satellite pits, some of which occurs below water table (BWT). Where not utilised in processing or site maintenance, surplus groundwater from BWT mining is discharged to the environment, the majority of which occurs via the W12 (Topvar) discharge outfall to Brumby Creek, an ephemeral creekline that traverses the Woodie Woodie active mining area.

ConsMin are seeking to expand their operations at Woodie Woodie, known as the Woodie Continued Operations Project (WCOP). The WCOP will require extension the currently approved operational boundary to the north, south and west, to create a development envelope of 12,708 ha (the Development Envelope). The WCOP will include mining and expansion of existing, as well as additional, open pits, some of which will occur BWT. Therefore, development of surplus surface water discharge infrastructure will likely be required within the Development Envelope, to facilitate further BWT mining, and supplement the existing discharge infrastructure located on Brumby Creek.

ConsMin have identified several potential impacts to surface waters which may be affected by the WCOP, including:

- Alteration of surface water flows in watercourses due to active discharge of excess water;
- Alteration to surface water quality and sediment quality downstream of discharge outfalls; and
- Mine dewatering resulting in changes to groundwater quality and quantity (and subsequent impacts to groundwater-supported surface waters) (ConsMin 2020b).

Given the potential for discharge and drawdown impacts to surface waters from the WCOP, Stantec Australia Pty Ltd (Stantec) were engaged by ConsMin to undertake an aquatic ecology baseline study of rivers and creeklines within, and adjacent to, the Development Envelope (the Study). The objective of the Study was to develop an understanding of existing aquatic ecology values of the Development Envelope and surrounds, to inform regulatory approvals for the proposed expansion and additional discharge of surplus water, aligning with the Western Australian Environmental Protection Authority (EPA)'s Inland Waters environmental factor. The objective was addressed by:

- Completing a desktop assessment on aquatic ecology values, focusing on previous records of conservation significant taxa;
- Undertaking dual phase (dry and wet season) field surveys, with systematic sampling of water quality, aquatic biota and vertebrate fauna;
- Identification of all aquatic biota and vertebrate fauna to genus or species level, where possible;
- Collation and analysis of data, including spatial and temporal investigation of aquatic ecology values; and
- Undertaking an assessment of the potential impacts on aquatic ecosystems and their biota related to increased discharge and drawdown impacts.

1.2 Existing Environment

1.2.1 Biogeographical Context

The Interim Biogeographic Regionalisation for Australia (IBRA) is a bioregional framework dividing Australia into 89 bioregions and 419 subregions based on climate, lithology/geology, landforms, soils, vegetation, flora and fauna, as well as land use (Thackway and Cresswall 1995). Woodie Woodie is located within the Chichester subregion of the Pilbara bioregion (**Figure 1-2**). The Chichester subregion is the largest of four Pilbara subregions, encompassing 47% (9,044,560 ha) of the Pilbara bioregion (McKenzie *et al.* 2009). Within the Chichester subregion, Woodie Woodie is situated among the southern Gregory Ranges, the most easterly ranges prior to the Great Sandy Desert (ConsMin 2020b).

The Chichester subregion comprises the northern section of the Pilbara Craton, an ancient and arid landscape characterised by undulating Archean granite and basalt plains with substantial areas of basalt ranges (Kendrick and McKenzie 2003). The basalt plains host a shrub steppe of *Acacia inaequilatera* over *Triodia* spp. hummock grasslands, while tree steppes of *Eucalyptus leucophloia* occur on the ranges (Kendrick and McKenzie 2003).

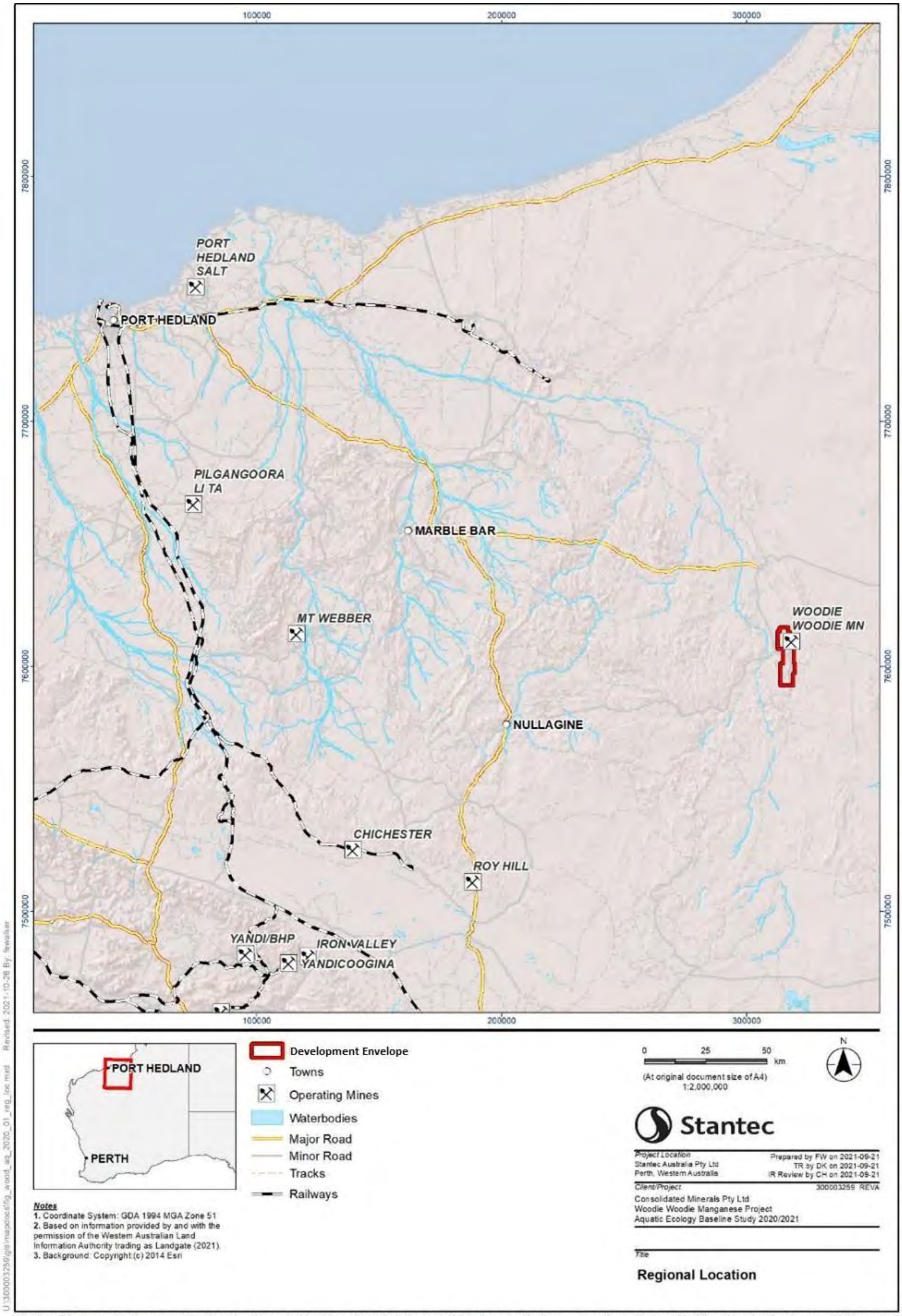

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Figure 1-1: Regional location of Woodie Woodie and the Development Envelope.

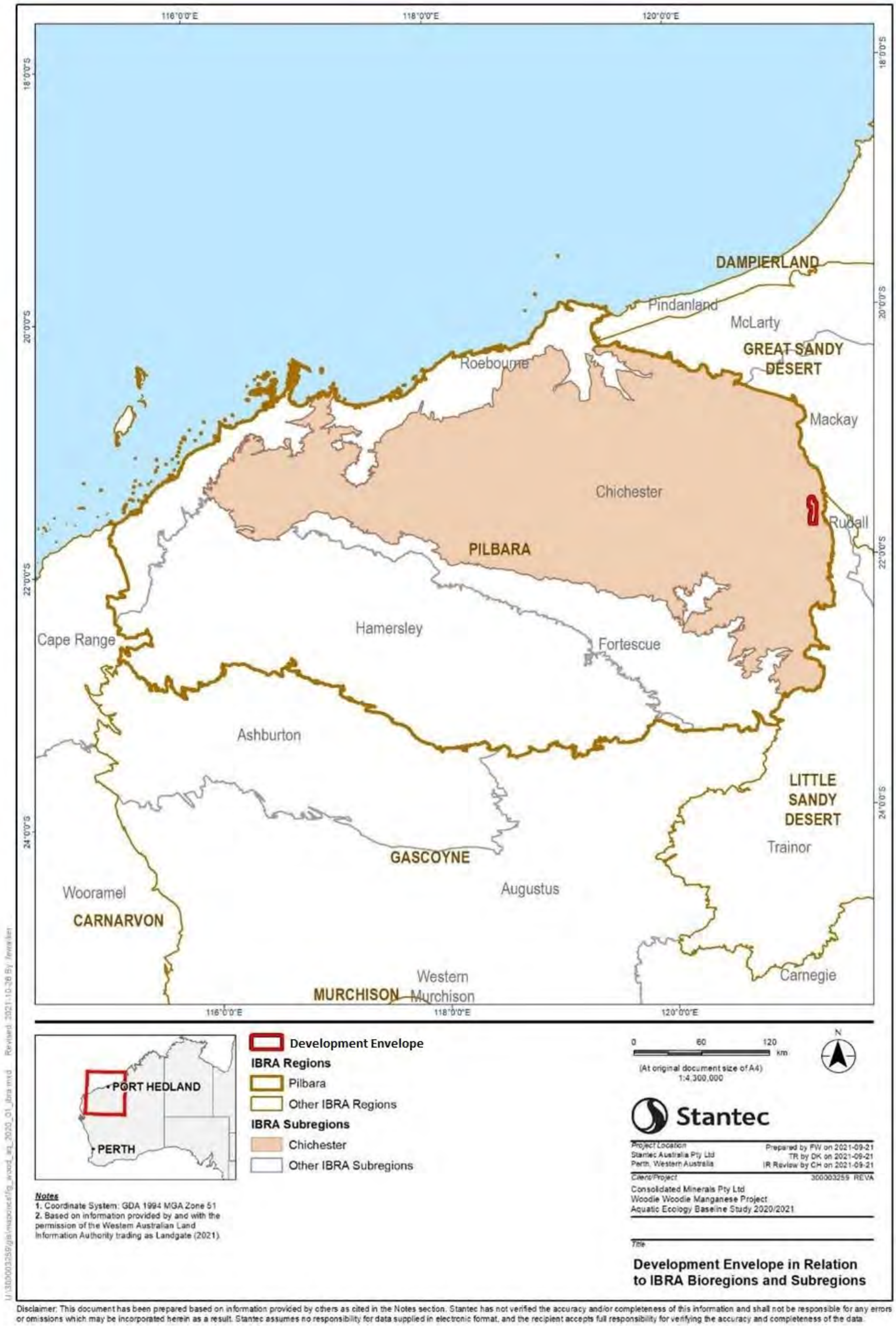

Figure 1-2: IBRA setting of the Development Envelope.

1.2.2 Climate

The Pilbara bioregion has an arid to semi-tropical climate, and hot, dry conditions prevail for most of the year (McKenzie *et al.* 2003). Rainfall in the region is highly seasonal, dependent on summer cyclones and autumn thunderstorms, with most rainfall occurring between December and March in response to tropical cyclone activity (**Figure 1-3**). In addition, high evaporation causes an extreme moisture deficit (Loomes and Braimbridge 2010).

The nearest Bureau of Meteorology (BOM) station where a complete dataset is available is Mandora (station number 004019), located approximately 200 km north of the Development Envelope. The long-term mean annual rainfall recorded at Mandora is 378 mm. In the six months prior to the Study (May to November 2020), Mandora recorded 145 mm of rainfall, over 80 mm more than the long-term May to November average (62 mm), due to high rainfall May. However, in the six months prior to the wet season survey (December to May), rainfall at Mandora was around 110 mm less than the long-term December to May average, with below average rainfall recorded in February, March, April and May. Temperatures at Mandora (and across the Pilbara region) generally exceed 35°C from October to March (**Figure 1-3**).

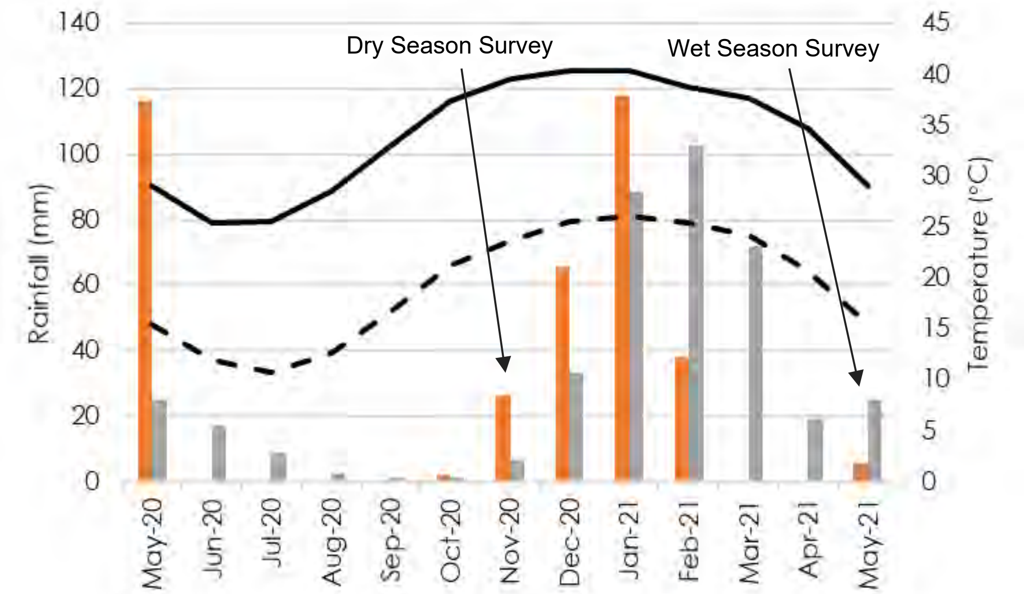

Figure 1-3: Monthly rainfall May 2020 to May 2021 (■), average monthly rainfall (■), average maximum temperature (—), and average minimum temperature (- - -) at Mandora BOM Station (004019).

1.2.3 Hydrology and Discharge

The dominant surface hydrological feature in the vicinity of the Development Envelope is the Oakover River, which flows in a northerly direction approximately 10 km to the west of the Development Envelope (**Figure 1-4**). The 376 km long Oakover River is a major tributary of the De Grey River, and has a catchment area of 16,383 km^2 (Loomes and Braimbridge 2010). The Oakover River itself has 22 tributaries, and numerous permanent pools, many of which are groundwater-fed (Loomes and Braimbridge 2010).

Three westerly flowing ephemeral tributaries of the Oakover River traverse the Development Envelope; Muddauthera Creek in the north, Brumby Creek in the centre, and Warri Warri Creek in the south (ConsMin 2020b) (**Figure 1-4**). Brumby Creek and Warri Warri Creek join to form a single tributary on the western boundary of the Development Envelope, which then joins the Oakover River approximately 4 km to the west (ConsMin 2020b) (**Figure 1-4**). Flow typically only occurs for a short period following wet season rainfall events, with no natural permanent, groundwater-supported waterbodies occurring within the Development Envelope. However, Muddauthera Creek does support a series of temporary pools which can persist for several months following rainfall (ConsMin 2020b).

Dewatering of several mine pits currently takes place at Woodie Woodie to facilitate mining BWT, with the majority of surplus water discharged to Brumby Creek (just upstream of its confluence with Warri Warri Creek), via the W12 (Topvar) discharge outfall (**Figure 1-4, Plate 1-1**). Discharge of surface water from W12 commenced in July 2015. However, in March 2016, Woodie Woodie was placed into care and maintenance, leading to cessation of discharge in September 2016. A total of 5.09 GL had been discharged to Brumby Creek to that point (**Table 1-1**). Discharge recommenced in September 2017 following resumption of operations. Since recommencement, discharge volume has ranged from 7.65 to 9.98 GL/annum, with a total of 32.05 GL discharged to Brumby Creek to September 2020 (**Table 1-1**), at an average rate of 0.31 m^3/s. Continual discharge to Brumby Creek means the system flows perennially, with discharge also influencing over 20 km of the Oakover River downstream of its confluence with Brumby Creek (**Figure 1-5**).

To enable further BWT mining over the life of the WCOP, it is anticipated that the discharge volume will increase to a maximum of 40 GL/annum, with a staged approach planned based on mine planning. Stage one, which will occur over the majority of the WCOP, will involve increasing the discharge volume from W12, with the total 40 GL/annum discharged directly to Brumby Creek. The second stage will involve the creation of a second discharge outfall (referred to as 'Canyon'), to be installed on Warri Warri Creek, as mining progresses towards the southern section of the Development Envelope (**Figure 1-4**). Under the second stage, it is expected that 75% (up to 30 GL/annum) will be discharged from Canyon to Warri Warri Creek, with the remaining volume discharged from W12.

Table 1-1: Volumes discharged to Brumby Creek (W12 discharge outlet) since July 2015.

Year	Discharge Volume (GL)
July 2015 - August 2016	5.09
September 2017 to August 2018	7.65
September 2018 to August 2019	9.98
September 2019 to August 2020	9.34
Total	32.05

Plate 1-1: The W12 (Topvar) discharge outfall.

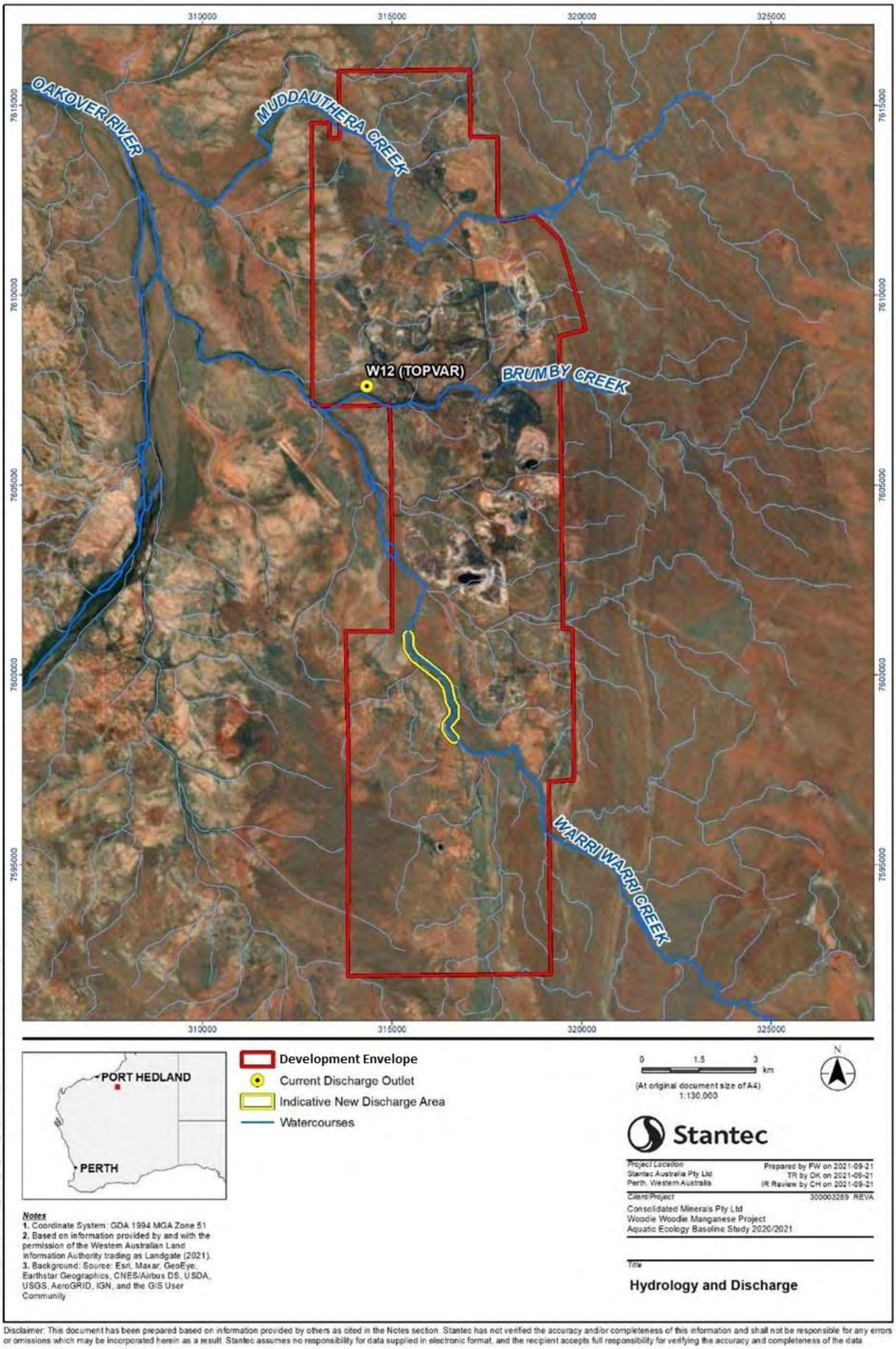

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Figure 1-4: Hydrology and catchments, showing W12 (Topvar) discharge point, Muddauthera Creek, Brumby Creek, Warri Creek (plus indicative discharge location) and the Oakover River.

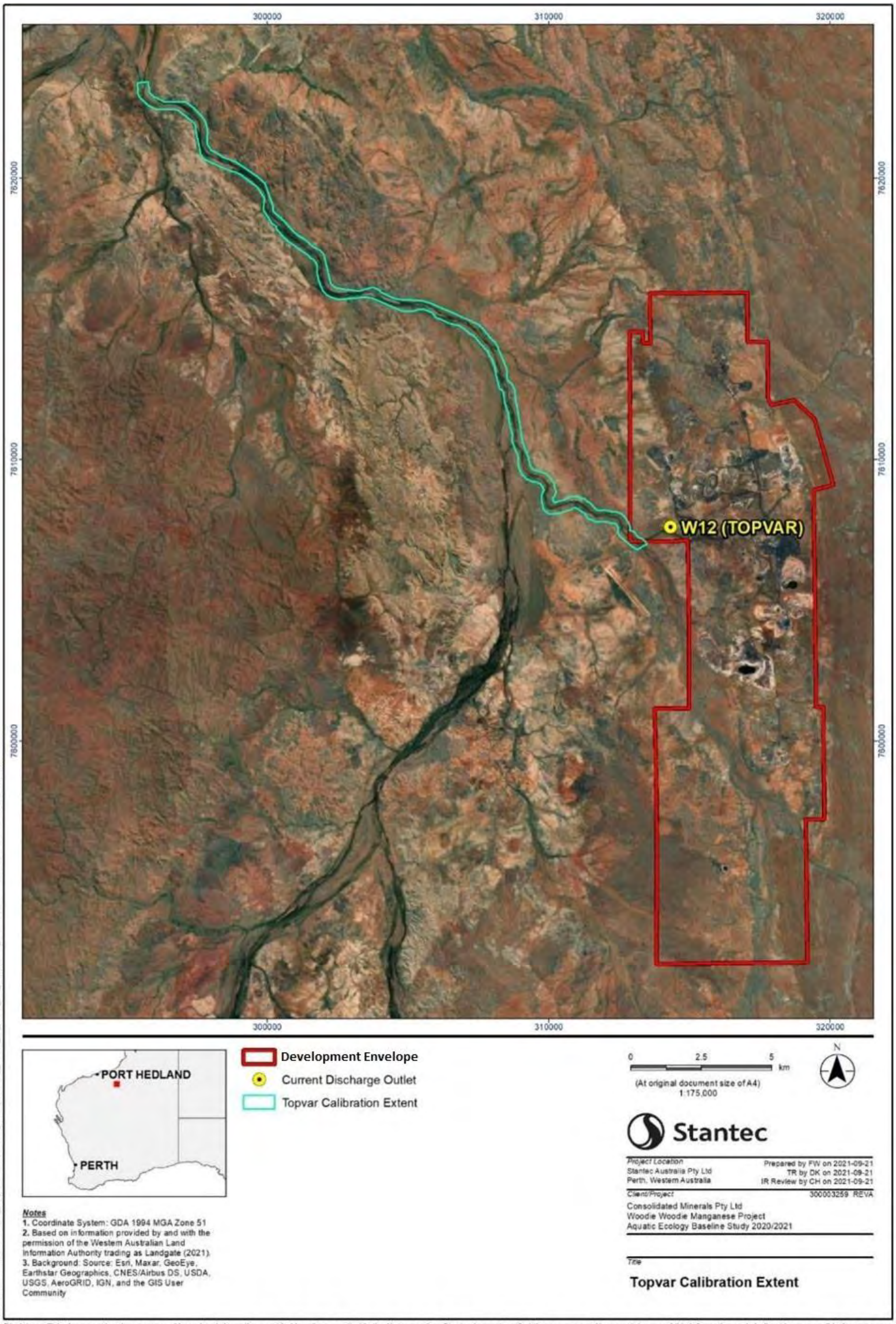

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Figure 1-5: Modelled current discharge (calibration) extent from the W12 (Topvar) discharge outfall (Cardno 2021).

1.2.4 Hydrogeology and Drawdown

The main aquifers of the Development Envelope are within the Pinjian Chert Breccia and the Upper Carawine Dolomite units, which together form the primary aquifer of the region (ConsMin 2020b). Several other lithologies in the Development Envelope form aquitards, including the Jeerinah, Lower Carawine Dolomite and the Paterson formations. The Pinjian Chert Breccia comprises a major aquifer of the Development Envelope and where present, is typically confined by the Paterson Formation, although it is otherwise unconfined. The Upper Carawine Dolomite unit, which is near the contact with the Pinjian Chert Breccia aquifer and/or manganese deposits, is also unconfined (ConsMin 2020b). The specific yield of the two aquifers is considered to be low due to low primary porosity, except in areas where large vughs and cavities have developed (ConsMin 2020b).

Groundwater in the Development Envelope generally flows in an east to west direction towards the Oakover River. Groundwater recharge occurs by rainwater infiltration through overlying unsaturated sediments, estimated to constitute approximately 15% of annual rainfall (ConsMin 2020b). Groundwater quality reflects rapid recharge from infiltrating groundwater, and is considered fresh to slightly brackish, circum-neutral to alkaline, low in metals but with relatively high nitrogen and nitrate concentrations, as is typical for groundwaters in the Pilbara region (ConsMin 2020b).

Depth to groundwater in the Development Envelope ranges from 10 to 200 m (**Figure 1-6**). Depth to groundwater is greater in the northern section of the Development Envelope (typically 80 to 200 m) (**Figure 1-6**), due to historic and ongoing dewatering of BWT pits (ConsMin 2020b). In the southern section of the Development Envelope, which has not been subject to as much dewatering, depth to groundwater typically ranges from 10 to 100 m, with shallowest depth to groundwater (<20 m) associated with the Warri Warri Creek drainage channel (**Figure 1-6**). Regardless, it is likely that drawdown is largely constrained to within the east and west boundaries of the Development Envelope, due to the presence of low permeability faults and geological units (ConsMin 2020b).

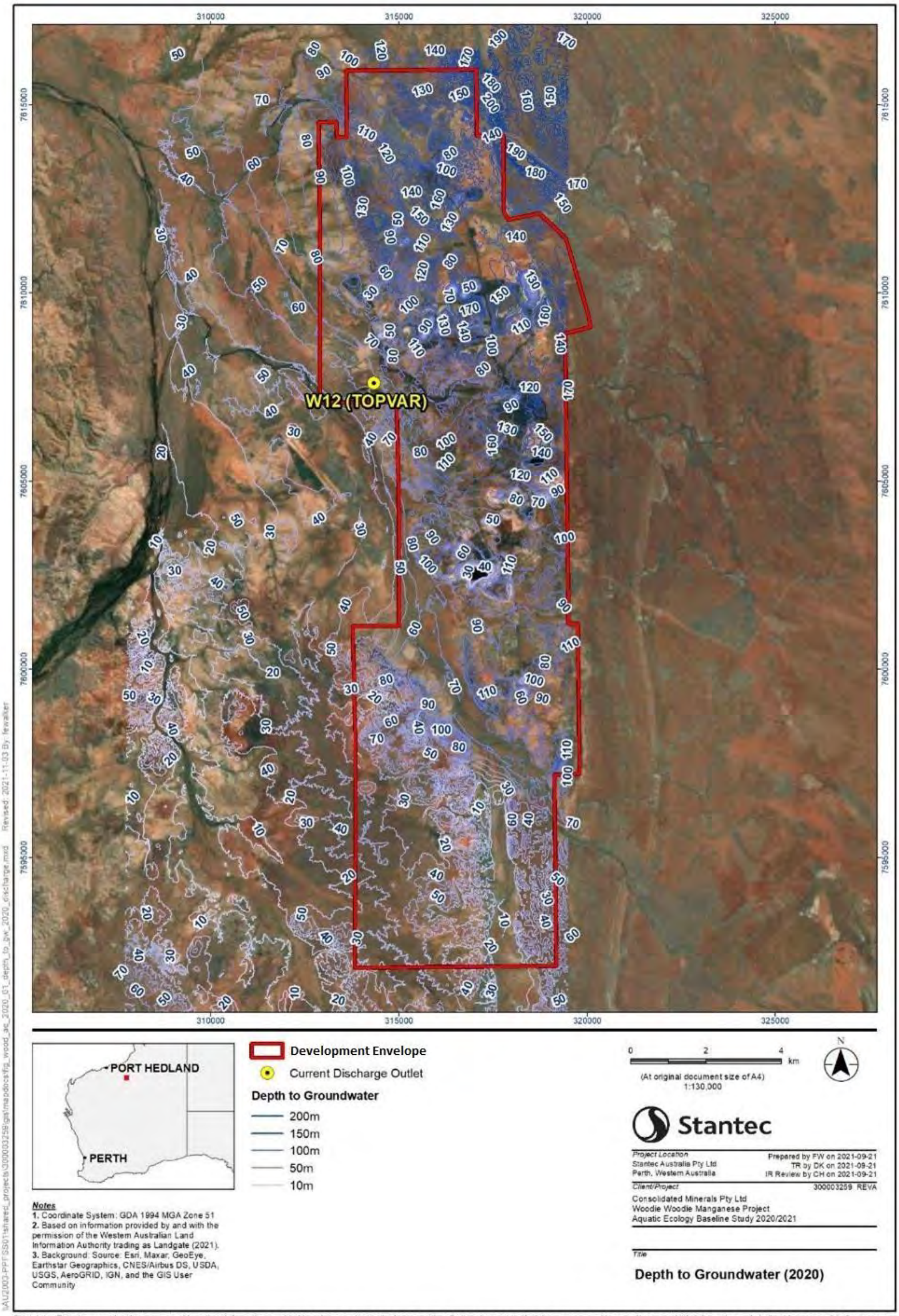

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Figure 1-6: Current (2020) depth to groundwater within and adjacent to the Development Envelope.

2 Methods

2.1 Desktop Assessment

2.1.1 Database Searches

Database searches were undertaken to determine the likelihood of the occurrence of communities and aquatic biota of conservation significance that are likely to occur within or adjacent to the Development Envelope. A community or species was deemed to be of conservation significance if it was listed under the Western Australian *Biodiversity Conservation Act 2016* (BC Act), the federal *Environment and Biodiversity Conservation Act 1999* (EPBC Act), or the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. A total of nine databases were searched or consulted, comprising State and Commonwealth resources (**Table 2-1**).

Table 2-1: Database searches conducted for the Study.

Custodian	Database Name	Method of Search	Buffer
Department of Biodiversity, Conservation and Attractions (DBCA)	NatureMap	Central coordinates 51K 311243 m E, 7606062 m S	40 km
Department of Agriculture, Water and the Environment (DAWE)	Protected Matters Search Tool (PMST)		50 km
DBCA	Threatened and Priority Fauna		
DBCA	Threatened Ecological Communities (TEC) and Priority Ecological Communities (PEC)		
Western Australian Museum (WAM)	Crustacea Database	Coordinates (51 K) NW Corner: 258386 m E, 7661108 m S SE Corner: 358567 m E, 7557597 m S	10,300 km^2
WAM	Entomology (Insect) Database		
WAM	Mollusc Database		
DAWE	Directory of Important Wetlands in Australia (DIWA)	Landgate Locate v5 Online Mapping Tool	Pilbara region
DAWE	Australian Ramsar Wetlands: Internationally Important Wetlands	Landgate Locate v5 Online Mapping Tool	Pilbara region

2.1.2 Literature and Data Review

A literature search of publicly available information relating to aquatic and riparian ecosystems was undertaken to gain an understanding of aquatic biota communities of the Oakover River system, including within or adjacent to the Development Envelope, where available. Information was compiled from reports, journals, and relevant government or regulatory publications and previous study data provided by ConsMin, as summarised in **Table 3-3**.

2.2 Field Survey

2.2.1 Sampling Rational

The objective of the EPA's Inland Water Environmental Factor Guideline (EPA 2018) is "*to maintain the hydrological regimes and quality of groundwater and surface water so that environmental values are protected*" (EPA 2018). Guidance focuses on impacts to significant ecosystems such as springs and pools, particularly in arid areas, as well as their aquatic biota and ecological processes

The EPA has not developed prescriptive technical guidance for surveying Inland Waters in Western Australia. However, the National Water Quality Management Strategy (NWQMS) provides a framework for the management of water quality in Australia and New Zealand; the Water Quality Management Framework (WQMF) (ANZG 2018; Australian Government 2018). To protect the environmental values of waterways, the WQMF applies a weight of evidence approach to collect, analyse and evaluate qualitative, semi-quantitative or quantitative environmental and biological lines of evidence (LoE), typically comprising a range of ecological components across multiple trophic levels, to make an overall assessment (Australian Government 2018).

Measuring indicators from multiple LoE provides greater weight (or certainty) to assessment conclusions, and subsequent management decisions. Therefore, and in accordance with the WQMF, the following LoE were selected to characterise and assess ecosystem condition in this Study, and sampled at each site:

- water quality;
- sediment quality;
- phytoplankton (algae);
- diatoms;
- aquatic macrophytes;
- aquatic invertebrates (zooplankton and macroinvertebrates);
- fish; and
- other aquatic vertebrates (frogs, reptiles and water birds).

2.2.2 Sites and Sampling Design

A total of 12 sites were sampled during the Study, comprising four sites within the current discharge footprint (downstream discharge sites), four sites upstream of the current discharge footprint (upstream reference sites), and four temporary pools on ephemeral creeklines within or adjacent to the Development Envelope (temporary pools) (**Table 2-2**, **Figure 2-1, Figure 2-2**). Of the downstream discharge sites, two were located on Brumby Creek (BCD1 and BCD2), and two were located on the Oakover River downstream of the Brumby Creek confluence (ORD1 and ORD1). Downstream discharge sites and reference sites (ORU1,2, 3 and 4) aligned with current Woodie Woodie water quality compliance monitoring sites, and were sampled in both the dry season (November 2020) and wet season (May 2021) (**Table 2-2**).

Of the four temporary pool sites, two were located on Muddauthera Creek within the Development Envelope (MCP1 and MCP2). The remaining two sites were located on Warri Warri Creek; one upstream (east) of the Development Envelope on the Nifty Access Road (NP), and downstream (west) of the Development Envelope within predicted discharge footprint of the proposed Canyon discharge outfall (WWC1) (**Table 2-2**). The temporary pools did not hold surface water during the dry season, and so were only sampled during the wet season survey (**Table 2-2**).

The field sampling program was led by Principal Aquatic Scientist Chris Hofmeester (10 years' experience), with assistance from Senior Aquatic Scientist Tom de Silva (dry season) and Graduate Aquatic Scientist Brianna Sullivan (wet season). Sampling assistance was also provided by ConsMin environment staff including Kaylee Prince, Jacqui Roberts and Luke Barret. Sampling was conducted under DBCA Regulation 27 Fauna Taking Licence BA27000346, and DPIRD Fisheries Exemption #3587.

2.2.3 Water Quality

At each site, *in situ* readings of pH, salinity (as electrical conductivity; EC), dissolved oxygen (% saturation and mg/L) and water temperature (degrees Celsius) were taken using a YSI Pro-Plus water meter. Additionally, water samples were collected for analysis of nutrients, anions and cations and dissolved metals, using sterilised bottles provided by the NATA-accredited Australian Laboratory Services (ALS), containing preservative where required. Nutrient and metals water samples were first filtered through a 0.45 μm Millipore filter, with samplers wearing nitrile gloves to avoid contamination. Bottles were sealed and kept cool for the duration of the field surveys, following which they were couriered to ALS (Wangara), for the analysis of the suite of parameters outlined in **Table 2-3.**

Analytical water quality results were compared to the Australian and New Zealand (ANZG 2018) Default Guideline Values (DGVs) for fresh waters. General parameters were compared against stressor DGVs for slightly-moderately disturbed ecosystems in tropical northern Australia, while dissolved metals were compared against toxicant DGVs at the level of 95% species protection (except for some potentially bioaccumulating metals, whereby 99% species DGVs were applied). Surface water pH was also classified according to the system developed by Foged (1978), comprising acidic (4.5 to 6.5), circumneutral (6.5 to 7.5), and alkaline (>7.5) conditions.

Table 2-2: Summary of sites sampled during the Study

System	Site	Type	Easting	Northing	Dry Season (Nov 2020)	Wet Season (May 2021)	Location
Oakover River	ORU1	Upstream Reference	294498	7581340	✓	✓	Approximately 30 km upstream (south) of the Oakover/Brumby Creek confluence (discharge inflow). Also known as Skull Springs.
	ORU2		306058	7600785	✓	✓	Approximately 10 km upstream (south) of the Oakover/Brumby Creek confluence (discharge inflow). Also known as Running Waters.
	ORU3		308669	7604415	✓	✓	Approximately 7 km upstream (south) of the Oakover/Brumby Creek confluence (discharge inflow). Located just downstream of the Oakover River crossing.
	ORU4		308571	7606663	✓	✓	Approximately 3 km upstream (south) of the Oakover/Brumby Creek confluence (discharge inflow).
Brumby Creek	BCD1	Downstream Discharge	314205	7607477	✓	✓	100 m downstream of the W12 (Topvar) discharge outlet.
	BCD2		311074	7608465	✓	✓	3.3 km downstream of the W12 (Topvar) discharge outlet.
Oakover River	ORD1		305331	7615606	✓	✓	Approximately 6.5 km downstream (northwest) of the Oakover/Brumby Creek confluence (discharge inflow). Within the minimum discharge extent of the W12 (Topvar) discharge outlet.
	ORD2		296091	7622712	✓	✓	Approximately 18 km downstream (northwest) of the Oakover/Brumby Creek confluence (discharge inflow). Within the minimum discharge extent of the W12 (Topvar) discharge outlet. Also known as Carawine Gorge.
Muddauthera Creek	MCP1	Temporary Pools	315246	7611960	Dry	✓	Northern section of the Development Envelope, very close (within 200 – 300 m) to several mine pits, within the zone of current and historic groundwater drawdown.
	MCP2		315118	7613376	Dry	✓	Northern section of the Development Envelope, very close (within 500 m) to several mine pits, within the zone of current and historic groundwater drawdown.
Warri Warri Creek	WWC1		314724	7603901	Dry	✓	Located approximately 3.5 km upstream (south) of the Warri Warri Creek/Brumby Creek confluence. Potentially within the predicted discharge footprint of the proposed second discharge outfall.
	NP		320771	7602059	Dry	✓	Located 3.5 km upstream (east) of the Development Envelope. Likely outside the zone of current and historic groundwater drawdown.

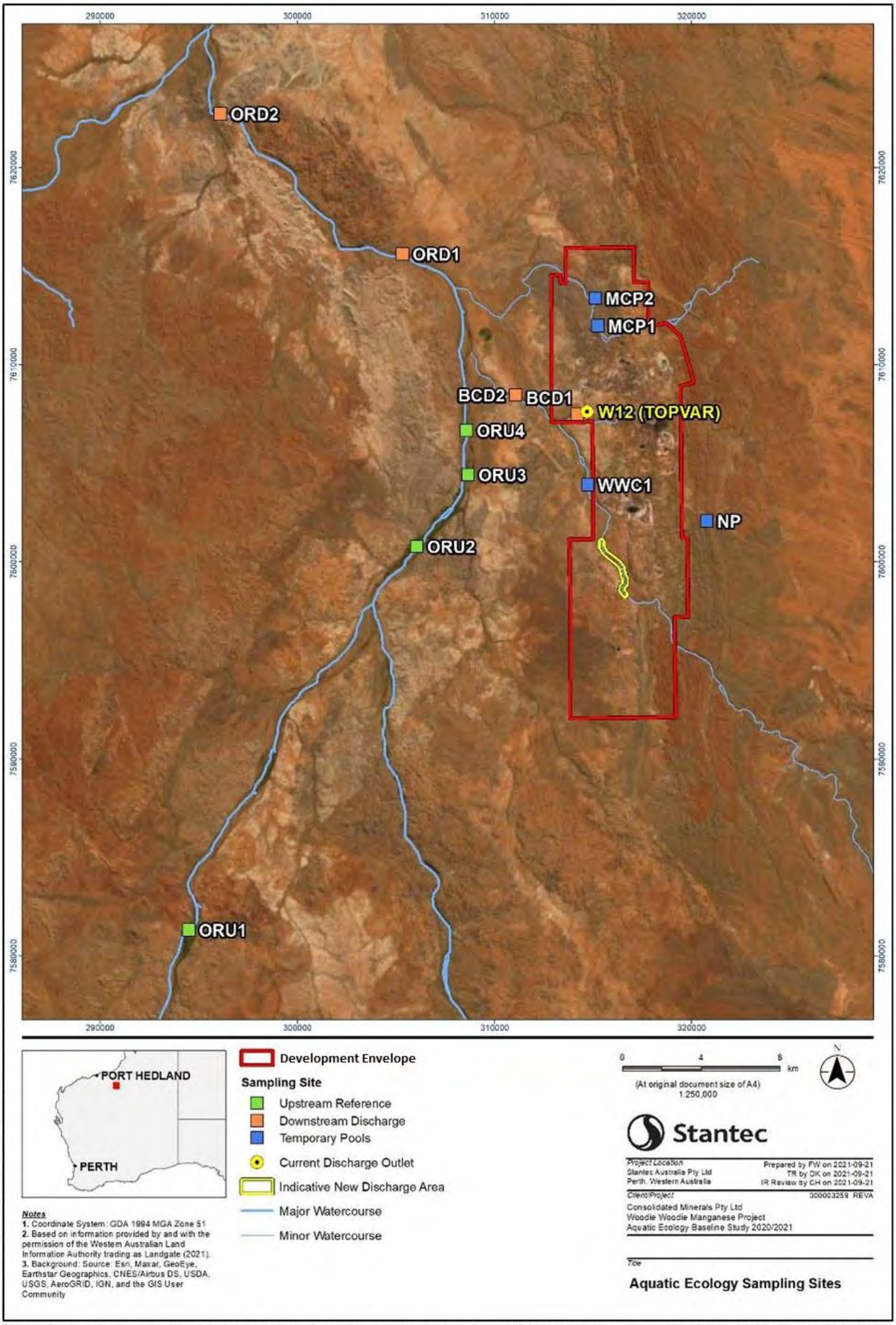

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Figure 2-1: Location of sites sampled during the Study.

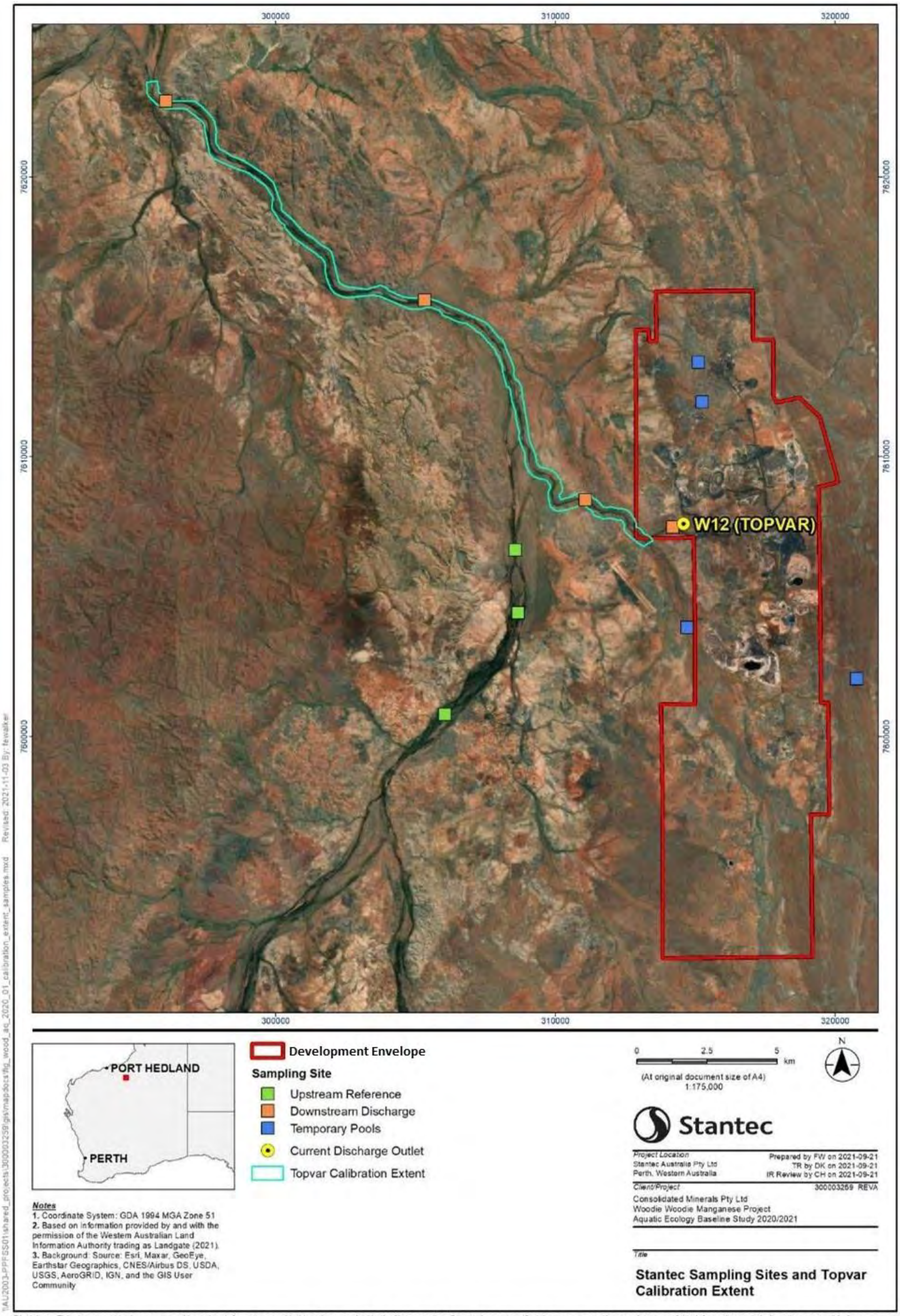

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Figure 2-2: Location of sites sampled during the Study, in relation to the current discharge extent from the W12 (Topvar) discharge outfall.

Table 2-3: Analytical suite for water samples collected during the Study.

Basic Parameters and Nutrients	Anions and Cations	Dissolved Metals	
pH	Chloride (Cl)	Aluminium (Al)	Iron (Fe)
Electrical Conductivity (EC)	Bicarbonate (HCO)	Arsenic (As)	Manganese (Mn)
Total Dissolved Solids (TDS)	Carbonate (CO)	Barium (Ba)	Molybdenum (Mo)
Turbidity	Sulphate (SO_4)	Boron (B)	Nickel (Ni)
Suspended Solids (SS)	Sodium (Na)	Cadmium (Cd)	Selenium (Se)
Nitrite + Nitrate (NO_x)	Magnesium (Mg)	Chromium (Cr)	Uranium (U)
Total Kjeldahl Nitrogen (TKN)	Calcium (Ca)	Cobalt (Co)	Vanadium (V)
Total Nitrogen (TN)	Potassium (K)	Copper (Cu)	Zinc (Zn)
Total Phosphorus (TP)		Lead (Pb)	

2.2.4 Sediment Quality

At each site, the top 2 cm of sediment was scraped into a sterilised glass jar (excluding voids), with samplers wearing nitrile gloves to avoid contamination. Jars were sealed and kept cool for the duration of the field surveys, following which they were couriered to ALS for the analysis of the suite of parameters outlined in **Table 2-4**.

Analytical sediment quality results were compared to the ANZG (2018) Default Guideline Values (DVGs) and Guideline Values-High (GV-High), with the latter indicating levels where toxic effects to biota may be expected. Sediment pH was also classified according to Hazelton and Murphy (2007), which ranges from very strongly acidic (<5.0) to very strongly alkaline (>9.0).

Table 2-4: Analytical suite for sediment samples collected during the Study.

Basic Parameters and Nutrients	Metals	
Electrical Conductivity (EC)	Aluminium (Al)	Lead (Pb)
Total Soluble Salts (TSS)	Arsenic (As)	Manganese (Mn)
Moisture Content	Barium (Ba)	Mercury (Hg)
Nitrite + Nitrate (NO_x)	Boron (B)	Molybdenum (Mo)
Total Kjeldahl Nitrogen (TKN)	Cadmium (Cd)	Nickel (Ni)
Total Nitrogen (TN)	Chromium (Cr)	Selenium (Se)
Total Phosphorus (TP)	Copper (Cu)	Uranium (U)
Total Organic Carbon (TOC)	Cobalt (Co)	Vanadium (V)
	Iron (Fe)	Zinc (Zn)

2.2.5 Macrophytes

Macrophytes (emergent and submerged forms) were opportunistically collected, where observed. Macrophyte samples were examined under a dissecting microscope in the laboratory and identified to genus or species level (where possible) using morphological and reproductive features. Taxonomic verification of macrophytes was undertaken by experienced taxonomist Chris Hofmeester, using appropriate taxonomic literature.

2.2.6 Phytoplankton

Phytoplankton was collected with a 20 µm mesh net, towed for approximately 30 m through the water column of each site. The net was thoroughly rinsed between sites to prevent cross-contamination. Phytoplankton samples were transferred into a 70 mL vial and kept cool to preserve algal structure. In the Stantec laboratory, three representative slides from each sample were mounted on glass microscopy slides and examined under a compound microscope at 40x magnification. The relative abundance of algal taxa from the phytoplankton samples was recorded, and was calculated per cell, colony, or filament, dependent on morphological form. Taxa were identified to genus and species level by experienced aquatic scientist Jake Daviot, with verifications provided by experienced algal taxonomists Dr Erin Thomas and Dr Fiona Taukulis, using appropriate taxonomic literature.

2.2.7 Benthic Diatoms

Benthic diatoms were opportunistically collected from the surface of twigs, sediments, rocks, debris and macrophytes in shallow waters at each site. Samples were placed in 50 mL polycarbonate containers and kept cool for preservation. In the Stantec laboratory, diatoms were treated in 70% nitric acid to remove organic material, and permanent slides were prepared. Three replicate slides were made from each sample, with enumeration and identification carried out at 100x magnification under a compound microscope. A maximum of 100 diatoms were counted from each site, to provide a representation of community structure. Taxa were identified by Jake Daviot to species level, where possible, with verification provided by Dr Fiona Taukulis, using relevant taxonomic guides.

2.2.8 Aquatic Invertebrates

Aquatic macroinvertebrates were sampled at each site using a 250 µm D-frame dip net using a kick/sweep motion (**Plate 2-1A**) over a distance of approximately 50 m, targeting all available habitat types including riffles, detritus, woody debris, open water column, benthic sediments and submerged and emergent macrophytes. Material retained in the dip net was emptied into a 250 µm, with large objects such as sticks and cobbles removed by hand. Samples were then transferred to a 1L polycarbonate container and preserved in 100% ethanol, for transfer to the Stantec laboratory. Microinvertebrates (zooplankton) were sampled using a 53 µm plankton net swept through the water column over a standardised (50 m) longitudinal reach. Samples were placed into 250 ml polycarbonate containers and preserved in 100% ethanol.

Each sample was processed under dissecting microscope, with specimens separated into their broad taxonomic groups (typically family level). Subsequently, each collected specimen was identified to lowest taxonomic rank possible (typically species-level) under dissecting and compound microscopes by Chris Hofmeester. For several aquatic microinvertebrate (zooplankton) groups, specialist identification and technical advice was also required (**Table** 2-5). For the purposes of data analysis and reporting, microinvertebrate and macroinvertebrate data was combined.

Table 2-5: Aquatic invertebrate taxonomy specialists utilised during the Study.

Group	Personnel	Affiliation
Ostracoda	Dr Stuart Halse	Bennelongia Environmental Consultants
Copepoda and Cladocera	Jane McRae	Bennelongia Environmental Consultants

2.2.9 Fish

Fish were targeted using integrated fishing methods, consisting of beach seine, gill netting (where it is deemed safe and appropriate to do so), and visual observation. At each site, gill nets of 10 mm, 13 mm, 19 mm and 25 mm mesh were deployed for a set time of 20 minutes, with nets constantly checked and cleared to ensure fish are not placed under undue stress. Two beach seine hauls (**Plate 2-1B**) were conducted at each site to target smaller bodied/juvenile species. All captured fish were placed in a 20 L bucket, and then identified, measured for standard length (from the tip of the snout to the posterior end of the last vertebra) and released. Fish nomenclature followed that of Allen *et al.* (2002).

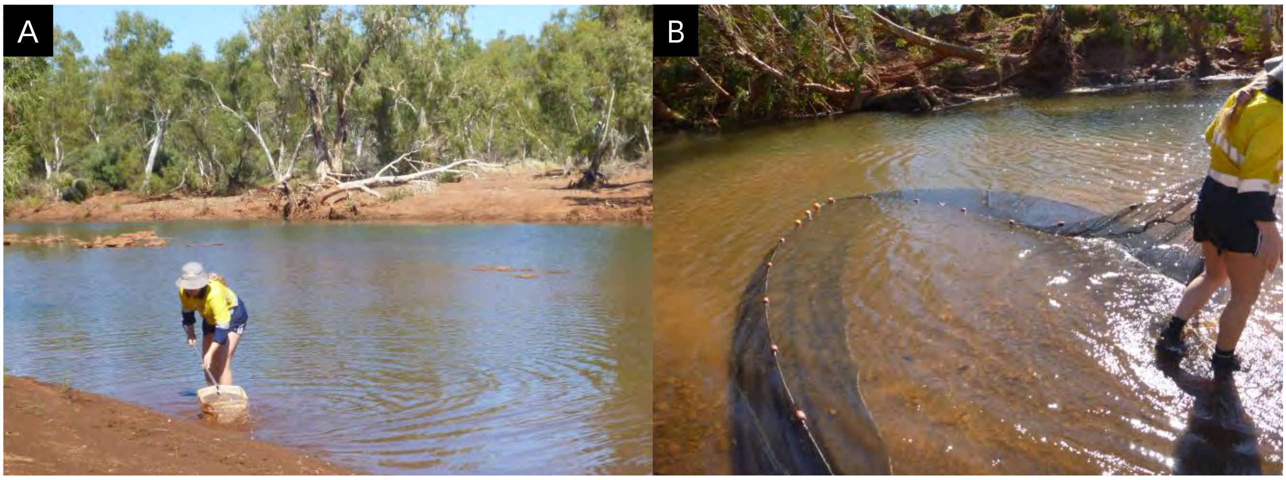

Plate 2-1: Examples of macroinvertebrate 'kick-sweep' sampling (A) and conducting a seine net haul targeting fish fauna (B).

2.2.10 Vertebrate Fauna

Opportunistic observations of other vertebrate fauna (frogs, freshwater turtles, waterbirds and Pilbara Olive Python) utilising aquatic ecosystems were made in the field, with identification to species level, where possible.

2.3 Statistical Analysis

Principal components analysis (PCA) was used to investigate patterns in abiotic parameters (water and sediment quality), while multidimensional scaling (MDS) was applied to biotic communities to determine relationships. These techniques were performed in the statistical package PRIMER, Version 7.0. PCA was applied to analytical water quality data from both seasons. Prior to analysis, values below the level of analytical detection were halved, while parameters with more than 50% of values below detection were removed from the dataset. Selected parameters were transformed to reduce skewness (ensuring the data was normally distributed) and collinear variables (those with a linear relationship) were removed during pre-treatment of the data. The results of the PCA are shown in the form of a plot, on which sites that are similar are located closer together. Vectors radiate from the centre of the plot, representing the influence of each parameter. Higher concentrations of a parameter tend to occur near the end point of the vector. The percentage variance is used to explain the strength of the PCA; presented over the first two axes of the plot. A value of more than 60% is considered a useful interpretation of the results (Clarke and Warwick 2001).

MDS analysis was performed on the algal, diatom and aquatic invertebrate data to determine similarities in community structure between sites. Prior to analyses, data was transformed where required, to reduce skewness. Similar to PCA, the results of the MDS procedure are represented as a plot, grouping sites with similar taxa composition together. The strength of the analyses is indicated by a stress value that is generated by the MDS, with a value of <0.2 providing an adequate explanation of the data (Clarke and Warwick 2001). The SIMPROF routine was also run in PRIMER, which detects statistically significant evidence of separate clusters amongst sites. Any significant clusters detected by SIMPROF were overlain as circles on the MDS plot (Clarke and Warwick 2001).

3 Results and Discussion

3.1 Desktop Assessment

3.1.1 Database Search

According to the database searches, one priority ecological communities (PEC) (DBCA 2020) occurs within 50 km of the Development Envelope; the Mosquito Land System (**Figure 3-1**). The Mosquito Land System is restricted to a small area to the east of Nullagine (approximately 50 km southwest of the Development Envelope), and is a unique land system comprising stony plains and projecting ridges on schist and other metamorphic rocks. Hummock grasslands cover the majority of the system, however, the stony saline plains support *Triodia longiceps* (knitting needle spinifex) grasslands with scattered chenopod shrubs such as *Maireana melanocoma* and the Priority species *Atriplex spinulosa (Van Vreeswyk et al. 2004).*

The nearest wetland of national significance, the De Grey River system, is located approximately 230 km to the north-west of the Development Envelope. The De Grey River stretches for a distance of 160 km from the confluence of the Oakover and Nullagine Rivers to the Indian Ocean near Poissonnier Point (DAWE 2020). The river supports an extensive series of permanent pools, which provide significant refuge for freshwater fishes and at least 20 species of waterbirds during the dry season and in drought conditions (DAWE 2020).

According to the NatureMap, Protected Matters and DBCA Threatened and Priority Database searches, a total of 147 bird, four amphibian, two fish, 450 invertebrate, 30 mammal and 94 reptile species have been recorded within 50 km of the Development Envelope. Of these taxa, 10 are listed for conservation significance and considered to be associated with inland waters (**Table 3-1**).

Of these, the red knot *Calidris canutus* (shorebird) and the Pilbara olive python *Liasis olivaceus barroni* have been recorded within the Development Envelope, where they are likely temporary visitors to ephemeral pools following inundation during the wet season. Meanwhile, the glossy ibis *Plegadis falcinellus,* wood sandpiper *Tringa glareola*, common sandpiper *Actitis hypoleucos*, osprey *Pandion cristatus* and Pilbara threadtail damselfly *Nososticta pilbara* have been recorded utilising pools and waterbodies of the Oakover River (and associated tributaries) adjacent to the Development Envelope (**Figure 3-2**). However, it should be noted that the record of *Nososticta pilbara* is likely erroneous, with recent comprehensive macroinvertebrate surveys of the Pilbara region suggesting this species is restricted to wetlands of the Millstream National Park (Pinder *et al.* 2010).

Searches of the WAM Insecta, Crustacea and Mollusc databases returned a total of 119 invertebrate records (43 insects, seven crustaceans and 69 molluscs) from the 10,300 km^2 search area. None of the taxa recorded are listed for conservation significance under the BC Act or EPBC Act. However, seven taxa were considered obligate aquatic species associated with inland waters, summarised in **Table 3-2**.

Table 3-1: Significant taxa associated with inland waters recorded from within 50 km of the Development Envelope.

Group	Taxa	Common Name	Significance	
			BC Act	EPBC Act
Bird	*Actitis hypoleucos*	Common Sandpiper	Migratory	Migratory
Bird	*Plegadis falcinellus*	Glossy Ibis	Migratory	Migratory
Bird	*Gelochelidon nilotica*	Gull-billed Tern	Migratory	Migratory
Bird	*Pandion cristatus*	Osprey	Migratory	Migratory
Bird	*Calidris canutus*	Red Knot	Endangered	Endangered
Bird	*Tringa glareola*	Wood Sandpiper	Migratory	Migratory
Bird	*Calidris ferrunginea*	Curlew Sandpiper*	Critically Endangered	Critically Endangered
Bird	*Rostratula alexandrae*	Australian Painted Snipe*	Endangered	Endangered
Reptile	*Liasis olivaceus barroni*	Pilbara Olive Python	Vulnerable	Vulnerable
Invertebrate	*Nososticta pilbara*	Pilbara Threadtail (Damselfy)	P2	-

Table 3-2: WAM aquatic invertebrate records from within the designated search area.

Group	Species	Common Name
Crustaceans	*Humphreyscandona capillus*	Copepod
	Leicacandona quasihalsei	Copepod
Insects	*Berosus dallasae*	Water scavenger beetle
	Pseudagrion microcephalum	Blue river damsel (damselfly)
	Diplacodes bipunctata	Wandering percher (dragonfly)
Molluscs	*Corbicula* sp.	Freshwater bivalve
	Gyraulus sp.	Freshwater snail

3.1.2 Literature Review

The literature review revealed that a limited number of studies have focussed on the aquatic biota of the Oakover River. In 1984, Masini and Walker (1989) undertook a study of inland waters of the Pilbara region, sampling phytoplankton (algae), fish and waterbirds with four sites sampled on the Oakover River. Between 2000 and 2002, Morgan and Gill (2004) undertook a comprehensive study of fish fauna across all major Pilbara river systems, including six sites on the Oakover River and associated tributaries. Subsequently, Pinder *et al.* (2010) completed a region-wide survey of aquatic invertebrates, collecting zooplankton (microinvertebrates) and macroinvertebrates from over 100 sites, eight of which were on the Oakover River. More recently (2019 to 2021), BHP and Rio Tinto have each commissioned aquatic fauna monitoring surveys, with Skull Springs (located on ConsMin tenure) sampled as a regional reference location.

Based on these studies, over 500 aquatic invertebrates, 16 algal taxa, nine fish and five waterbirds were recorded from the Oakover River system (**Table 3-3**). The majority were common with a widespread distribution. However, three taxa listed on the IUCN Red List of Threatened Species were recorded, including:

- *Eurysticta coolawanyah* (Pilbara pin damselfly);
- *Hemicordulia koomina* (Pilbara emerald dragonfly); and
- *Anguilla bicolor* (Indonesian short-finned eel).

Both *Eurysticta coolawanyah* and *Hemicordulia koomina* are endemic to the Pilbara region, where they inhabit streams, rivers and riverine pools (IUCN 2021b;c). Both species are listed as Vulnerable on the IUCN Red List as they are known from only a small range (extent of occurrence of less than 20,000 km^2 for *E. coolawanyah*, and less than 6,000 km^2 for *H. koomina*), with habitat alteration (declining water levels) due to development activities and climate change considered to be key threats to their persistence (IUCN 2021b). However, Pinder *et al.* (2010) recorded *H. koomina* from over 40 locations across the Pilbara, with *E. coolawanyah* recorded from over 15 locations, suggesting both species are more broadly distributed than proposed by the IUCN.

Anguilla bicolor is the only representative of the family Anguillidae (freshwater eels) known from Western Australia, and has only been recorded from the De Grey, Fortescue and Yule rivers in the Pilbara region (Morgan and Gill 2004). This species has a catadromous life cycle, spending most of its life (typically 20 years or more) in freshwaters, before migrating to the ocean to spawn and then die (Morgan and Gill 2004). It has a relatively widespread distribution across eastern and southern Africa, Southeast Asia and northern Australia, however, It is listed as Near Threatened on the IUCN Red List as it is targeted widely for human consumption and leather products across Asia (IUCN 2021a).

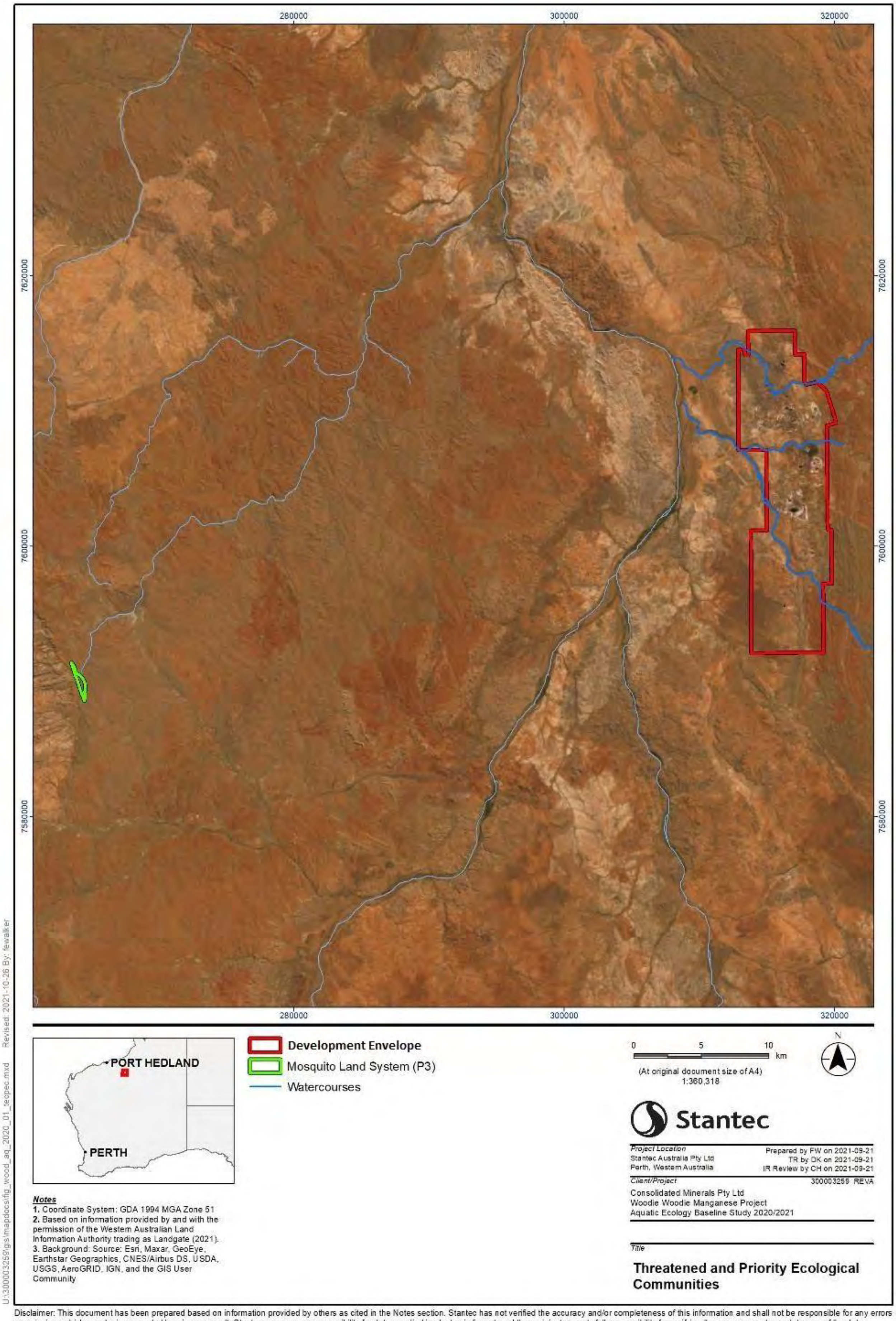

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Figure 3-1: TECs/PECs located within 50 km of the Development Envelope.

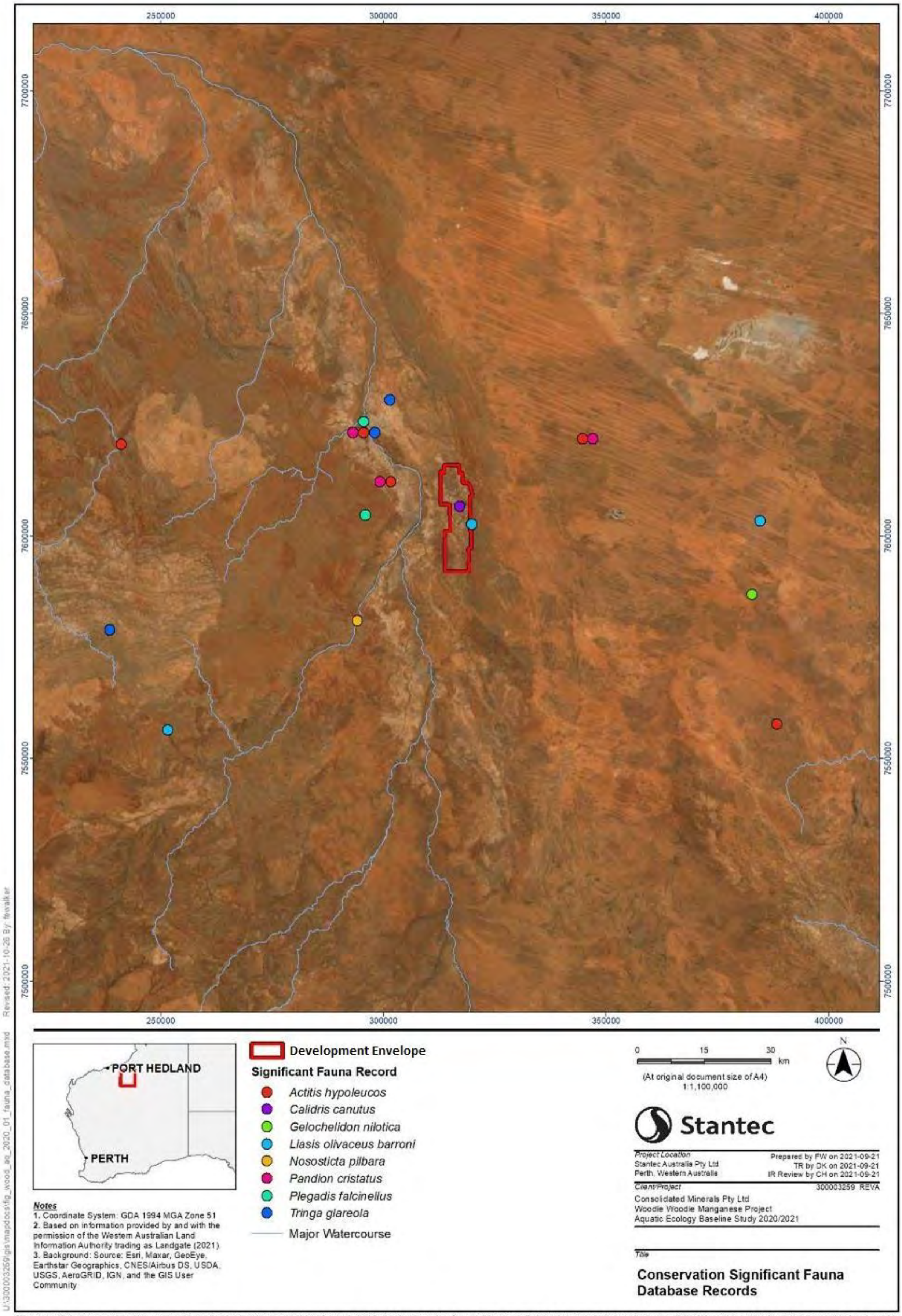


Figure 3-2: Database records for Threatened and Priority Fauna within 50 km of the Development Envelope.

Table 3-3: Literature search results of aquatic ecology studies undertaken on the Oakover River (and associated tributaries) in the vicinity of the Development Envelope.

Reference	Title	Sampling Components	Survey Timing	No. Sampling Locations (Oakover River)	Key Findings*
Masini and Walker (1989)	• Inland Waters of the Pilbara Western Australia Part II	• Water quality, • Algae, • Waterbirds	• October 1984	• Four sites	• Water quality typically alkaline (pH 7.5 to 9.5), fresh (EC <1500 µS/cm) and clear (<5 ppm TSS), total nitrogen > total phosphorous. • 16 algal taxa, comprising Chlorophyta (green algae), Cyanophyta (blue-green algae), Diatomaceae (diatoms) and Charales (Charophytes). • Five species of waterbird, including: – *Pelicanus conspicillatus* (Australian pelican); – *Phalacrocorax* sp. (cormorant); – *Ardea pacifica* (white-necked heron); – *Ardea novaehollandiae* (white-faced heron); and – *Anas superciliosa* (Pacific black duck)
Morgan and Gill (2004)	• Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia — evidence for three subprovinces	• Water quality • Fish	• December 2000 to November 2002	• Six sites	• Six obligate freshwater fish species, including: – *Nematalosa erebi* (bony bream); – *Arius graeffei* (lesser salmon catfish); – *Neosilurus hyrtlii* (Hyrtl's eel-tailed catfish); – *Melanotaenia australis* (western rainbowfish); – *Craterocephalus cuneiceps* (Murchison River hardyhead); and – *Leiopotherapon unicolor* (spangled perch). • Historic record of the IUCN Red Listed (Near Threatened) *Anguilla bicolor* (Indonesian short-finned eel) • Two estuarine/marine species, including: – *Mugil cephalus* (sea mullet); and – *Megalops cyprinoides* (tarpon).
Pinder *et al.* (2010)	• An arid zone awash with diversity: patterns in the distribution of aquatic invertebrates in the Pilbara region of Western Australia	• Aquatic invertebrates	• Autumn and spring, between 2003 and 2006	• Eight sites comprising: – Five clear river pools; – One ephemeral creek; and – Two spring/spring fed creek pools	• Total of 518 aquatic invertebrate taxa recorded, comprising 12 phyla/classes and over 100 families • Invertebrate taxa richness (per site) ranging from 35 to 164 • Two IUCN Red List taxa recorded: – *Eurysticta coolawanyah* (Pilbara pin damselfly), listed as Vulnerable; and – *Hemicordulia koomina* (Pilbara emerald dragonfly), also listed as Vulnerable.
Rio Tinto (2021)	• Raw data from a fish survey conducted at Skull Springs	• Fish	• June 2021 (late-wet season)	• One spring/spring fed creek pool	• Three fish species, including: – *Nematalosa erebi* (bony bream); – *Melanotaenia australis* (western rainbowfish); and – *Leiopotherapon unicolor* (spangled perch).
BHP (2020)	• Raw data from an aquatic biota survey conducted at Skull Springs and Running Waters	• Aquatic invertebrates, • Fish	• October 2019 and May 2020	• One spring/spring fed creek pool	• 66 to 72 invertebrate taxa (includes sampling of macroinvertebrates, zooplankton and hyporheic fauna) • No conservation listed taxa recorded • Four fish species, including: – *Nematalosa erebi* (bony bream); – *Melanotaenia australis* (western rainbowfish); – *Leiopotherapon unicolor* (spangled perch); and – *Megalops cyprinoides* (tarpon).

3.2 Field Survey

3.2.1 Habitat Characterisation

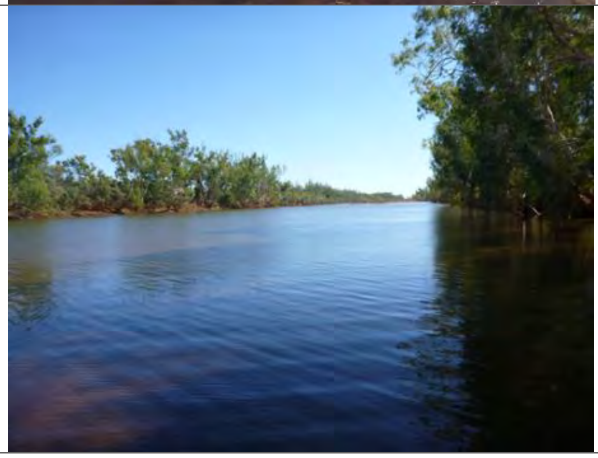
Due to a combination of an arid to semi-tropical climate, unique geography and geomorphology, and the presence of extensive alluvial aquifers, inland waterbodies of the Pilbara are diverse, comprising claypans, salt marshes, rockpools and springs, as well as creeks and rivers, the majority of which are ephemeral. However, some rivers feature permanent/semi-permanent pools, which are either fed by groundwater, or are located within large, rocky gorges (Pinder *et al.* 2010). Sites sampled during the study comprised a combination of permanent and semi-permanent riverine pools, perennial creeks (influenced by discharge) and temporary pools on ephemeral creeklines.

A summary of sampling sites, including a description of their morphological, hydrological, habitat and benthic substrate characteristics, is provided in **Table 3-4**. Of the 12 sites sampled during the Study, six were located on the Oakover River, including all four upstream reference sites, and two downstream discharge sites. Two of the upstream reference sites (ORU1 and ORU2) were permanent, spring-fed pools, with little variation between dry and wet season sampling (**Table 3-4**). Comparatively, the other two upstream reference sites (ORU3 and ORU4) were semi-permanent pools influenced by rainfall, comprising small, shallow waterbodies in the dry season, and large, deep pools during the wet season (**Table 3-4**).

The two downstream sites on the Oakover River (ORD1 and ORD2) were also permanent waterbodies. ORD1 shared similar morphological, substrate and habitat features to ORU3 and ORU4 upstream, however, there was little change in pool size and depth between dry and wet season sampling due to discharge influence (**Table 3-4**). ORD2 was a more typical permanent riverine pool, being located at the base of a large, rocky gorge, which is sufficiently deep and shaded for water to persist permanently (**Table 3-4**). Both permanent and semi-permanent riverine pools of the Pilbara are considered ecologically important, as they support the highest diversity of aquatic fauna of any wetland type in the region, as well as providing critical refugia for aquatic and terrestrial biota in an otherwise arid landscape (Pinder *et al.* 2010).

The remaining sites were located on ephemeral creeks traversing the Development Envelope. Ephemeral creeks of the Pilbara region typically only flow following cyclonic rainfall, where high, scouring currents occur for several days, followed by a period of declining ‘baseflows’ lasting a few weeks. Thereafter, waters recede to temporary pools that rarely persist for more than six months (Pinder *et al.* 2010). Temporary pool sites WWC1, MCP1, MCP2 and NP were examples of the latter, only holding water during wet season sampling (**Table 3-4**). Comparatively, the remaining two discharge sites, BCD1 and BCD2, flow perennially due to discharge from the W12 outfall (**Table 3-4**). These sites were therefore considered more representative of the spring-fed creek systems that occur throughout the Pilbara region, which typically present as short sections of permanently flowing water with alternating riffles and small pools (Pinder *et al.* 2010).

Table 3-4: Habitat characterisation and photographs of upstream reference sites, downstream discharge sites, and temporary pools sampled during the Study,

Site	Dry Season	Wet Season	Description
Upstream Reference Sites			
ORU1			Situated within a broad (over 500 m wide) section of the upper Oakover River, with surface hydrology characterised by a series of groundwater-fed braided riffles and clear water pools. Due to groundwater influence, there was minimal change in surface hydrology or habitat between dry and wet season sampling. The pool sampled was large; 200 m in length and 30 m wide. Maximum pool depth was approximately 1.5 m. Benthic substrate composition consisted of a complex of coarse alluvial material, including gravel, pebbles and cobbles, with some scattered larger boulders, and small areas of bedrock. In-stream habitat comprised submerged and emergent macrophytes, large woody debris, and organic detritus, as well as large beds of filamentous algae. The riparian zone was broad (between 200 – 300 m width on either side of the pool), dominated by an overstorey *Melaleuca argentea,* and an understorey of sedges including *Cyperus* spp. and *Eleocharis* spp. Also known as Skull Springs.
ORU2			Located within a broad (over 700 m wide) section of the upper Oakover River, comprising a very large (over 1 km long, 20 m wide), clear, spring-fed pool. Maximum pool depth 2.5 m. Benthic substrates consisted of a complex of coarse alluvial material, including gravel, pebbles and cobbles, overlying a hard rocky base. In-stream habitat included large woody debris, overhanging branches, dense root mats, with some small patches of submerged macrophytes and filamentous algae. The riparian zone was broad (between over 300 m width on either side), dominated by an overstorey *Melaleuca argentea,* and an understorey of sedges including *Cyperus* spp. and *Eleocharis* spp. Also known as Running Waters.
ORU3			A semi-permanent riverine pool, with surface hydrology primarily influenced by rainfall. During the dry season, the pool was a small (5 m in length, 0.5 m in depth) and clear, located within a pit of scoured bedrock. During the wet season, the pool was broad (over 200 m length) relatively deep (over 1.5 m) and slightly turbid. Dense macrophyte and algal growth was recorded, particularly in the dry season, though in stream habitat was otherwise limited. Benthic substrate composition was dominated by coarse riverine alluvial substrates (gravel, pebbles and cobbles) over a hard rocky base. In the wet season, this was overlain by a thick layer of clay and silt, particularly on the pool margins. The riparian zone primarily comprised a dense fringe of *Melaleuca argentea* and *Eucalyptus* spp., becoming sparse with distance from the central river channel.
ORU4			A relatively small (30 m) and very shallow (0.4 m) turbid pool during the dry season, expanding to a large pool over 200 m in length and 1.5 m deep during the wet season. Macrophyte and algal growth was dense in both seasons, while 'green water' was present in the dry season, indicating a bloom of green algae or cyanobacteria. In stream habitat was limited in the dry season, but more variable in the wet season (comprising large woody debris, dense root mats and organic detritus), due to the greater size and coverage of the pool. Benthic substrate composition was dominated by coarse riverine alluvial substrates (gravel, pebbles and cobbles), overlain by a thick layer of clay and silt, particularly on the pool margins. The riparian zone comprised a dense fringe of *Melaleuca argentea* and *Eucalyptus* spp. Cattle were observed drinking from the pool during both seasons.

Site	Dry Season	Wet Season	Description
Downstream Discharge Sites			
BCD1			A narrow (15 m wide), shallow (0.2 to 0.6 m) section of creekline, flowing perennially due to discharge from the Topvar (W12) outfall located 100 m upstream. Benthic substrate composition primarily consisted of coarse alluvial material, including gravel, pebbles and cobbles. In-stream habitat comprised large beds of submerged and emergent macrophytes, large woody debris, and organic detritus. The riparian zone was narrow (between 10 – 20 m width on either side of the channel), dominated by an overstorey *Melaleuca argentea* and *Eucalyptus* spp., and an understory of scattered *Cyperus* spp. There was limited change in surface hydrology or habitat between the dry and wet seasons due to discharge influence.
BCD2			A relatively narrow (20 m wide) section of creekline, just downstream of the Woodie Woodie access road. Flows perennial due to discharge from the Topvar (W12) outfall, located ~3.3 km upstream. Benthic substrates primarily consisted of gravel, pebbles and cobbles, forming shallow (0.2 to 0.4 m deep) riffle zones between deeper pools (up to 1 m) overlying scoured bedrock. In-stream habitat comprised large beds of submerged and emergent macrophytes (with *Typha domingensis* particularly abundant), large woody debris, and organic detritus. The riparian zone was narrow (between 10 – 30 m width on either side of the channel), comprising *Melaleuca argentea* and *Eucalyptus* spp. over scattered *Cyperus* sedges. There was limited change in surface hydrology or habitat between the dry and wet seasons due to discharge influence.
ORD1			A permanent riverine pool, with surface hydrology influenced by discharge, as well as rainfall. During both seasons, the pool was broad (over 200 m length) relatively deep (over 1 m), with clear water in the dry season, and slightly turbid water in the wet season. Dense macrophyte was recorded in both seasons, particularly on the pool edges, causing a build-up of clay and silt. Otherwise, benthic substrate composition was dominated by coarse riverine alluvial substrates (gravel, pebbles and cobbles). In stream habitat comprised large woody debris, dense root mats and organic detritus. The riparian zone primarily comprised a dense fringe of *Melaleuca argentea* and *Eucalyptus* spp., becoming sparse with distance from the central river channel. Cattle were observed drinking from the pool during both seasons.
ORD2			An extensive, permanent riverine pool located at the base of a large gorge and cliff face. During both seasons, the pool was broad (over 500 m length, 70 m wide), very deep (over 2m), with slightly turbid water. Dense macrophyte beds were present in both seasons, particularly on the pool edges, causing a build-up of clay and silt. Otherwise, benthic substrate composition was dominated by coarse riverine alluvial substrates (gravel, pebbles and cobbles). Organic detritus was also abundant along with pool margins, although the riparian zone was sparse, with a narrow fringe of *Mealeuca* and *Eucalyptus* spp. along the pool margins. Also known as Carawine Gorge.

Site	Dry Season	Wet Season	Description
Temporary Pools			
MCP1	Not Sampled		A temporary pool located at the base of a small, rocky cliff face, with surface hydrology influenced by rainfall. Surface water was absent in the dry season. During the wet season, the pool was relatively small (20 m long, 10 m wide), but deep, with a maximum depth of over 2 m at the base of the cliff face. Benthic substrates comprised a matrix of sand and gravel, over a hard rocky base. In stream habitat was limited to some small patches of leaf litter and detritus on the pool margins. Riparian vegetation was absent. There was evidence of heavy cattle usage.
MCP2	Not Sampled		A relatively large (200 m long, 10 m wide, 1 m deep) pool at the base of a large, rocky cliff face. Surface water was absent in the dry season. Dense filamentous algae and macrophyte growth was recorded during the wet season, particularly on the pool edges, causing a build-up of clay and silt. Otherwise, benthic substrate composition was dominated by sand and gravel over hard bedrock, and instream habitat comprised scattered large woody debris, leaf litter and other organic detritus. Riparian vegetation was sparse, with a small number of *Eucalyptus* on the pool margins. There was evidence of heavy cattle usage.
NP	Not Sampled		A series of moderately sized (30 to 50 m long, 10 to 20 m wide, 0.5 to 1 m deep) pools within a narrow gorge. Surface water was absent in the dry season. Benthic substrates comprised a matrix of sand and gravel over a hard rocky base. In-stream habitat was limited to some small patches of leaf litter and detritus on the pool margins. Riparian vegetation was largely absent. Cattle were observed drinking at the pool during sampling.
WWC1	Not Sampled		A very small (10 m long by 3 m wide), shallow (max depth 0.3 m) pool against an incised area of riverbank. In stream habitat was limited to some small patches of organic detritus and leaf litter, with no macrophyte growth, although 'green water' was present, indicating a bloom of green algae or cyanobacteria. Benthic substrates comprised a matrix of sand, gravel and pebbles, underlying a shallow layer of silts and clay. The riparian zone was sparse, with some scattered *Eucalyptus*. There was evidence of heavy cattle usage.

3.2.2 Water Quality

The pH measurements from surface waters during the Study ranged from circumneutral (7.2 at ORU2 during the dry season) to alkaline (9.25 at WWC1 during the wet season) (Hazelton and Murphy 2007). Overall, pH was spatially and seasonally homogenous, including at downstream discharge (range 7.78 to 8.87), upstream reference (range 7.2 to 8.51) and temporary pool (range 8.35 to 9.25) sites (**Table 3-5**, **Table 3-6**). Surface water pH was above the ANZG (2018) upper DGV for lowland rivers of tropical northern Australia (6.5 to 8.0) at most sites during both seasons (**Figure** 3-3**C**). However, this is considered typical for semi-permanent river pools and spring fed pools of the Pilbara, as documented by Pinder *et al.* (2010). The pH of surface waters can vary according to factors such as surface runoff (which may be poorly buffered), the presence of organic matter and local catchment geology (Boulton and Brock 1999). Primary productivity also has a strong influence on pH (Reddy and DeLaune 2008) and during photosynthesis, algae and macrophytes can remove carbon dioxide and alter the buffering capacity of surface waters, which is known to cause large increases in pH (Schütte and Elsworth 1954).

Salinity, measured as electrical conductivity (EC) was considered fresh (<5,000 µs/cm) at all sites in both seasons (Williams 1998b) (**Table 3-5**, **Table 3-6**). During the dry season, EC at discharge sites ranged from 880 µs/cm (ORD1) to 1,322 (BCD1), while EC at upstream reference sites ranged from 741 µs/cm (ORU1) to 4,241 µs/cm (ORU4) (**Table** 3-5, **Table 3-6**). Wet season EC was generally lower, and ranged from 582 µs/cm (BCD2) to 1,200 µs/cm (BCD1) at discharge sites, 476 µs/cm (ORU1) to 1,086 µs/cm (ORU2) at upstream reference sites, and from 313 µs/cm (NP) to 683 µs/cm (WWC1) at temporary pools (**Table 3-5**, **Table 3-6**).

High variation in salinity between the dry and wet seasons was mostly associated with semi-permanent river pools (e.g. ORU3, ORU4, ORD2), with EC likely increasing during the dry season due to evapoconcentration effects, and being diluted by fresh rainwater during the wet season. Comparatively, sites influenced dewatering discharge (e.g. BCD1, BCD2, ORD1), as well as permanent, groundwater-fed pools (e.g. ORU1 and ORU2) remain fresh during the dry season due the discharge of low EC groundwater. Although EC exceeded the ANZG (2018) DGV of 250 µs/cm at all sites in both seasons (**Figure 3-3B**), EC values Pilbara riverine systems typically exceed this level (Pinder *et al.* 2010), and there is a general acceptance that when conductivity is less than 1500 µS/cm, arid zone freshwater ecosystems experience little ecological stress (Dunlop *et al.* 2005).

Ionic composition at all sites was dominated by Na, with Mg/Ca sub-dominance interchangeable, followed by K (**Table** 3-5, **Table 3-6**). The dominance of anions followed HCO_3 > Cl > SO_4 > CO_3 at the majority of sites. Overall, major ion composition did not substantially change across sites between seasons. The ionic composition of waterbodies in the Pilbara can vary markedly (Pinder *et al.* 2010), and is typically influenced by factors such as catchment geology, groundwater influence and evapoconcentration (Hart and McKelvie 1986).

Dissolved oxygen (mg/L) (DO) measurements showed a relatively normal range across all sites in both seasons, representing well oxygenated surface waters, with only a few records below 2.0 mg/L, considered low (**Table 3-5**, **Table 3-6, Figure 3-3A**). DO at downstream discharge sites ranged from 2.09 mg/L at ORD1 (dry season) to 9.58 mg/L at ORD2 (wet season), while at upstream reference sites, DO ranged from 1.28 mg/L at ORU4 (dry season) to 9.16 mg/L at ORU4 (wet season). Among the temporary pools, DO ranged from 8.41 mg/L (NP) to 17.11 mg/L (WWC1). (**Table 3-5**, **Table 3-6, Figure 3-3A**).

Low levels of DO are associated with anoxia, which can potentially lead to mortality of aquatic biota, as well as the of release nutrients and metals bound in sediments (Connell 2005). However, while concentrations below 2 mg/L, or approximately 25% oxygen saturation (at 25°C), are considered critically limiting (Williams 1998a), dissolved oxygen exhibits substantial diurnal variation in response to biological and physical processes (Boulton and Brock 1999; Reddy and DeLaune 2008). Super-saturation, where DO is above 100% saturation, occurs when net photosynthesis exceeds total oxygen consumption and is common in areas of high algal growth. Super-saturated DO was recorded at WWC1, which was a small shallow pool when visited, with a high amount of algal growth evident (**Table 3-4**).

Surface waters were generally clear at the time of sampling, with turbidity below the ANZG (2018) DGV (15 NTU). The exceptions were the temporary pools WWC1 and NP during the wet season, and the upstream reference site ORU4 during the dry season (**Figure 3-3D**). Elevated turbidity at these sites was related to the suspension of fine sediments caused by cattle, which were observed utilising each of these sites (**Plate 3-1A,B**).

During the dry season, concentrations of total nitrogen (TN) at downstream discharge sites ranged from 0.2 mg/L (ORD1 and ORD2) to 1.8 mg/L (BDC1), while during the wet season, TN ranged from 0.2 (ORD2) to 1.7 mg/L (BCD1). TN exceeded ANZG (2018) stressor (eutrophication) DGV (0.3 mg/L) at BCD1, BCD2, ORU2 and ORU4 in the dry season, and at BCD1, BCD2, ORD1, ORU2 and all temporary pools sites during the wet season (**Table 3-5, Table 3-6, Figure 3-4A)**. The two Brumby Creek downstream discharge sites (BCD1 and BCD2) and one upstream reference site (ORU2) also recorded nitrite+nitrate (nitrate) concentrations greater than the stressor DGV of 0.7 mg/L, during both the wet and dry seasons (**Table 3-5, Table 3-6, Figure 3-4A**). In addition, nitrate concentration exceeded the toxicity DGV for 95% species protection at ORU2 in the dry season (**Figure 3-4C**).

Elevated TN and nitrate are characteristic of discharge water from Woodie Woodie, with TN concentrations at the W12 discharge outfall typically ranging between 1.4 and 2 mg/L, and nitrate ranging between 1.5 and 1.9 mg/L (ConsMin

2020a), reflected in the current data from BCD1 and BCD2. More broadly, this is associated with naturally elevated TN in groundwater, mostly occurring as nitrate, which is common across the Pilbara region, primarily derived from nitrogen-fixing vegetation (Appleyard 2000). Naturally elevated TN in groundwater was also expressed in surface waters at the spring-fed reference site ORU2. TN concentrations at ORU2 were 3.3 mg/L and 2.3 mg/L, and nitrate concentrations were 2.99 and 2.01 mg/L, in the dry and wet seasons, respectively.

Overall, highest TN concentration was recorded at temporary pool WWC1 (13 mg/L), several orders of magnitude higher than the ANZG (2018) DGV (**Table 3-5, Table 3-6, Figure 3-4A**). Elevated TN at temporary pools was associated with unrestricted livestock access, evapoconcentration effects, as well as the presence of nitrogen-producing cyanobacteria which were in bloom at WWC1 the time of sampling. Total phosphorus (TP) concentrations were also in exceedance of ANZG (2018) DGVs at temporary pool sites WWC1 and MCP1, as well as all sites (except ORU1) during the dry season (**Table 3-5, Table 3-6, Figure 3-4B**). Elevated TP is also considered typical of Pilbara surface waters, particularly in the dry season, attributed to the ubiquitous presence of livestock as well as evapoconcentration of pools (Pinder *et al.* 2010). TP concentrations are typically below analytical detection limits in Woodie Woodie discharge water (ConsMin 2020a).

The majority of dissolved metals were recorded at levels below respective analytical detection limits and/or ANZG (2018) DGVs (**Table 3-5**, **Table 3-6**). Three exceptions included:

- Dissolved boron, which slightly exceeded the 95% DGV (0.94 mg/L) at reference site ORU4 during the wet season (1.04 mg/L) (**Figure 3-5A**);
- Dissolved copper, which slightly exceeded the 95% DGV (0.0014 mg/L) at temporary pool WWC1 during the wet season (0.0016 mg/L) (**Figure 3-5B**); and
- Dissolved zinc, which exceeded the 95% DGV (0.008mg/L) at BCD1 during the wet season (0.014 mg/L) (**Figure** 3-5**C**).

Naturally elevated dissolved boron, copper and dissolved zinc are commonly reported from surface waters of the Pilbara region, more broadly associated with local geology and the weathering of sedimentary rocks (WRM 2009;2015;2017). Elevated dissolved zinc at discharge site BCD1 is unlikely to be related to discharge, as concentrations at W12 are typically below analytical detection limits (ConsMin 2020a).

Overall, water quality was relatively homogenous at upstream reference, downstream discharge and temporary pools across both the wet and dry seasons, reflected in the PCA with the majority of sites forming a large cluster (**Figure** 3-6). However, water quality was distinct at two sites, as shown by the PCA:

- temporary pool WWC1; and
- upstream reference site ORU4 during the dry season.

Both sites comprised small, shallow pools and had strongly alkaline pH (>8.5), turbid water, low (ORU4) or supersaturated (WWC1) DO, and elevated nutrient concentrations. Additionally, ORU4 also recorded the highest EC and dissolved boron concentrations of any site in either season. Both sites were being used heavily by cattle and experiencing cyanobacterial blooms, with impacts exacerbated by evaopoconcentration effects, as both pools were reaching the end of their hydroperiod (drying out) at the time of sampling (**Plate 3-1A,B**).

Plate 3-1: Photographs showing cattle drinking from ORU4 during the dry season (A), and the receded nature of WWC1 in the wet season (B).

Table 3-5: Summary of water quality results at downstream discharge and upstream reference sites during the dry season 2020.

Water Quality Parameters		LOR	Downstream Discharge				Upstream Reference				ANZG (2018)	
			BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	Stressor DGVs	Toxicant DGVs
Basic	pH (unit)		7.99	8.20	8.32	8.87	7.47	7.20	8.12	8.52	6.5 - 8.0	-
	Total Dissolved Solids	10	662	570	562	658	410	646	796	4190	-	-
	Dissolved Oxygen		7.47	6.27	2.09	5.81	1.57	3.79	5.32	1.28	-	-
	Electrical Conductivity (µS/cm)		1,322	1,041	880	1,259	742	1,185	1,451	4,241	250	-
	Suspended Solids	5	<5	<5	<5	<5	<5	<5	<5	20	-	-
	Turbidity (NTU)	0.1	0.2	1.1	1.3	1.6	1.5	<0.1	4.4	16.7	15	-
Ions	Sodium	1	134	102	124	148	52	75	99	854	-	-
	Magnesium	1	45	38	46	48	35	51	66	314	-	-
	Calcium	1	46	37	26	14	47	66	48	28	-	-
	Potassium	1	5	4	6	8	5	10	12	83	-	-
	Chloride	1	159	125	142	210	58	149	262	1960	-	-
	Sulphate	1	72	54	52	66	19	84	114	81	-	-
	Bicarbonate	1	323	298	320	255	299	303	249	757	-	-
	Carbonate	1	19	27	19	49	<1	<1	12	164	-	-
Nutrients	Total Nitrogen	0.1	1.8	0.9	0.2	0.2	<0.1	3.3	0.1	3.2	0.3	-
	Total Phosphorus	0.01	0.01	0.01	0.02	0.01	<0.01	0.02	0.02	0.06	0.01	-
	Total Kjeldahl Nitrogen	0.1	0.2	0.1	0.2	0.2	<0.1	0.3	0.1	3.2	-	-
	Nitrite + Nitrate	0.01	1.56	0.84	<0.01	<0.01	<0.01	**2.99**	<0.01	<0.01	0.7 [E]	2.1 [T]
Metals & Trace Elements	Aluminum	0.01	<0.005	<0.005	<0.005	0.0100	<0.005	<0.005	0.0050	0.0090	-	0.055
	Arsenic	0.00	0.0004	0.0006	0.0010	0.0008	0.0003	0.0002	0.0005	0.0096	-	0.024
	Barium	0.00	0.004	0.020	0.110	0.111	0.470	0.010	0.176	1.250	-	-
	Boron	0.01	0.294	0.260	0.280	0.320	0.168	0.267	0.237	**1.040**	-	0.94
	Cadmium	0.00	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	-	0.002
	Chromium	0.00	0.0006	0.0003	<0.0002	<0.0002	<0.0002	0.0006	<0.0002	0.0003	-	0.00031
	Cobalt	0.00	<0.0001	<0.0001	<0.0001	<0.0001	0.0003	<0.0001	<0.0001	0.0008	-	-
	Copper	0.00	<0.0005	<0.0005	<0.0005	0.0007	<0.0005	<0.0005	<0.0005	0.0006	-	0.0014
	Iron	0.00	0.002	0.010	0.012	0.007	0.012	<0.002	0.020	0.114	-	0.7
	Lead	0.00	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.0034
	Manganese	0.00	0.004	0.014	0.035	0.004	0.859	0.003	0.060	0.548	-	1.9
	Molybdenum	0.00	0.0007	0.0008	0.0010	0.0012	0.0005	0.0003	0.0006	0.0014	-	-
	Mercury *	0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	-	0.00006
	Nickel	0.00	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0027	-	0.011
	Selenium *	0.00	0.0022	0.0017	0.0006	<0.0002	<0.0002	0.0022	0.0005	0.0005	-	0.008
	Uranium	0.00	0.0025	0.0022	0.0016	0.0019	0.0005	0.0018	0.0019	0.0020	-	-
	Vanadium	0.00	0.0016	0.0026	0.0029	0.0026	0.0007	0.0014	0.0023	0.0064	-	-
	Zinc	0.00	<0.001	<0.001	0.0020	<0.001	<0.001	<0.001	0.0010	0.0020	-	0.008

- *all units are in mg/L unless stated otherwise;*
- *E denotes Eutrophication guideline; T denotes Toxicant guideline; asterix (*) denotes 99% DGV applied for bioaccumulating toxicants;*
- *values below the limit of reporting (LOR) are shown in grey text; and*
- *grey shading indicates values exceeding respective ANZG (2018) DGVs; bold text indicates values exceeding 95% DGV for toxicants.*

Table 3-6: Summary of water quality results at downstream discharge, upstream reference and temporary pool sites during the wet season 2021.

Water Quality Parameters		LOR	Downstream Discharge				Upstream Reference				Temporary Pools				ANZG (2018)	
			BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP	DGVs	Toxicant DGVs (95%)
Basic	pH (unit)		7.78	8.45	8.46	8.53	8.09	7.29	8.51	8.33	9.25	8.35	8.65	9.09	6.5 - 8.0	-
	Total Dissolved Solids	10	594	623	594	426	294	602	408	500	426	228	278	176	-	-
	Dissolved Oxygen		7.79	7.28	5.08	9.58	8.4	5.05	8.74	9.16	17.11	11.5	11.26	8.41	-	-
	Electrical Conductivity (µS/cm)		1,200	582	923	727	476	1,065	717	839	683	342	442	313	250	-
	Suspended Solids	5	<5	<5	<5	<5	<5	<5	<5	<5	1380	6	<5	31	-	-
	Turbidity (NTU)	0.1	0.4	1.4	2.4	4.1	0.5	0.6	1.6	4.3	962	4	1.3	13.6	15	-
Ions	Sodium	1	114	121	110	76	33	75	62	72	77	23	28	28	-	-
	Magnesium	1	42	43	45	34	26	50	37	43	26	16	38	13	-	-
	Calcium	1	45	41	43	40	40	66	38	54	27	39	33	19	-	-
	Potassium	1	4	4	7	7	4	10	8	8	16	6	5	6	-	-
	Chloride	1	119	130	148	96	36	132	89	106	85	30	28	19	-	-
	Sulphate	1	53	57	65	39	13	73	40	54	43	5	6	5	-	-
	Bicarbonate	1	377	318	277	222	206	288	212	263	205	170	238	124	-	-
	Carbonate	1	2	18	13	9	<1	<1	14	<1	<1	<1	12	9	-	-
Nutrients	Total Nitrogen	0.1	1.7	1.2	0.3	0.2	0.2	2.3	0.2	<0.1	13	0.6	0.3	0.6	0.3	-
	Total Phosphorus	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	1.36	0.02	0.01	0.01	0.01	-
	Total Kjeldahl Nitrogen	0.1	0.2	0.2	0.1	0.2	<0.1	0.3	0.2	<0.1	13	0.5	0.3	0.6	-	-
	Nitrite + Nitrate	0.01	1.5	1.02	0.16	0.02	0.16	2.01	<0.01	<0.01	<0.01	0.1	<0.01	<0.01	0.7 [E]	2.1 [T]
Metals & Trace Elements	Aluminum	0.0050	<0.005	<0.005	0.0060	0.0050	<0.005	<0.005	<0.005	<0.005	0.0060	0.0100	<0.005	0.0200	-	0.055
	Arsenic	0.0002	0.0003	0.0004	0.0004	0.0005	<0.0002	<0.0002	0.0003	0.0003	0.0013	0.0004	0.0005	0.0005	-	0.024
	Barium	0.0005	0.0030	0.0267	0.1390	0.1850	0.2110	0.0593	0.1140	0.1460	0.0913	0.1120	0.1750	0.0377	-	-
	Boron	0.005	0.227	0.231	0.213	0.160	0.075	0.187	0.153	0.127	0.249	0.062	0.101	0.081	-	0.94
	Cadmium	0.0001	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	<0.00005	-	0.002
	Chromium	0.0002	0.0006	0.0004	<0.0002	<0.0002	<0.0002	0.0004	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	-	0.0034
	Cobalt	0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0007	0.0001	0.0001	0.0003	-	-
	Copper	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0005	<0.0005	0.0016	0.0010	0.0009	0.0014	-	0.0014
	Iron	0.0020	0.0050	0.0060	0.0070	0.0060	0.0320	0.0050	0.0040	0.0120	0.0200	0.0090	0.0150	0.0300	-	0.7
	Lead	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-	0.0034
	Manganese	0.0005	0.004	0.007	0.010	0.069	0.083	0.010	0.002	0.038	0.043	0.005	0.037	0.009	-	1.9
	Molybdenum	0.0001	0.0008	0.0009	0.0009	0.0007	0.0003	0.0003	0.0004	0.0004	0.0037	0.0010	0.0010	0.0016	-	-
	Mercury *	0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	<0.00004	-	0.00006
	Nickel	0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	0.0014	<0.0005	0.0006	0.0006	-	0.011
	Selenium *	0.0002	0.0014	0.0014	0.0006	<0.0002	<0.0002	0.0014	<0.0002	<0.0002	0.0003	<0.0002	<0.0002	<0.0002	-	0.008
	Uranium	0.0001	0.0020	0.0020	0.0018	0.0013	0.0004	0.0015	0.0010	0.0011	0.0040	0.0005	0.0007	0.0006	-	-
	Vanadium	0.0002	0.0018	0.0024	0.0030	0.0040	0.0011	0.0012	0.0025	0.0016	0.0127	0.0015	0.0026	0.0068	-	-
	Zinc	0.0010	**0.0140**	<0.001	<0.001	<0.001	0.0030	0.0010	<0.001	0.0060	0.0010	0.0020	<0.001	<0.001	-	0.008

- *all units are in mg/L unless stated otherwise;*
- *E denotes eutrophication guideline; T denotes toxicant guideline; asterix (*) denotes 99% DGV applied for bioaccumulating toxicants;*
- *values below the limit of reporting (LOR) are shown in grey; and*
- *grey shading indicates values exceeding respective ANZG (2018) DGVs; bold text indicates values exceeding 95% DGV for toxicants.*

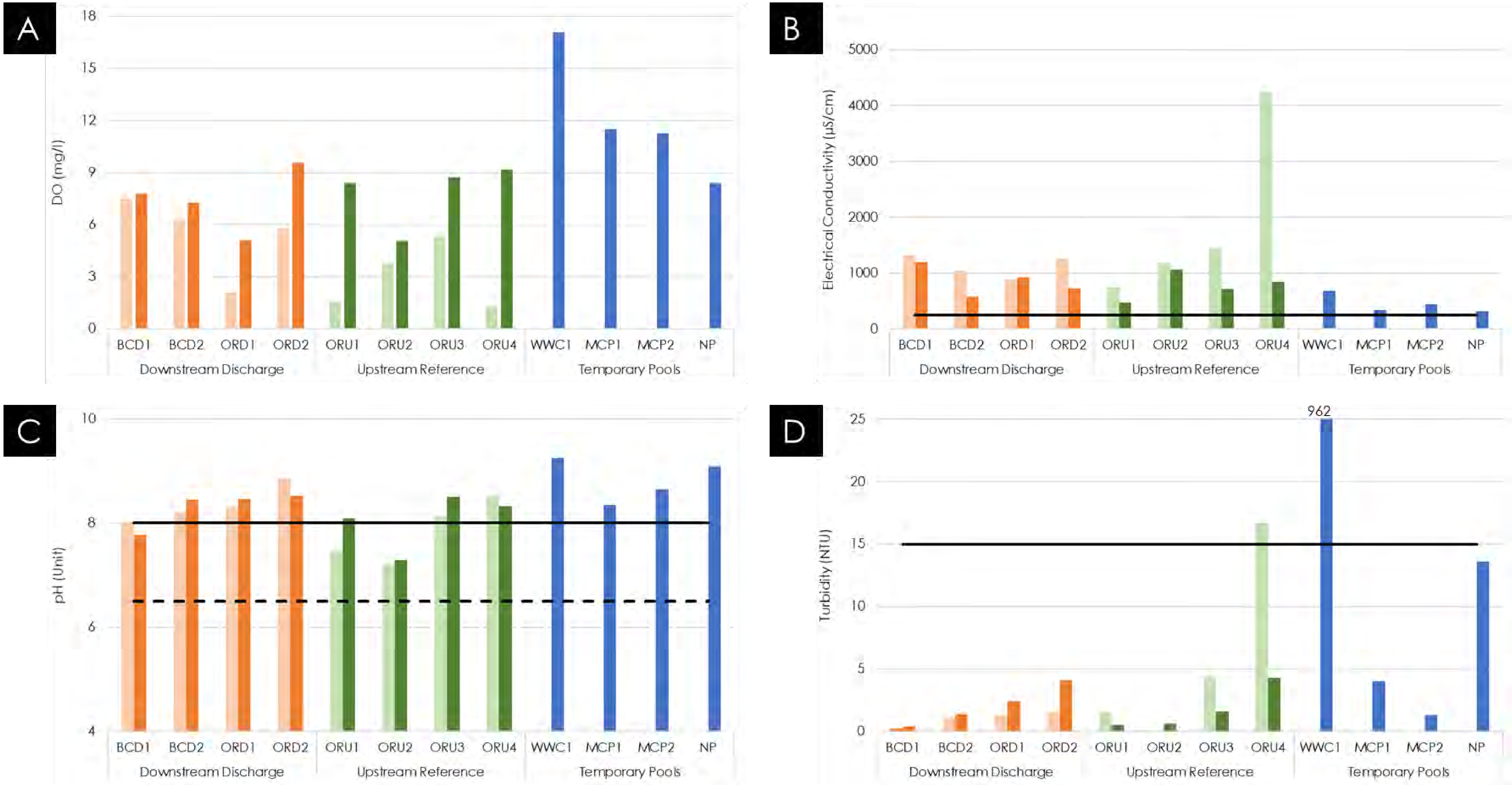


Figure 3-3: Water quality of downstream discharge, upstream reference and temporary pool sites during the Study; (A) dissolved oxygen, (B) salinity, (C) pH, and (D) turbidity, showing ANZG (2018) lower (---) and upper (—) stressor DGVs (■■ = dry season, ■■ = wet season and ■ = temporary pools).

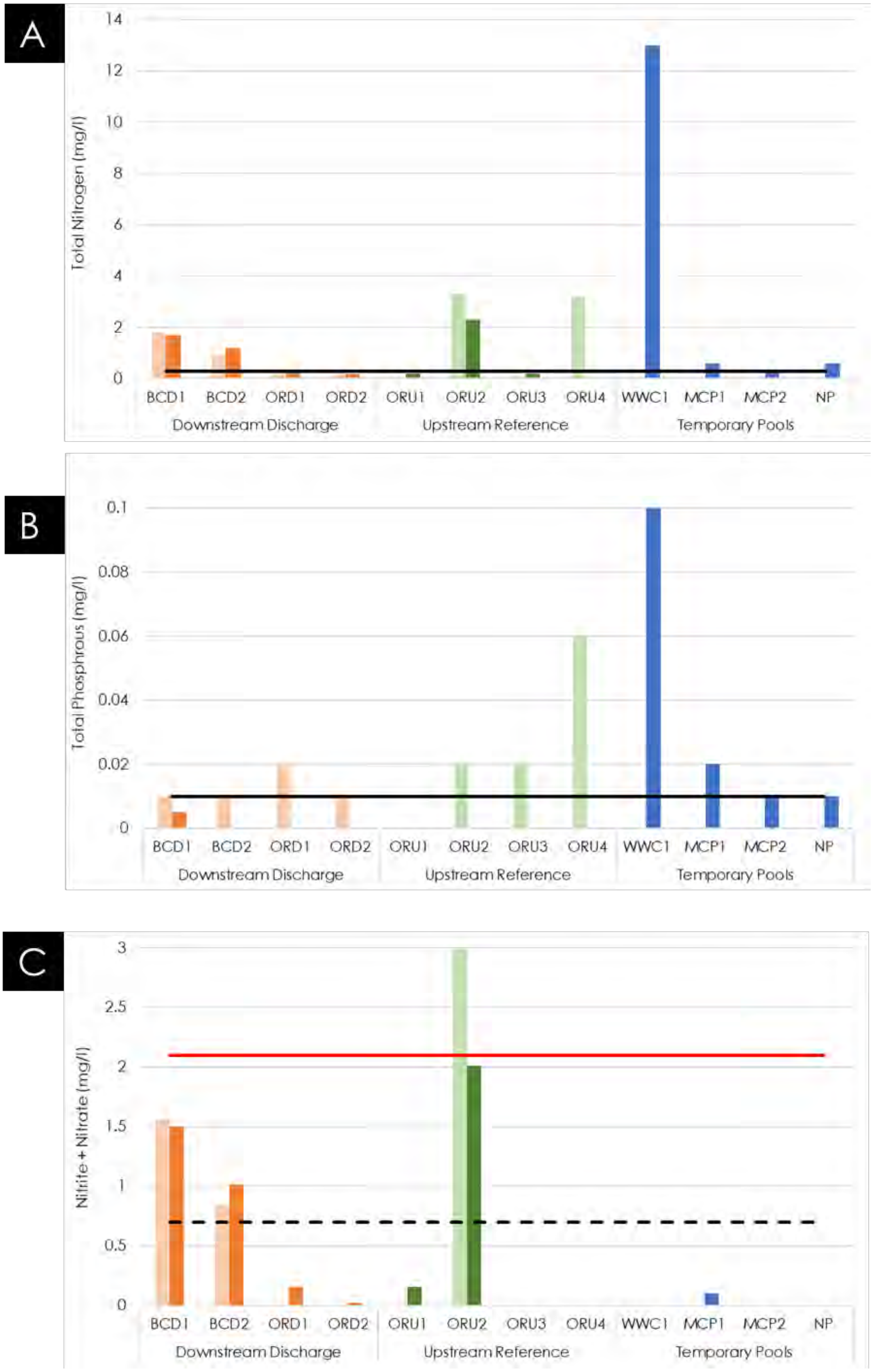


Figure 3-4: Water quality (nutrients) of downstream discharge, upstream reference and temporary pool sites during the Study; (A) total nitrogen, (B) total phosphorus, and (C) nitrite+nitrate, showing ANZG (2018) eutrophication (---), stressor (—) and toxicant 95% (—) DGVs (■■ = dry season, ■■ = wet season and ■ = temporary pools).

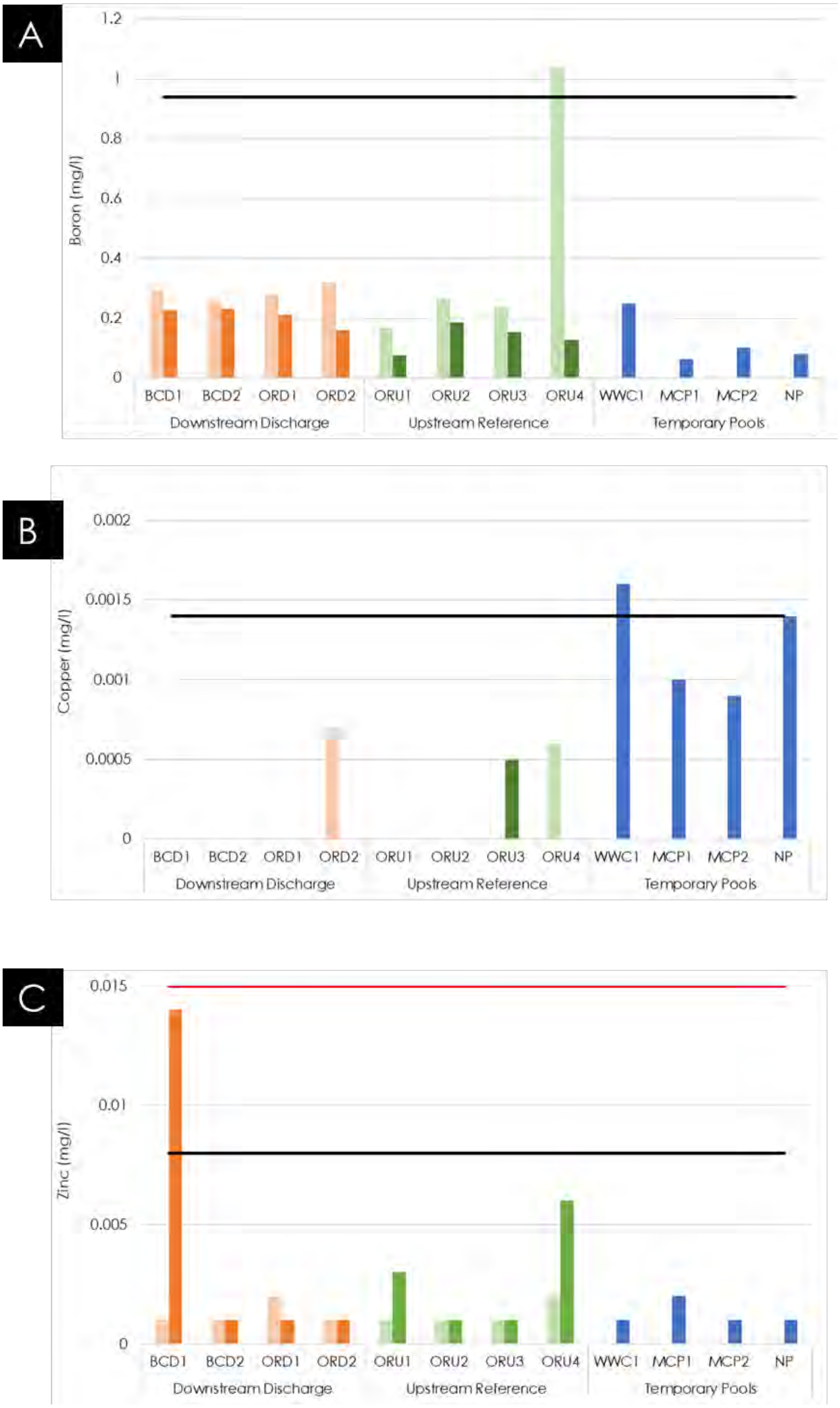


Figure 3-5: Water quality (select metals) of downstream discharge, upstream reference and temporary pool sites during the Study; (A) boron, (B) copper, and (C) zinc, showing ANZG (2018) toxicant 95% (—) and 90% (—) DGVs (■■ = dry season, ■■ = wet season and ■ = temporary pools).

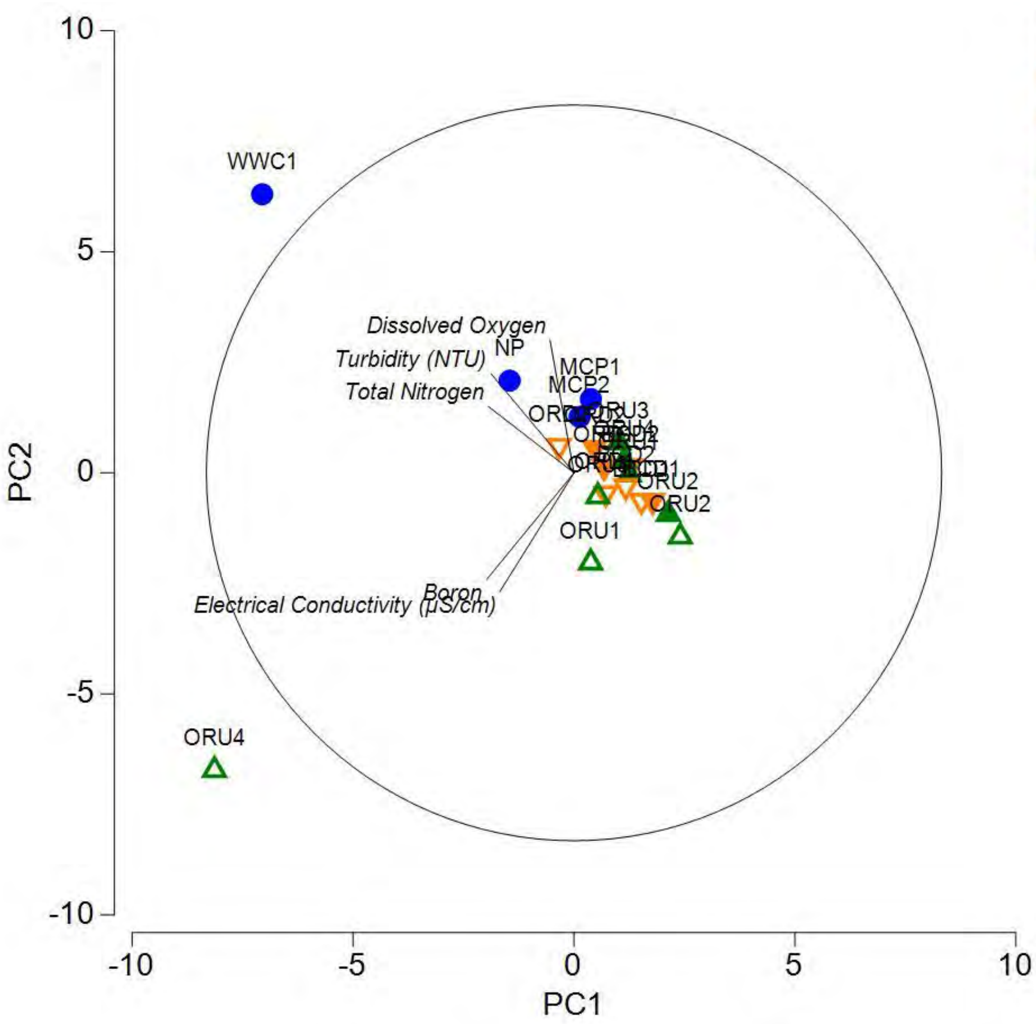


Figure 3-6: PCA of water quality of downstream discharge, upstream reference and temporary pool sites, with 61.70% variation in overall water quality data explained by the first two axes (▲ = upstream reference wet season, △ = upstream reference dry season, ▼= downstream discharge wet season, ▽ = downstream discharge dry season, ● = temporary pools).

3.2.3 Sediment Quality

Sediments form an important component of aquatic ecosystems, and support a wide range of organisms (McKenzie *et al.* 2004; Pulford and Flowers 2006). They also serve as a sink for any contaminants entering a waterbody (Simpson *et al.* 2005). Sediment salinity (measured as total soluble salts, TSS) at discharge sites ranged from 315 mg/kg at BCD1 (wet season) to 1,390 mg/kg at ORD1 (dry season), while at reference sites ranged from 88 mg/kg at ORU1 (wet season) to 3,990 mg/kg at ORU4 (dry season) (**Table 3-7**, **Table 3-8**, **Figure 3-7A**). At temporary pool sites, TSS was lowest at MCP2 (273 mg/kg), and highest at NP (775 mg/kg) (**Table 3-8**, **Figure 3-7A**). Markedly high sediment salinity at ORU4 during the dry season was associated with evaopocentration effects as the pool reached the end of its hydroperiod, while overall, salinity was lower during the wet season at all sites (**Figure 3-7A**), likely related to dissolution of stored salts following wet season rainfall. Sediment salinity at wetlands and rivers in arid regions of Western Australia can display a high spatial heterogeneity (Simpson *et al.* 2005), associated with alternate wetting and drying cycles (Boulton and Brock 1999; McComb and Qui 1998).

Ionic composition generally followed that of water quality, with Na being dominant cation across discharge and upstream reference sites during both the dry and wet seasons, although the dominance of other cations (K, Mg and Ca) was interchangeable (**Table 3-7**, **Table 3-8**). Comparatively, Ca was the dominant cation at temporary pools. The dominance of anions typically followed HCO_3>Cl>SO_4>CO_3 (**Table 3-7**, **Table 3-8**). Spatial and temporal variation in ionic balance and concentrations are common in saline systems throughout the Pilbara region, and is considered typical of inland waterbodies in Western Australia (Gregory 2008; Hart and McKelvie 1986). The dominance is likely a result of localised geology influencing sediment composition (Chakrapani 2002; Gorham 1961).

Concentration of TN was variable between sites and seasons. Highest TN concentration was recorded at temporary pool site NP 3,960 mg/kg, and was also relatively high at discharge site BCD2 (1,960 mg/kg) during the dry season, and temporary pool WWC1 (750 mg/kg) during the wet season (**Table 3-7**, **Table 3-8**, **Figure 3-7B**). Sediment TN was generally lower at reference sites, ranging from 30 mg/kg at ORU1 (wet season) to 500 mg/kg at ORU4 (dry season) (**Table 3-7**, **Table 3-8**, **Figure 3-7B**). TP was more homogenous across sampling sites and seasons, typically ranging between 70 mg/kg and 240 mg/kg, with the exception of temporary pool sites NP and WWC1, where TP concentrations were 318 mg/kg and 267 mg/kg, respectively (**Table 3-7**, **Table 3-8**, **Figure 3-7C**).

Relatively high TN and TP concentrations at NP and WWC1 are likely related to the breakdown of animal waste from unrestricted livestock access to these pools, along with evaopconcentration effects. Elevated TN at discharge site BCD2 may reflect discharge influence, with TN also elevated in discharge water. However, livestock impacts also cannot be discounted, with numerous cattle observed drinking from the site at the time of sampling. Spatial and temporal variation in nutrient concentrations in arid zone river systems can also be influenced by factors such as organic matter inputs from fringing vegetation, the breakdown of microbes and algae, and sediment mineral composition (Reddy and DeLaune 2008).

The majority of metals were below analytical detection limits or ANZG (2018) GVs/GV-highs across all sites and seasons. Two exceptions were:

- Chromium, which was 2x above the GV at upstream reference site ORU1 during the dry season (165 mg/kg); and
- Nickel, which was slightly above the GV at discharge site BCD2 (30 mg/kg) and reference site ORU1 (24 mg/kg) during the dry season, and BCD1 (24 mg/kg) during the wet season (**Table 3-7**, **Table 3-8**, **Figure 3-8**).

It is likely that elevated nickel concentrations in the sediments of BCD1 and BCD2 reflect natural background concentrations within the catchment, given nickel concentrations were not recorded above analytical detection limits in discharge water, and elevated concentrations were also recorded at reference site ORU1. Enrichment of nickel and chromium in sediments is characteristic of many inland waterbodies in Western Australia, attributed to natural mineralisation (Förstner 1977; Gregory 2008).

Overall, sediment quality was relatively homogenous at upstream reference, downstream discharge and temporary pools across both the wet and dry seasons, reflected in the PCA with the majority of sites forming a large cluster (**Figure 3-9**). However, sediment quality was distinct at three sites, as shown by the PCA:

- Upstream reference site ORU1 in the dry season;
- Downstream discharge site BCD2 in the dry season; and
- Temporary pool site NP.

The distinct sediment quality at ORU1 in the dry season was primarily due to higher concentrations of some metals, including barium, chromium, manganese and nickel, compared to other sites. Comparatively, downstream discharge site BCD2 recorded relatively high concentrations of copper, lead and zinc during the dry season, although all values were below ANZG (2018) DGVs. Discrete sediment quality at temporary pool site NP was mainly driven by the high TN concentration (3,960 mg/kg), almost twice as high as the next TN concentration recorded during the Study (1,960 mg/kg at BCD2 during the dry season). High TN at NP was mainly associated with the breakdown of livestock waste, with cattle observed utilising the waterbody at the time of sampling.

Table 3-7: Summary of sediment quality results at downstream discharge and upstream reference sites during the dry season 2020.

Sediment Quality Parameters		Limit of Reporting	Downstream Discharge				Upstream Reference			ANZG (2018)	
			BCD1	BCD2	ORD1	ORD2	ORU1	ORU3	ORU4	GV	GV-High
Basic	Electrical Conductivity (µS/cm)	1	129	317	428	164	103	131	1,230	-	-
	Total Soluble Salts	5	418	1,030	1,390	532	334	426	3,990		
	Moisture Content (%)	1.0	14.2	47.2	27.8	8.6	8.5	10.2	22.9	-	-
Cations and Anions	Sodium	10	60	260	400	130	20	40	570	-	-
	Magnesium	10	20	120	60	30	20	20	170	-	-
	Calcium	10	30	150	50	20	30	30	30	-	-
	Potassium	10	<10	40	40	20	<10	<10	100	-	-
	Chloride	10	30	150	270	150	<10	50	1,140	-	-
	Sulfate	10	20	190	140	120	<10	50	110	-	-
	Bicarbonate	5	190	555	602	185	204	127	564	-	-
	Carbonate	5	40	<5	30	17	26	14	8	-	-
Nutrients	Total Nitrogen	20	180	1,960	520	180	180	30	500	-	-
	Total Phosphorus	2	189	211	147	143	171	71	144	-	-
	Total Organic Carbon (%)	0.5	<0.5	3.4	1.0	<0.5	<0.5	<0.5	1.1	-	-
	Total Kjeldahl Nitrogen	20	180	1,960	520	180	180	30	500	-	-
	Nitrite + Nitrate	0.1	0.1	<0.1	0.1	0.2	0.2	<0.1	<0.1	-	-
Metals and Trace Elements	Aluminium	50	6,310	9,960	6,500	3,660	4,170	1,830	5,180	-	-
	Arsenic	5	<5	<5	<5	<5	<5	<5	<5	20	70
	Barium	10	100	170	110	160	1,010	640	210	-	-
	Boron	50	<50	<50	<50	<50	<50	<50	<50	-	-
	Cadmium	1	<1	<1	<1	<1	<1	<1	<1	2	10
	Chromium	2	24	59	51	114	165	45	63	80	370
	Cobalt	2	10	15	7	6	20	6	9	-	-
	Copper	5	15	52	18	13	22	20	23	65	270
	Iron	50	23,200	38,900	36,500	71,300	87,100	28,600	41,800		
	Lead	5	<5	32	7	9	12	<5	6	50	220
	Manganese	5	1,180	5,050	920	518	9,310	5,510	1,550	-	-
	Mercury	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15	1.00
	Molybdenum	2	<2	<2	<2	<2	<2	<2	<2	-	-
	Nickel	2	16	30	13	11	24	7	18	21	52
	Selenium	5	<5	<5	<5	<5	<5	<5	<5	-	-
	Uranium	0.1	0.2	1.6	0.5	0.5	0.9	0.3	0.5	-	-
	Vanadium	5	36	72	60	116	154	48	69	-	-
	Zinc	5	28	43	21	11	19	9	24	200	410

- *all units are in mg/kg unless stated otherwise;*
- *values below the limit of reporting (LOR) are shown in grey text;*
- *grey shading indicates values exceeding ANZG (2018) GV; bold text indicates values exceeding GV-High;*
- *a sediment sample could not be obtained from upstream reference site ORU2 due to sediment characteristics (hard bedrock).*

Table 3-8: Summary of sediment quality results at downstream discharge, upstream reference and temporary pool sites during the wet season 2021.

	Sediment Quality Parameters	Limit of Reporting	Discharge Sites				Reference Sites			Temporary Pools			ANZG (2018)	
			BCD1	BCD2	ORD1	ORD2	ORU1	ORU3	ORU4	WWC1	MCP2	NP	GV	GV-High
Basic	Electrical Conductivity (µS/cm)	1	93	119	379	153	26	117	112	152	80	228	-	-
	Total Soluble Salts	5	315	406	1,290	521	88	398	382	517	273	775		
	Moisture Content (%)	1.0	23.8	15.7	30.2	41.7	20.1	22.0	23.4	21.9	23.1	53.9	-	-
Cations and Anions	Sodium	10	70	100	270	120	20	50	60	90	20	90	-	-
	Magnesium	10	20	20	90	50	<10	30	20	40	30	80	-	-
	Calcium	10	30	20	70	100	<10	30	20	100	40	200	-	-
	Potassium	10	<10	<10	60	30	<10	20	10	30	10	50	-	-
	Chloride	10	30	50	130	100	<10	40	30	70	20	40	-	-
	Sulfate	10	20	30	50	20	<10	20	30	90	10	50	-	-
	Bicarbonate	5	172	231	919	460	53	226	185	418	186	529	-	-
	Carbonate	5	17	10	15	<5	<5	<5	<5	<5	<5	<5	-	-
Nutrients	Total Nitrogen	20	100	450	1,520	1,450	30	100	60	750	150	3,960	-	-
	Total Phosphorus	2	134	174	232	240	157	148	146	267	185	318	-	-
	Total Organic Carbon (%)	0.5	0.7	1.1	2.2	2.4	<0.5	0.9	<0.5	1.9	<0.5	5.3	-	-
	Total Kjeldahl Nitrogen	20	100	450	1,520	1,450	30	100	60	750	150	3,960	-	-
	Nitrite + Nitrate	0.1	<0.1	<0.1	0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	-	-
Metals and Trace Elements	Aluminium	50	8,400	4,690	8,510	8,250	3,210	4,270	4,080	7,180	6,540	10,700	-	-
	Arsenic	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	20	70
	Barium	10	150	400	250	190	100	130	150	80	110	100	-	-
	Boron	50	<50	<50	<50	<50	<50	<50	<50	<50	<50	<50	-	-
	Cadmium	1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2	10
	Chromium	2	30	33	36	36	64	38	74	40	17	24	80	370
	Cobalt	2	14	11	12	12	6	8	7	12	11	15	-	-
	Copper	5	29	55	29	31	16	18	18	26	21	35	65	270
	Iron	50	30,200	44,300	32,800	34,200	30,600	27,300	42,100	36,900	25,200	34,600	-	-
	Lead	5	10	43	11	6	<5	6	8	9	8	<5	50	220
	Manganese	5	1,970	31,000	1,920	1,400	529	1,050	937	900	1,520	618	-	-
	Mercury	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.15	1.00
	Molybdenum	2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	-	-
	Nickel	2	24	13	18	20	16	14	15	20	17	18	21	52
	Selenium	5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	-	-
	Uranium	0.1	0.3	0.6	0.4	0.5	0.2	0.5	0.3	0.5	0.2	0.6	-	-
	Vanadium	5	47	61	54	56	47	42	70	54	40	62	-	-
	Zinc	5	35	20	27	26	14	16	19	38	31	35	200	410

- *all units are in mg/kg unless stated otherwise;*
- *values below the limit of reporting (LOR) are shown in grey text;*
- *grey shading indicates values exceeding ANZG (2018) GV; bold text indicates values exceeding GV-High;*
- *a sediment sample could not be obtained from upstream reference site ORU2 due to sediment characteristics (hard bedrock); the sediment sample from temporary pool site MCP1 was damaged in transit to the laboratory and could not be analysed.*

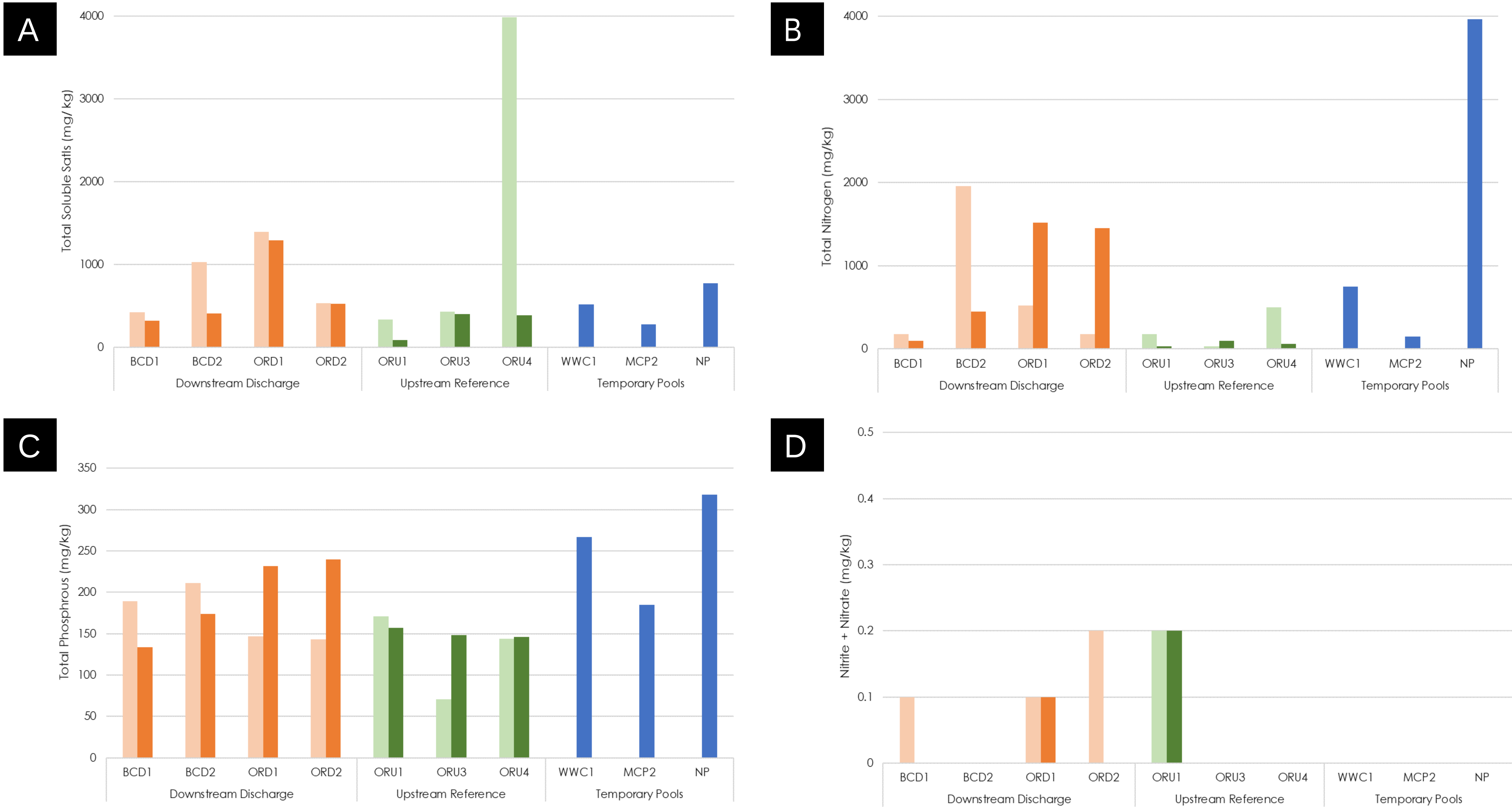


Figure 3-7: Sediment quality of downstream discharge, upstream reference and temporary pool sites during the Study; (A) total soluble salts, (B) total nitrogen, (C) total phosphorus, and (D) nitrite + nitrate (■■ = dry season, ■■ = wet season and ■ = temporary pools).

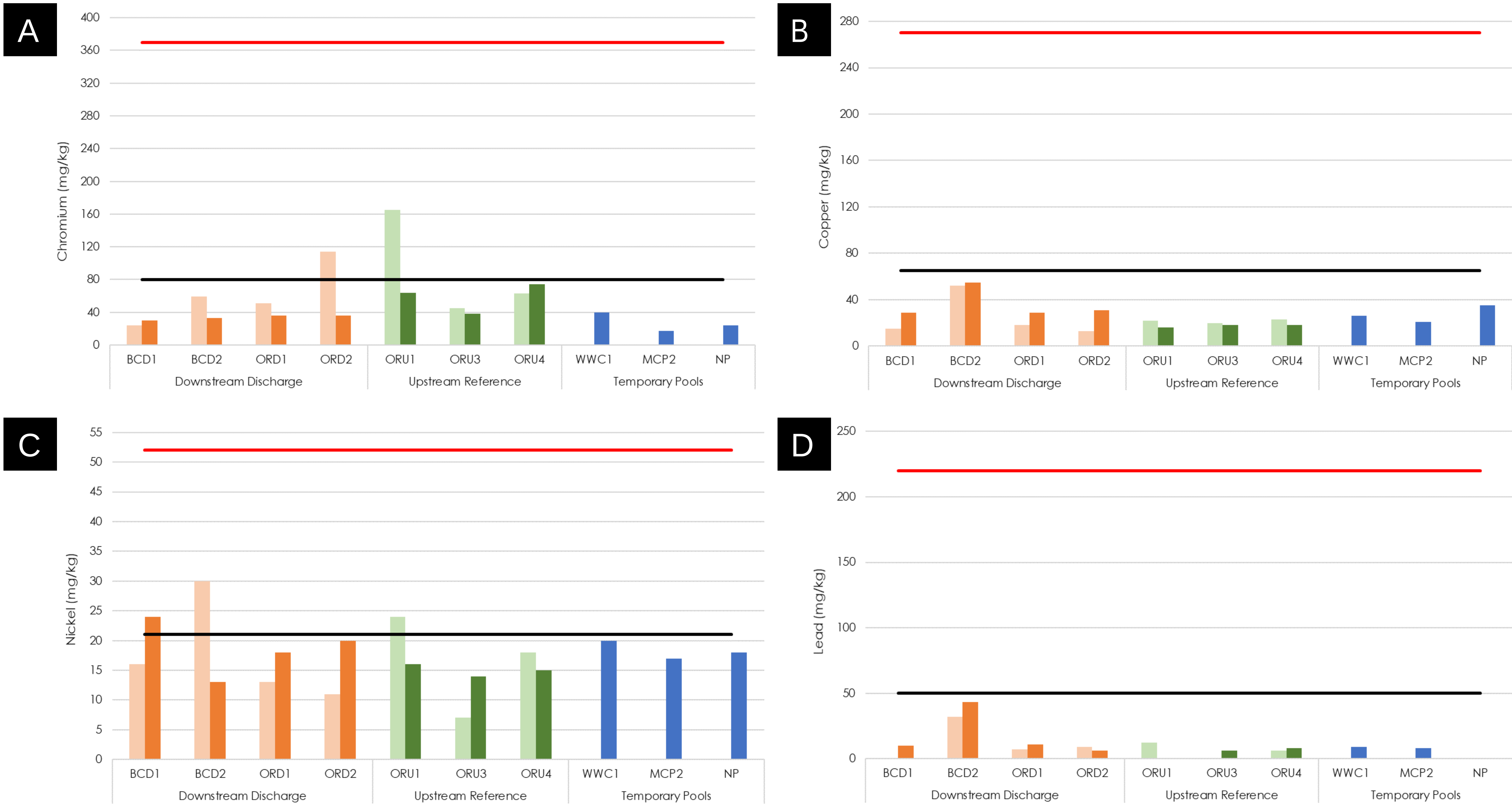


Figure 3-8: Sediment quality (select metals) of downstream discharge, upstream reference and temporary pool sites during the Study; (A) total soluble salts, (B) total nitrogen, (C) total phosphorous, and (D) nitrite + nitrate, showing ANZG (2018) GVs (—) and GV-High (—) (■■ = dry season, ■■ = wet season and ■ = temporary pools).

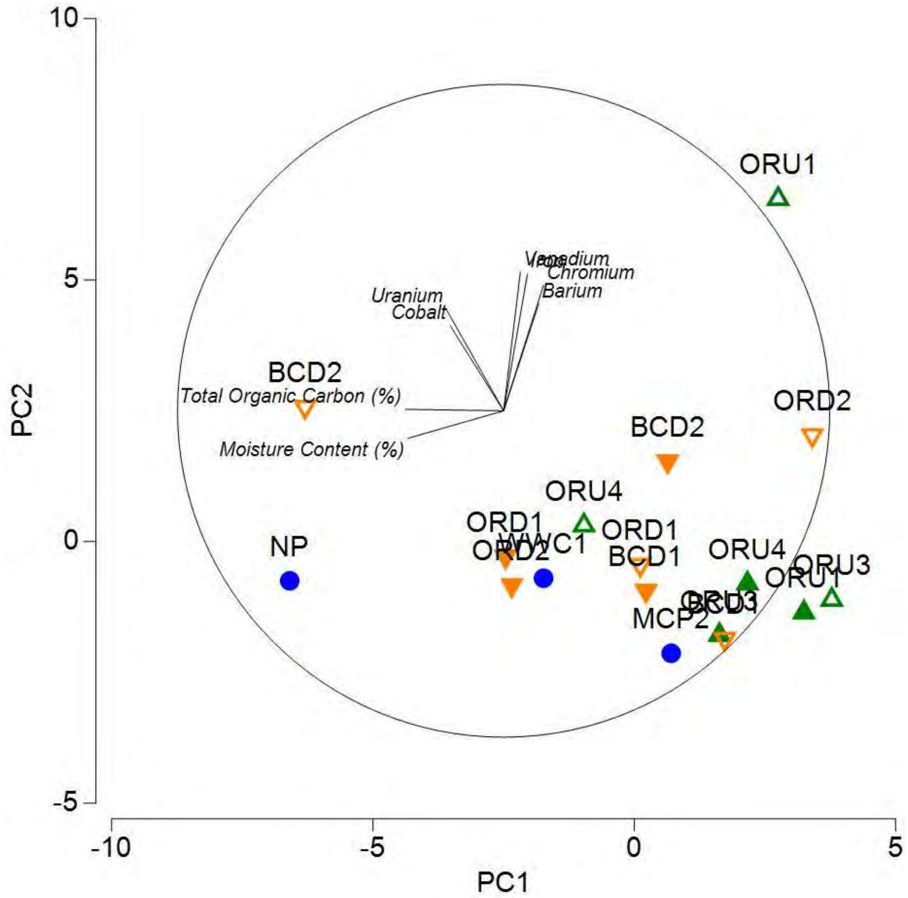


Figure 3-9: PCA of sediment quality of downstream discharge, upstream reference and temporary pool sites, with 61.70% variation in overall sediment quality data explained by the first two axes (▲ = upstream reference wet season, △ = upstream reference dry season, ▼= downstream discharge wet season, ▽ = downstream discharge dry season, ● = temporary pools).

3.2.4 Macrophytes and Algae

3.2.4.1 Macrophytes

Macrophytes are aquatic plants that can survive at least some period of inundation. In arid climates submerged, free-floating and emergent species occur, which are of considerable ecological importance (Williams 1983). Macrophytes have a vital role in nutrient cycling within aquatic systems, as well as providing diverse structural habitats and shelter for invertebrates and fish (Bunn *et al.* 2006; Sainty and Jacobs 2003). Many aquatic plants also produce desiccation resistant seeds, an adaptation to lengthy dry periods, and germinate in favourable conditions to aid in the recovery of wetlands during flooding (Brock *et al.* 2006).

During the Study, a total of nine aquatic macrophyte species belonging to six different families were recorded, comprising both submerged and emergent forms (**Table 3-9**). Among the submerged macrophytes, Hydrocharitaceae was the most well represented family (two taxa), with the remaining families (Characeae, Potamogetonaceae and Haloragaceae) comprising one taxa each (**Table 3-9**). Emergent macrophyte families included Cyperaceae (three taxa) and Typhaceae (one taxa) (**Table 3-9**). None of the taxa collected are considered restricted in distribution, and have been previously identified within the De Grey River system and/or in the Pilbara bioregion more broadly (Loomes and Braimbridge 2010; Masini and Walker 1989; Pinder and Leung 2009; van Dam *et al.* 2005).

A total of eight macrophyte taxa were recorded from both downstream discharge sites and upstream reference sites, while only one taxon was recorded from temporary pool sites (**Table 3-9**). *Schoenoplectus subulatus* (**Plate 3-2F**) was the most widespread emergent macrophyte taxa, recorded at all four discharge sites, and three upstream reference sites (**Table** 3-9). This taxon typically dominates the emergent vegetation of rivers and creeklines in the Pilbara region, forming dense beds along banks and within shallower areas (Lyons 2015; Pinder *et al.* 2010). Comparatively, *Cyperus vaginatus* and *Eleocharis geniculata* are more commonly associated with permanent pools and springs (Pinder *et al.* 2010), which was reflected in their distribution during the Study. *Cyperus vaginatus* was only recorded from the permanently flowing discharge sites BCD1 and BCD2, as well as spring-fed sites ORU1 and ORU2, while *Eleocharis geniculata* was only present at ORU1 and ORU2. In general, emergent macrophytes provide important structural habitat in the water column for aquatic larvae with mobile adult stages, such as dragonfly larvae (Gooderham and Tsyrlin 2002; Pinder and Leung 2009), as well as cover and nesting material for waterbirds (Sainty and Jacobs 2003).

Among the submerged macrophytes, *Najas marina* and *Myriophyllum verrucosum* were the most common taxa, recorded at seven sites each (**Table 3-9**). These are among the most common aquatic macrophyte taxa in the Pilbara region (Lyons 2015; Pinder *et al.* 2010). *Najas marina* (**Plate 3-2A**) is a cosmopolitan submerged macrophyte species known to inhabit waterbodies of fresh to mesosaline salinity, often with alkaline pH, and occupies a variety of depths (Sainty and Jacobs 2003). *Myriophyllum verrucosum* (**Plate 3-2B**) is a fast growing and adaptable species occurring in fresh and brackish waterbodies across Australia (Sainty and Jacobs 2003). Dispersal occurs via both stem fragments and seeds, with this taxa able to form dense beds soon after flooding (Sainty and Jacobs 2003).

Myriophyllum verrucosum was the only submerged macrophyte recorded from a temporary pool site (MCP2) (**Table 3-9**), where it occurred in dense meadows, reflecting the propensity of this species to disperse and rapidly establish following flood events, regardless of the ephemeral hydrological regime. *Chara* sp./*Nitella* sp. (**Plate 3-2D**) were also relatively common, recorded at three discharge, and three reference sites (**Table 3-9**). These taxa belong to the Charophyceae (stoneworts) group of algae and both are widespread, cosmopolitan genera present in clear waters from arid wetlands throughout Australia (Brock *et al.* 2006; Montoya 2009). *Chara* is often found in clear, alkaline waters and may be considered an indicator of healthy ecosystems (Casanova 2005; Coops 2002).

Between sites, highest macrophyte diversity occurred at reference site ORU1 (eight taxa during both the dry and wet seasons), followed by discharge sites BCD1 and BCD2 (six taxa in both seasons) (**Table 3-9**). Taxa diversity at these sites was associated with water permanency and morphological heterogeneity, with deep pools, shallow backwaters, areas of flow providing habitat for a variety of submerged and emergent macrophytes (Lyons 2015). In comparison, macrophytes were depauperate at temporary pool sites, with only one taxa recorded at MCP2 (**Table 3-9**). The ephemeral nature of temporary pool sites, subject to high energy/volume flows during the wet season, followed by a completely dry phase, provide unfavourable conditions for the establishment and persistence of macrophytes (Lyons 2015).

Between the wet and dry seasons, there was also little variation in macrophyte diversity and abundance at discharge sites BCD1, BCD2 and ORD1, and reference sites ORU1 and ORU2 (**Table 3-9**), reflecting perennial hydrological regimes influenced by discharge (BCD1, BCD2, ORD1) or groundwater (ORU1 and ORU2). Comparatively, declines in macrophyte diversity between the dry and wet seasons were recorded at reference sites ORU3 and ORU4, and discharge site ORD2 (**Table 3-9**). This was associated with flood events occurring between the dry and wet seasons, with high energy/volume flows known to dislodge and flush macrophytes downstream (Boulton and Brock 1999).

Table 3-9: Summary aquatic macrophytes recorded at downstream discharge, upstream reference and temporary pool sites during the Study. • = taxa comprised <25% of overall macrophyte composition at a site, •• = 25-50% composition, ••• = 50-75% composition, •••• = >75% composition.

Macrophyte Taxa	Downstream Discharge								Upstream Reference								Temporary Pools			
	BCD1		BCD2		ORD1		ORD2		ORU1		ORU2		ORU3		ORU4		WWC1	MCP1	MCP2	NP
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet				
Submerged Macrophytes																				
Characeae																				
Chara sp./*Nitella* sp.	•	•			•	•	•••	•••	••	••			•	•••	•••	••••				
Potamogetonaceae																				
Potamogeton sp.			•	••			•		•	•	•									
Hydrocharitaceae																				
Vallisnaria nana	•••	•••	•••	•••			•	•	••	•	•	•								
Najas marina	•	•	••	•	••	••			•	•		•	••••		••					
Haloragaceae																				
Myriophyllum verrucosum	•	•			•••	•••	•		•	•	•	•	•	••					••••	
Emergent Macrophytes																				
Typhaceae																				
Typha domingensis			•	•	•	•	•													
Cyperaceae																				
Schoenoplectus subulatus	••	••	••	••	•	•	•		•	•			•		•					
Cyperus vaginatus	•••	•••	•	•					•	•	•	•								
Eleocharis geniculata									•	•	•	•								
Diversity	**6**	**6**	**6**	**6**	**5**	**5**	**6**	**2**	**8**	**8**	**5**	**5**	**4**	**2**	**3**	**1**	**0**	**0**	**1**	**0**
Total Diversity	**9**																			

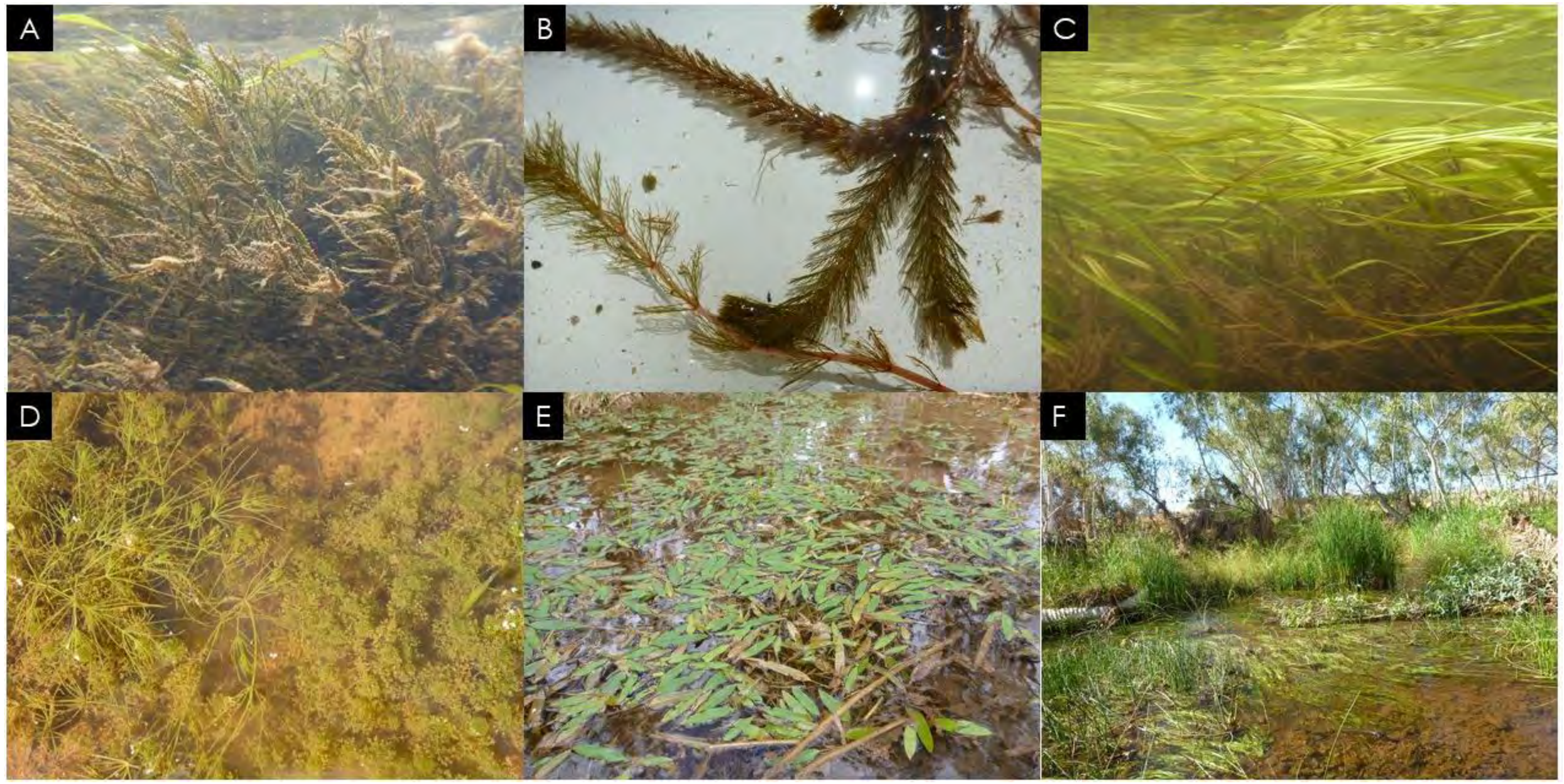


Plate 3-2: Examples of aquatic macrophytes recorded during the Study, including (A) *Najas marina,* (B) *Myriophyllum verrucosum*, (C) *Vallisnaria nana*, (D) Charophytes *Nitella* and *Chara,* (E) *Potamogeton* sp. and (F) emergent macrophytes at BCD2 including *Typha domingensis* and *Schoenoplectus subulatus.*

3.2.4.2 Phytoplankton

Algae can occur as either free-floating planktonic or benthic organisms (Bellinger and Sigee 2010). Planktonic algae are referred to as phytoplankton and in temporary waterbodies, have several important roles within aquatic ecosystems. This includes primary production through photosynthesis and nutrient cycling, and in the provision of food resources, supporting higher order consumers during major floods, known as the boom cycle (Bunn 1995; Porter *et al.* 2007; Sainty and Jacobs 2003). Phytoplankton in temporary waters also demonstrate seasonal succession of species, depending on trophic status and nutrient availability (Bellinger and Sigee 2010).

A total of 71 planktonic algae were recorded during the Study, across four different phyla (**Table 3-10**). Bacillariophyta (diatoms) was the most prevalent phyla in both the dry and wet seasons, comprising 41 taxa in total, followed by Chlorophyta (green algae; 17 taxa) and Cyanophyta (blue-green algae; 10 taxa), while Dinophyta (dinoflagellates; three taxa) had limited representation. The composition of phytoplankton varied across seasons, however, the number of taxa within phyla remained relatively consistent (**Figure 3-10A-C**). The taxa identified were also considered common and ubiquitous, known from inland waters and rivers throughout Australia (Entwisle *et al.* 1997) and globally (Bellinger and Sigee 2010).

The diversity of phytoplankton during the Study was comparable between the dry (53 taxa) and wet seasons (50 taxa), with diatoms contributing the majority of this; 29 and 30 taxa in the dry and wet seasons, respectively. Chlorophyta diversity was slightly higher in the dry season (14 taxa), compared to the wet season (10 taxa), while Cyanophyta and Dinophyta numbers were stable (seven and three taxa, respectively) in both seasons (**Figure 3-10A-C**). At individual sites, diversity was variable, with a maximum of $\geq$20 taxa recorded at several sites and seasons including ORD1 (downstream discharge in dry conditions), ORU3 (upstream reference in wet conditions) and a temporary pool (MCP2 in wet conditions) (**Figure** 3-11**A**). However, typically, site diversity ranged from five to 15 taxa, and decreased at the downstream discharge and upstream reference sites during the wet season (**Figure** 3-11**A**). This was likely due to a decrease in nutrients and water clarity, with increased volume and flow in response to rainfall, reducing phytoplankton productivity (Cooper 1996)

Seasonal differences were evident in the abundance of phytoplankton during the Study, with the dry season characterised by the diatom genus *Synedra* sp. 1 (260 cells in total), which is associated exclusively with freshwaters (John 2000). This species was widespread and was recorded from downstream discharge and upstream reference sites (**Table 3-10**). At the upstream reference site ORU4 during the dry season, a blue-green algal bloom of *Anabaena* sp. and *Aphanocapsa* sp. was evident (cumulative total of 400 cells) (**Table 3-10**). Cyanobacterial blooms commonly form in response to nutrient enrichment (Bellinger and Sigee 2010) and in this instance, it was likely attributed to elevated nutrients from cattle frequenting the site.

During the wet season abundance increased, and was dominated by the colonial green alga *Pediastrum* sp. (>900 cells), a freshwater genus (Entwisle *et al.* 1997) which, while recorded at several upstream and downstream sites, was particularly prevalent at temporary pools WWC1 (>350 cells) and NP (>450 cells) (**Table 3-10**). The dinoflagellate *Peridinium* sp. was also relatively widespread in the wet season, and abundant (>380 cells at MCP2 and NP) at the temporary pools (**Table** 3-10). This genus is a large, single-celled alga that is characteristic of freshwaters high in calcium and nutrients and is also bloom-forming (Bellinger and Sigee 2010; Entwisle *et al.* 1997) Diatom abundance also increased in the wet season, comprising several species of *Synedra* (cumulative total of >1400 cells), common at upstream and downstream sites including the temporary pools (**Table 3-10**).

Hierarchical cluster and SIMPROF analysis highlighted the differences in the assemblage of phytoplankton based on season and water quality. Three groups were evident according to SIMPROF, comprising the dry and wet season reach sites and the temporary pools (**Figure 3-12A**). Upstream reference sites in the wet season also displayed the most similar algal composition of over 60% (ORU 2 and ORU4) (**Figure 3-12A**). The temporary pools were also distinct in the nMDS analysis (**Figure 3-12B**), with approximately 30% similarity in composition, supporting an abundance of phytoplankton, likely due to increased nutrients (particularly TP) in comparison to the Oakover River and Brumby Creek sites. Shifts in phytoplankton composition in the downstream discharge and upstream reference sites were likely attributed to changes in water quality (specifically nutrients), water clarity and habitat availability over the seasons, key factors known to influence the algal assemblage in temporary waterbodies (Bellinger and Sigee 2010).

Table 3-10: Summary phytoplankton (total abundance) recorded at downstream discharge, upstream reference and temporary pool sites during the Study.

Algal Taxa	Dry Season								Wet Season										
	Downstream Discharge				Upstream Reference				Downstream Discharge			Upstream Reference				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Bacillariophyta																			
Achnanthidium sp.		1	3			20	3						2						
Amphora sp.		1	1		1	1								4		24			
Brachysira sp.														1					
Closterium setaceuum																			3
Closterium sp.											70	15	4	70	24				
Cocconeis sp.	200	19		1					3	12	4	3		10				3	
Craticula sp.										1									
Cyclotella sp.		*2*						*5*								*9*			
Cymbella sp.										27	14	28	30	1	4				
Cymbella turgida	1	19	18	1		50	2												
Diploneis sp.														1					
Encyonema sp.												8							
Fragilaria sp.						1													
Frustulia sp.																36		5	69
Gomphonema parvulum										1				1					
Gomphonema sp.						1													
Gyrosigma sp.	2	2	6	1			6	2	3	35	6			7	3				
Hantzschia amphioxys														1	3				
Hantzschia sp.			1																
Mastogloia sp.							2							14					
Navicula sp. 1													3		5	33		12	
Navicula sp. 2						1				9				8					
Navicula sp. 3		1																	
Navicula sp. 4						4													
Nitzschia closterium			1				7												
Nitzschia sigma									1			1	3	9					
Nitzschia sp. 1		3	1		8		4	1											
Nitzschia sp. 2										4				25	3				
Pinnularia sp.			1											2					
Rhopalodia sp. 1		14	1	69	4	27	44												
Rhopalodia sp. 2												4	7	14					
Rhopalodia sp. 3														2					
Sellaphora sp.										7						15		6	
Surirella sp. 1													3	15	15				27
Surirella sp. 2	5	10		2															
Synedra sp. 1		2	20	2	124	7	90	15											
Synedra sp. 2									4	2	9	31	130	11	130		54	335	
Synedra sp. 3									2	1		4					294	26	
Synedra sp. 4									10	4	4					6	117	220	48
Tabularia sp.																		143	9
Urosolenia sp.																		2	

Algal Taxa	Dry Season								Wet Season										
	Downstream Discharge				Upstream Reference				Downstream Discharge			Upstream Reference				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Chlorophyta																			
Botryococcus sp.			20	15				13											
Closterium sp. 1			3	3		1													
Closterium sp. 2													1	2				11	
Closterium sp. 3																3			
Cosmarium sp.	6	1		85			2		4			1						24	270
Gonium sp.		1																	
Cylindrocapsa sp.					3	4													
Micrasterias sp.							2												
Mougeotia sp.			2				2												
Oedogonium sp.			4	3	11	1	3			1								3	
Oocystis sp.													2		16				
Pediastrum sp.											2	1	30	5	43	363	9		468
Pseudosphaerocystis sp.			3	2															
Scenedesmus sp.							1									40	6	5	69
Spirogyra sp.			4		3	1						39	3						
Staurastrum sp.		5	2	22		2	2									57	39	24	39
Zygnema sp.	1		6	1	20	2						1							
Cyanophyta																			
Anabaena sp.		3		22				200				1				3		3	
Aphanocapsa sp.		5						200											
Aphanothece sp.			27				4		6										
Chroococcidiopsis sp.																10		54	
Chroococcus sp.			1			17				4	2						60	16	15
Cyanothece sp.																		23	
Merismopedia sp.		3	3	10			3	1			7				3				
Oscillatoria sp.	4			4	8	3		6											
Planktolyngbya sp.																		171	
Spirulina sp.			4																
Dinophyta																			
Euglena sp.		2													2	3		12	
Phacus sp.		1					4									66			
Peridinium sp.				12			1						85		12		12	408	384
Diversity	7	19	22	17	9	17	18	9	8	13	9	13	13	20	13	14	8	21	11
Abundance	219	95	132	255	182	143	182	443	33	108	118	137	303	203	263	668	591	1506	1401

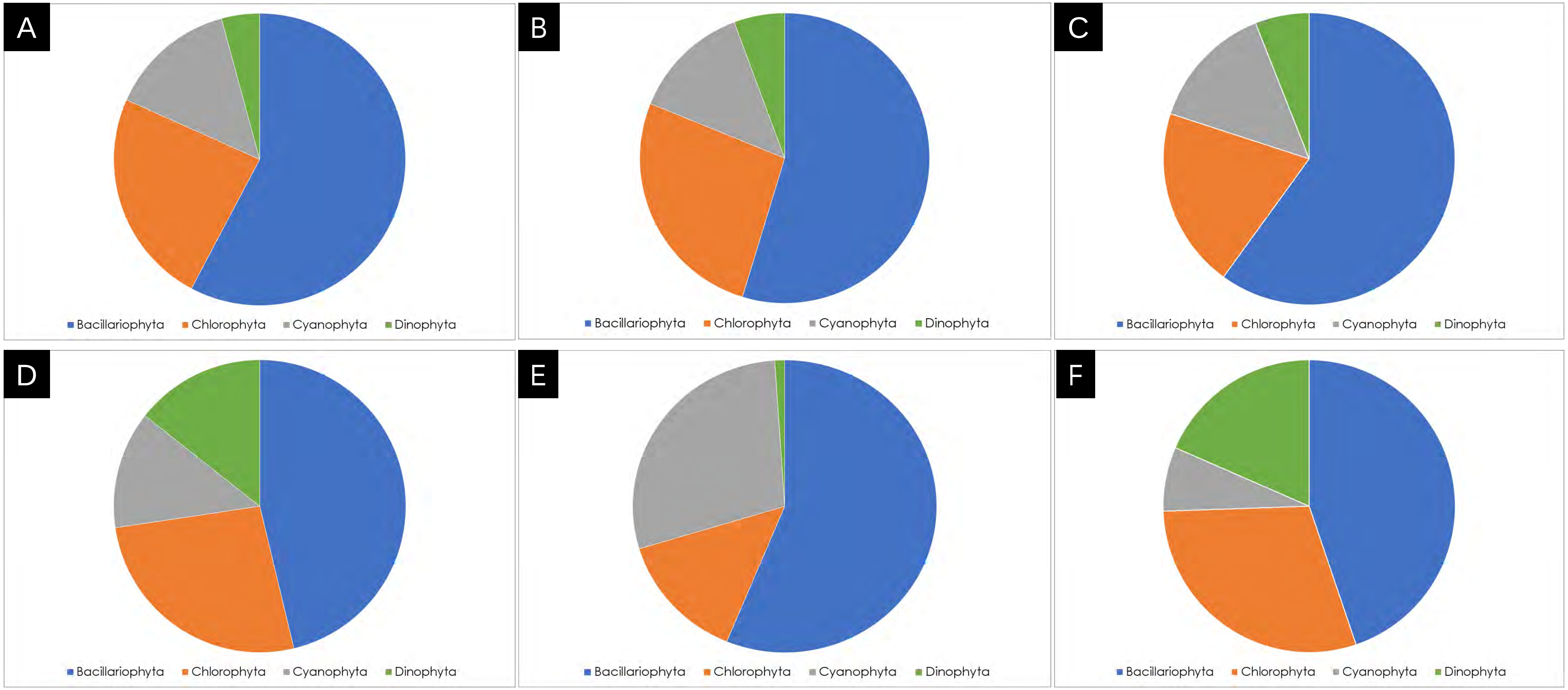


Figure 3-10: Pie charts summarising (A) overall diversity, (B) dry season diversity and (C) wet season diversity, (D) overall abundance, (E) dry season abundance and (F) wet season abundance of phytoplankton phyla recorded during the Study.

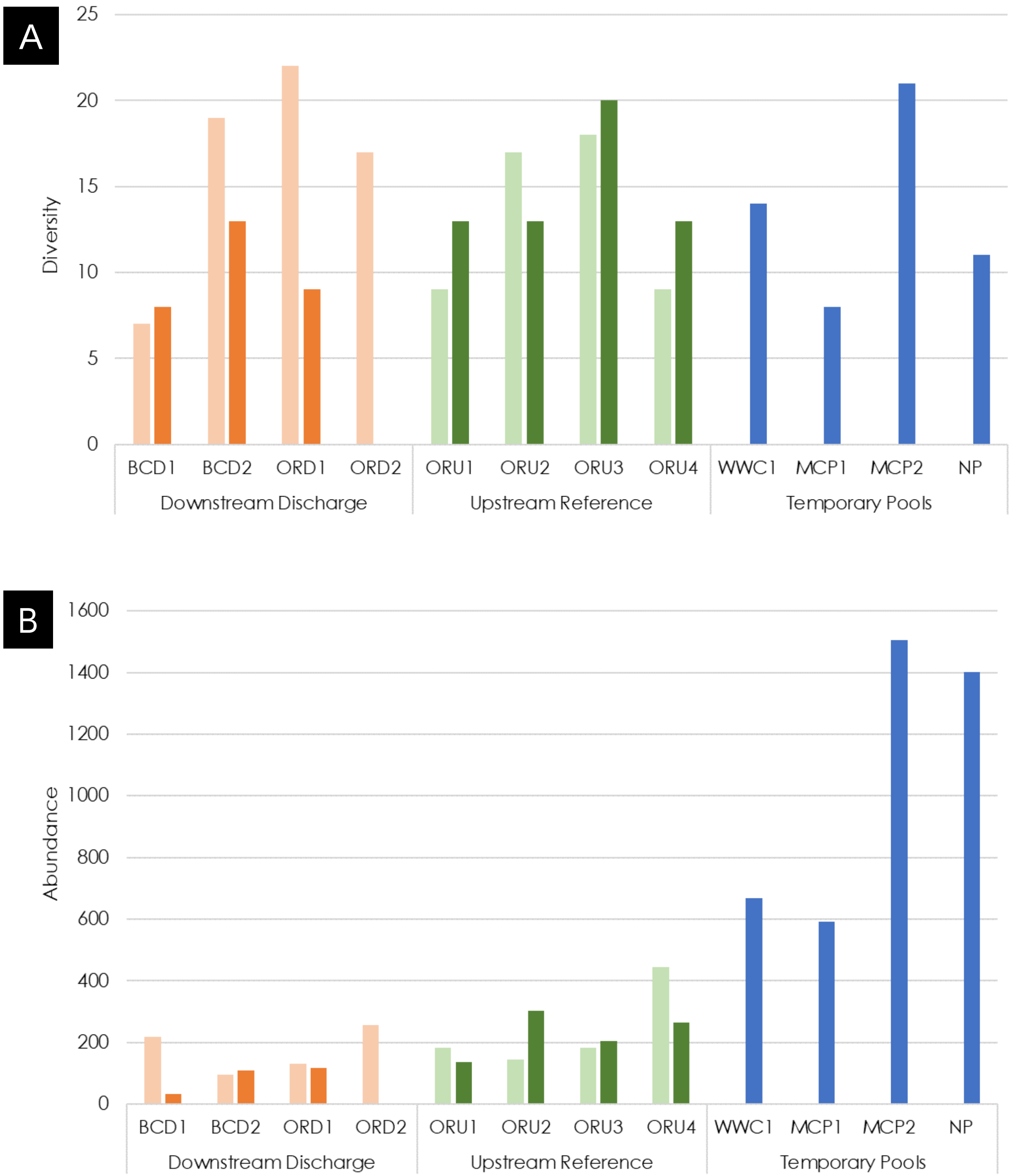
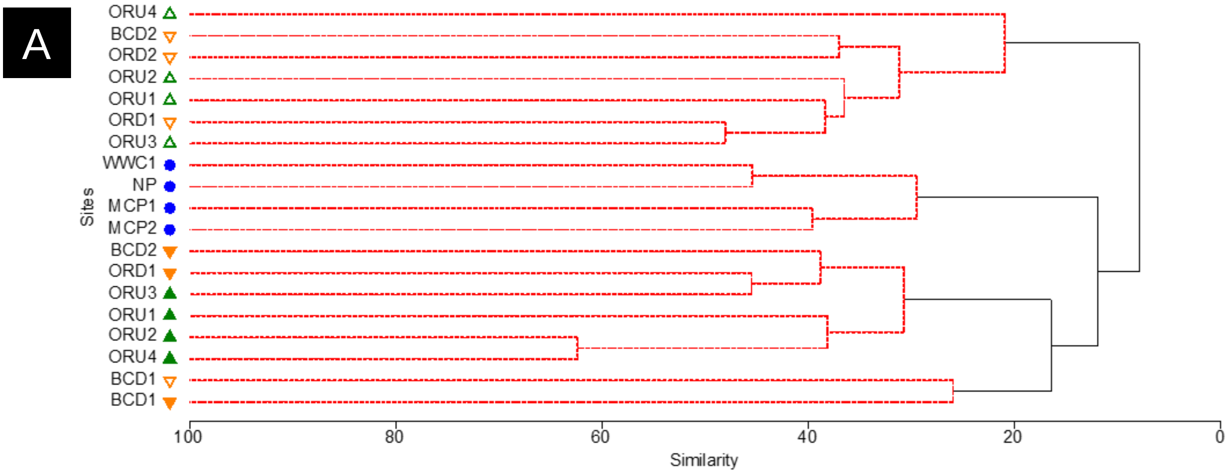


Figure 3-11: Phytoplankton diversity (A) and abundance (B) of downstream discharge, upstream reference and temporary pool sites (■■ = dry season, ■■ = wet season and ■ = temporary pools).



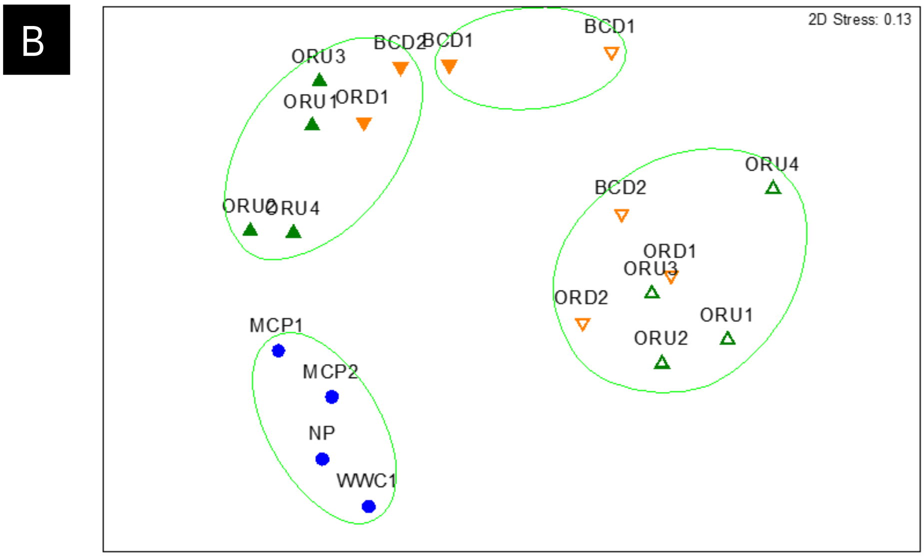


Figure 3-12: Cluster dendrogram (A) and nMDS (B) of phytoplankton samples of downstream discharge, upstream reference and temporary pool sites (▲ = upstream reference wet season, △ = upstream reference dry season, ▼= downstream discharge wet season, ▽ = downstream discharge dry season, ● = temporary pools). Green circles demonstrate significantly different clusters, as determined by SIMPROF.

3.2.4.3 Benthic Diatoms

Diatoms can persist in the moist sediments of rivers and lakes, due to their resilient and siliceous cell wall (termed a frustule), which characterise this group of microalgae (John 2000). They occupy in a wide variety of habitats from free floating (planktonic) to attached (periphytic) and are important contributors to the primary productivity of aquatic ecosystems (Blinn 1995; Campagna 2007; John 1998; Taukulis 2007). Diatoms often form the basis of the food chain, providing a food source for aquatic invertebrates, and are a key component of the benthic microbial community within temporary waters ((John 1998). They also have well-documented water quality tolerance limits and habitat preferences, meaning they are useful biological indicators of their environment (John 2000).

A total of 64 diatom taxa were identified from the benthos during the Study, with 43 species recorded in the dry season and 46 taxa recorded in the wet season (**Table 3-11**). Diatoms were abundant throughout the waterbodies sampled and are likely important primary producers contributing to ecosystem services. Slightly higher diversity in the wet season may reflect the inclusion of the temporary pools and increased site numbers. However, the most speciose genera were common to both surveys, comprising *Navicula* and *Nitzschia* (**Table 3-11**), consistent with inland waters throughout WA (John 1998; Taukulis 2007). The diatom assemblage also aligned with those known from freshwater streams and rivers (John 1998;2000), with the taxa recorded also having a cosmopolitan distribution throughout Australia and globally.

The site diversity of diatoms recorded during the Study typically varied from seven to 15 taxa, with a maximum of 18 taxa recorded at upstream reference site ORU4 during the wet season (**Figure 3-13**). Diversity also typically increased at the upstream reference site during the wet season, however, was more variable at downstream discharge sites, which may reflect differences in habitat availability and substrate composition. In comparison, the temporary pools exhibited lower diatom diversity (<10 taxa) (**Figure 3-13**), which can be attributed to the uniformity of habitat at these sites; largely sand and gravel over hard bedrock substrate, which may provide limited attachment sites for diatoms (Krejci and Lowe 1986).

In the dry season of the Study, *Rhopalodia gibberula*, *Cymbella turgida*, *Mastogloia smithii* and *Cocconeis placentula* were relatively abundant and widespread throughout downstream discharge and upstream reference sites (**Table 3-11**). These taxa are characteristic of freshwater conditions, with *Rhopalodia* and *Cymbella* genera also periphytic and often found in association with submerged macrophytes (John 2000). *Rhopalodia gibberula* was also dominant at downstream discharge site ORD2, while *Cymbella turgida* was present to a lesser extent (**Table 3-11**), with this site supporting dense macrophyte beds, providing favourable habitat for these taxa.

During the wet season of the Study, there was a shift in diatom composition, with *Achnanthidium minutissimum* prevalent and *Encyonema minutum* and *Gomphonema parvulum* also relatively abundant and widespread in the downstream discharge and upstream reference sites (**Table 3-11**). These taxa are all considered discriminating freshwater diatom taxa known from lakes and streams through WA (Taukulis 2007). The *Achnanthidium* genus is also associated with macrophyte habitat (John 2000).

In contrast, the temporary pools during the Study were characterised by *Aulacoseira granulata* (recorded from MCP1 and MCP2) and *Cyclotella meneghenianа* (recorded from all four temporary pool sites) (**Table 3-11**). *Cyclotella* is a typical planktonic diatom, while *Aulacoseira* is associated with mesotrophic or eutrophic conditions (John 2000); the latter reflecting the comparatively higher nutrient concentrations in the surface waters of these sites. While present in comparatively low numbers, *Nitzschia palea* and *Synedra ulna* were also widespread during the Study, recorded in both the dry and wet seasons, predominantly from the upstream reference and downstream discharge sites, and temporary pool WWC1 (**Table 3-11**). While both are known from freshwaters, *Nitzschia palea* is also associated with nutrient rich environments (John 1998).

There were two main site groupings according to the hierarchical classification and SIMPROF analysis, consisting of all upstream reference and downstream discharge sites in both dry and wet seasons, and the temporary pools, which were distinct (**Figure 3-14A**), supported by the nMDS (**Figure 3-14B**). The latter had approximately 25% similarity in diatom composition, while numerous minor groups were evident amongst the downstream discharge and upstream reference sites across seasons (**Figure 3-14A**). During the wet season, the downstream discharge site ORD1 and upstream reference site ORU2 had the highest similarity of community structure at approximately 60% (**Figure 3-14A**), likely due to homogenous habitat under flooded conditions. More broadly, the key environmental factors influencing the diatom assemblage in waterbodies throughout the region appear to be habitat (macrophyte presence) and substrate availability, as well as water quality (specifically nutrient concentrations).

Table 3-11: Summary benthic diatoms (relative abundance; maximum 100 frustules) recorded at downstream discharge, upstream reference and temporary pool sites during the Study.

Diatom Taxa	Dry Season								Wet Season											
	Downstream Discharge				Upstream Reference				Downstream Discharge				Upstream Reference				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Achnanthes plonensis	8		1									9	5	2	14					
Achnanthidium exiguum					12			8	4	6										
Achnanthidium minutissimum			10	4	5		25		1	45	26	28		39		14				
Achnanthidium reidensis								4												
Amphora coffeaeformis	2																			
Amphora aff. *ovalis*													2							
Amphora subturgida		15	1						9	4										
Anomoeoneis sphaerophora		2						10	28						1	3				4
Aulacoseira granulata																		74	20	
Bacillaria paxillifer					1															
Cocconeis distans							1													
Cocconeis placentula	25	20	20			2			19	35										
Craticula cuspidata																	2			2
Cyclotella meneghiniana											4						40	15	19	1
Cyclotella stelligera						3														
Cymbella cistula							1													
Cymbella turgida	10	27	14	1		20		1			8	5	14	3		2				
Diploneis subovalis	45						1		3		9		1	1	3	5		1		
Encyonema gracile						35														
Encyonema minutum						5			10		4		29	22	4	1				
Eunotia bilunaris													1							
Fallacia pygmaea												10								
Fragilaria capucina											4								7	
Gomphonema affine						1										1				
Gomphonema clevei									5											
Gomphonema parvulum		12	14			1				3	15	8	4	17	19	5				
Gyrosigma spencerii		1	4	1		1		3				2			4					
Hantzschia amphioxys																	1			
Hantzschia baltica																				1
Hantzschia distinctepunctata			1						1							1				
Mastogloia smithii				15	1		4	53												
Navicula cincta									2							1				
Navicula cryptocephala			1		11	10							13	1		15				
Navicula elegans								1												1
Navicula perminuta				15																
Navicula rhynchocephala		2				2									25	13			16	
Navicula salinarum		5							1											
Navicula subrynchocephala	3		9				15				4	12		10						
Navicula symmetrica																13				
Neidium affinae	3																			
Nitzschia amphibia					5	20	17	5		3	5				4	4				44
Nitzschia closterium											15	1		1		3				
Nitzschia gracilis																	30		12	45
Nitzschia lorenziana var. *subtilis*			2																	

Diatom Taxa	Dry Season								Wet Season											
	Downstream Discharge				Upstream Reference				Downstream Discharge				Upstream Reference				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Nitzschia palea	2				7		2		2	4	1	1	6	1	1	10	4			
Nitzschia sigma				2																
Nitzschia aff. *linearis*								3												
Nitzschia ?sigma					6															
Nitzschia subinflata																4	3			
Pinnularia gibba		2							1						10		2	1		1
Planothidium lanceolatum									2											
Pleurosigma elongatum								1												
Rhopalodia gibberula			6	62	2		26	10							2					
Sellaphora pupula																	7	2	16	
Stauroneis anceps		7			15															
Staurosira construens														2			10			
Surirerella flaviicygnorum		7	12												1					
Surirerella tenera	1		2																	
Synedra ulna	1				35		7						25	1	10	3		7	10	1
Tryblionella acuminata												4								
Tryblionella apiculata												1			2	2	1			
Tryblionella granulata												12								
Tryblionella punctata							1		12		5	7								
Tryblionella victoriae			3					1												
Diversity	10	11	15	7	11	11	11	12	15	7	12	13	10	12	14	18	10	6	7	9
Abundance	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

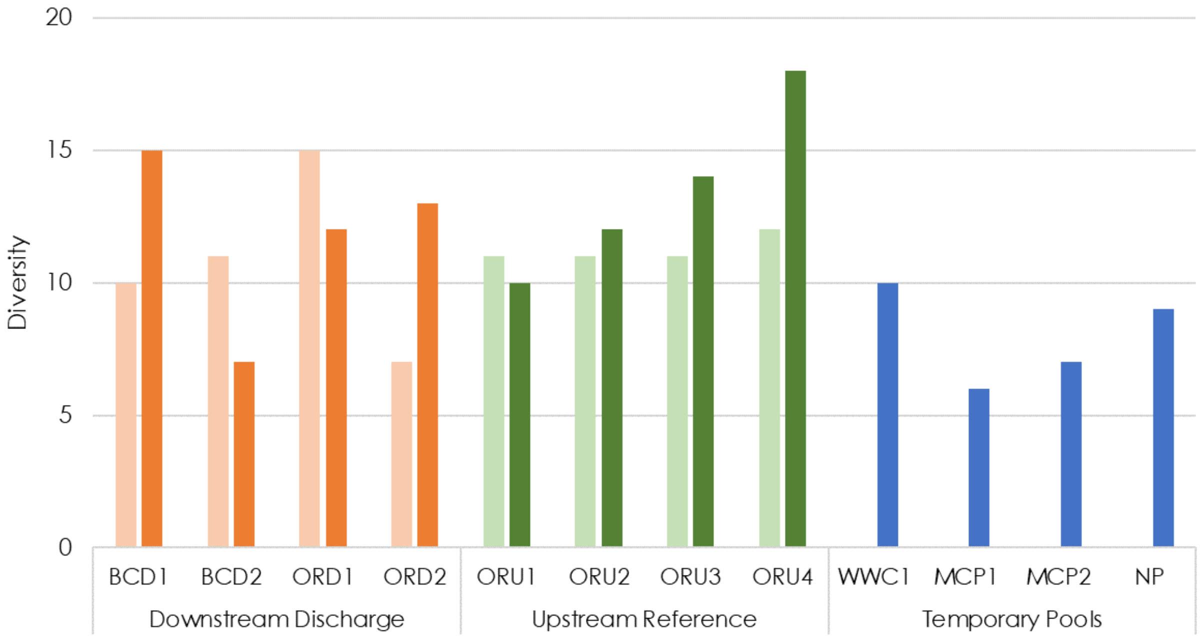


Figure 3-13: Benthic diatom of downstream discharge, upstream reference and temporary pool sites (■■ = dry season, ■■ = wet season and ■ = temporary pools).

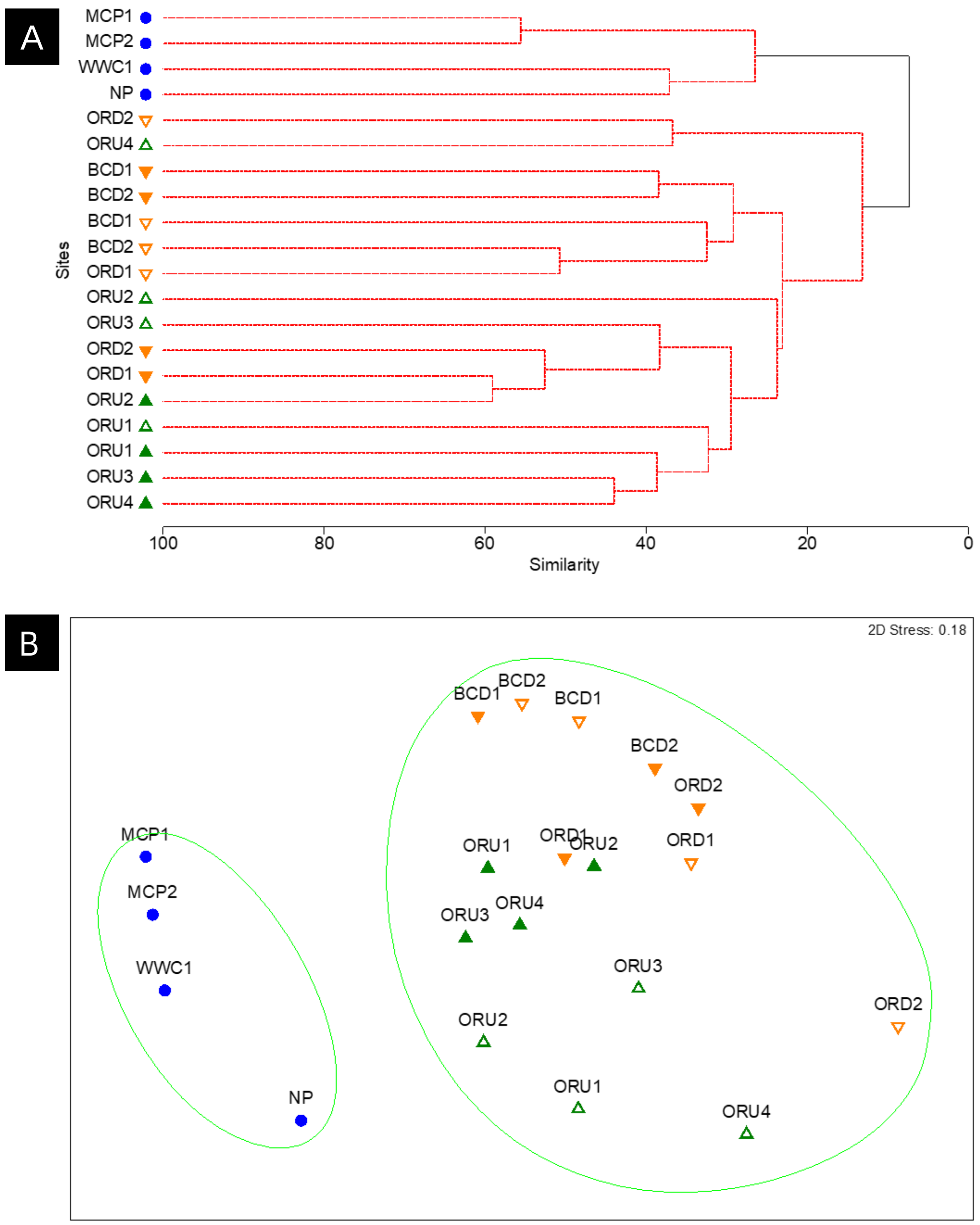


Figure 3-14: Cluster dendrogram (A) and nMDS (B) of benthic diatom samples of downstream discharge, upstream reference and temporary pool sites (▲ = upstream reference wet season, △ = upstream reference dry season, ▼= downstream discharge wet season, ▽ = downstream discharge dry season, • = temporary pools). Green circles demonstrate significantly different clusters, as determined by SIMPROF.

3.2.5 Aquatic Invertebrates

Aquatic invertebrates inhabit a range of environments from freshwater streams to inland salt lakes. They belong to a number of trophic groups, including consumers and decomposers, and play an integral role in ecosystem function (Gooderham and Tsyrlin 2002). They are a diverse group of biota sensitive to changes in water quality and can therefore be used as biological monitors to detect changes in physical and chemical parameters such as salinity, nutrients and metals (Cairns Jnr. and Pratt 1993; Dills and Rogers Jnr 1974; Hellawell 1986).

A total of 5,936 aquatic invertebrate specimens representing 170 taxa from eight higher order groups were recorded during the Study (**Table 3-12**). These groups included Insecta (insects), Gastropoda (aquatic snails and limpets), Bivalvia (freshwater clams and mussels), Arachnida (aquatic mites), Monogononta (rotifers) and the crustacean groups Branchiopoda (comprising Cladocera; water fleas), Maxillopoda (comprising copepods) and Ostracoda (seed shrimp) (**Table 3-12, Figure 3-15A-F**). Of these, insects were the dominant group, comprising 4,667 specimens and 135 taxa, followed by the Maxillopoda, comprising 542 specimens and 13 taxa, all of which were copepods (**Table 3-12, Figure** 3-15**A-F**). Aquatic mites were also relatively abundant (343 specimens), while the remaining groups typically comprised less than 200 specimens and seven taxa each (**Table 3-12, Figure 3-15A-F**).

Overall, the invertebrate community was generally consistent with previous studies of riverine systems of the Pilbara region, where insects are typically the dominant invertebrate group (Pinder and Leung 2009; Pinder *et al.* 2010; WRM 2009;2015;2017). A total of seven insect groups were recorded during the Study, including Diptera (true flies), Coleoptera (aquatic beetles), Ephemeroptera (mayflies), Hemiptera (true bugs), Lepidoptera (aquatic caterpillars), Odonata (dragonflies and damselflies) and Trichoptera (caddisflies) (**Table 3-12**). Of these groups, Diptera and Coleoptera were dominant, accounting for over 54% of all insect taxa and specimens recorded. All insect groups recorded were considered transient or opportunistic taxa, with highly mobile winged adult stages, which allows them to readily disperse within and between systems, and rapidly colonise newly inundated habitats when conditions are favourable (Gooderham and Tsyrlin 2002).

Diversity and abundance of aquatic invertebrates varied between seasons, with 113 taxa and 991 specimens recorded during the dry season, and 130 taxa and 4,944 specimens recorded during the wet season (**Table 3-12**). The increase in invertebrate diversity and abundance during the wet season was due, at least in part, to the increased sampling effort, with temporary pool sites not sampled during the dry season. However, increased diversity and abundance may also reflect greater habitat availability and overall biological productivity following wet season flooding, with most semi-permanent/permanent pools markedly expanding in size and depth between sampling events. Regardless, invertebrate community composition was relatively similar between the seasons, with insects dominant and Maxillopoda (copepods) co-dominant (**Figure 3-15A-F**).

Minor seasonal variations included higher abundance of Gastropoda and Ostracoda during the dry season (**Figure 3-15D**), with these groups typically preferring slow-flowing or lentic conditions (Szlauer-Lukaszewska and Pesic 2020; Tina Liu and Resh 1997). Meanwhile, aquatic mites were more abundant in the wet season (**Figure 3-15E**), primarily due to the large number of specimens (200) recorded from temporary pool site NP (**Table 3-12**). Aquatic mites are often abundant in temporary waterbodies, despite not showing specialised adaptations to desiccation. Instead, dispersal is facilitated by their larvae which parasitise on adult insects, which are often the first group to colonise newly-inundated pools (Bird *et al.* 2019).

The majority of aquatic invertebrate taxa recorded during the Study were common, ubiquitous species with distributions spanning the Pilbara, northern Australia or the Oceania region. The most widespread taxa were the mayfly *Tasmanocoenis* sp. P/*arcuata*, recorded from a total of 16 sites, and the chironomid (non-biting midge) *Larsia albiceps,* recorded from 15 sites (**Table 3-12**). Meanwhile, the most abundant taxa were the chironomid *Coelopynia pruinosa*. (575 specimens) and the caddisfly *Cheumatopsyche wellsae* (440 specimens) (**Table 3-12**). Chironomids such as *Larsia albiceps* and *Coelopynia pruinosa* often constitute the most common and abundant taxa of freshwater ecosystems worldwide, owing to their ability to tolerate a wide variety of environmental conditions, including low oxygen, high temperatures, high salinity and desiccation (Cornette *et al.* 2015), and both taxa are widely distributed across the Pilbara region (Pinder *et al.* 2010).

Tasmanocoenis sp. P/*arcuata* is also a common and broadly distributed species across the Pilbara region (Pinder *et al.* 2010), as well as more broadly across northern Australia (Alba-Tercedor and Suter 1990). Pinder *et al.* (2010) recorded this taxon from 72% of samples from the Pilbara region, from a wide variety of habitats including clear river pools, springs, ephemeral creeks, turbid wetlands and claypans. Comparatively, *Cheumatopsyche wellsae,* which is also widely distributed across northern Australia (Dean 2001), was almost exclusively recorded from flowing (lotic) habitats such as springs by Pinder *et al.* (2010). During the Study, the majority of *Cheumatopsyche wellsae* specimens were recorded from discharge site BCD2, and spring-fed reference site ORU2 during the wet season, reflecting its preference for lotic environments.

Three taxa endemic to the Pilbara region were recorded during the Study, including the aquatic beetle *Sternopriscus pilbaraensis,* the dragonfly *Hemicordulia koomina*, and the damselfly *Eurysticta coolawanyah.* Additionally, both *Hemicordulia koomina* and *Eurysticta coolawanyah* are listed as Vulnerable on the IUCN Red List of Threatened Species (IUCN 2021b;c), as discussed in **Section 3.1.2.** *Eurysticta coolawanyah* was recorded from discharge site BCD1 during the dry season, and from reference sites ORU1 and ORU4 and temporary pool sites WWC1 and MCP1 during the wet season. The record of *Eurysticta coolawanyah* from BCD1 immediately downstream of the W12 outfall indicates this species is exploiting the permanent habitat and relatively good water quality generated by discharge; conditions this species is known to prefer (Theischinger and Hawking 2006). Meanwhile, *Hemicordulia koomina* was only recorded from reference site ORU3 in the dry season, reflecting the relatively cryptic nature of this species (IUCN 2021c).

Between sites, dry season aquatic invertebrate diversity was highest at discharge site BCD1 (36 taxa), immediately downstream of the W12 discharge outfall, equivalent to diversity at upstream reference site ORU2 (**Figure 3-16A**). Lowest diversity was recorded at upstream reference site ORU1 (17 taxa), followed by ORU4 (20 taxa). During the wet season, diversity was highest at reference site ORU2 (52 taxa), followed by ORU3 (41 taxa) (**Figure 3-16A**). Meanwhile, lowest diversity occurred at temporary pool sites MCP2 (18 taxa) and NP (22 taxa) (**Figure 3-16A**).

Overall, diversity recorded at discharge sites (24 to 36 taxa) was well within the range of diversity recorded at upstream reference sites (17 to 52 taxa). However, there was little variation in diversity at discharge sites between seasons (**Figure 3-16A**), likely reflecting the homogenous water quality and perennial habitat created by discharge. Comparatively, diversity at upstream reference sites increased markedly between the dry and wet seasons, likely associated with greater habitat availability and productivity following wet season rainfall, as well as more favourable water quality, including reduced salinity. Diversity at temporary pool sites (18 to 31 taxa) (**Figure 3-16A**) was also broadly comparable to that recorded at upstream reference and discharge sites, reflecting the aquatic invertebrate taxa of the region being strongly adapted to dispersing and colonising ephemeral waterbodies (Bunn *et al.* 2006).

Aquatic invertebrate abundance was more variable between sampling sites and seasons. Between sites, invertebrate abundance within the downstream discharge reach ranged from 91 specimens (BCD2 in the dry season) to 414 specimens (also at BCD2 in the wet season) (**Figure 3-16B**). At upstream reference sites, abundance ranged from 30 (ORU1 during the dry season) to 870 specimens (also at ORU1 during the wet season), while at the temporary pools, abundance ranged from 100 specimens (MCP2) to 569 specimens (NP) (**Figure 3-16B**). At most of the downstream discharge and upstream reference sites, aquatic invertebrate abundance increased substantially between the dry and wet seasons, again likely reflecting greater habitat availability and higher water quality following wet season flooding, particularly at upstream reference sites. Invertebrate abundance was also relatively high (>400 specimens) at three of the four temporary pool sites (**Figure 3-16B**), which was driven by a combination of actively dispersing insect taxa (particularly Chironomindae), aquatic mites (which disperse via their parasitic larvae on transient insects), and taxa with desiccation-resistant life-stages, which emerge from the sediments following flood events, such as copepods (Bird *et al.* 2019; Gooderham and Tsyrlin 2002).

Overall, the aquatic invertebrate assemblage was less than 20% similar (Bray-Curtis Similarity) across all sites sampled (**Figure 3-17**). The low similarity in overall community composition reflects seasonal variation in assemblage composition within and between sites, as well as the wide variety of wetland types sampled, including large groundwater dependent pools, variably sized semi-permanent riverine pools, perennially flowing discharge sites and small, temporary pools. Additionally, low similarity was also attributable to the predominance of mobile insect groups which are transient and opportunistically invade the variety of wetland types. This resulted in a greater proportion of rare taxa (and lower similarity amongst sites), due to the high diversity within groups such as aquatic beetles (Coleoptera), fly larvae (Diptera) and true bugs (Hemiptera) (**Table 3-12**).

According to the hierarchical clustering and SIMPROF, the semi-permanent riverine pools on the Oakover River (ORU3 and ORU4), all temporary pools sites, and Oakover River downstream discharge sites ORD1 and ORD2 during the wet season, shared 25% assemblage similarity (**Figure 3-17A, B**). This was mostly due to the predominance the of several of common, ubiquitous and opportunistic insect taxa at these sites, such as the mayflies *Cloeon* sp. RedStripe and *Tasmanocoenis* sp. P/*arcuata*, the hemipteran *Paraplea brunni*, the chironomid *Larsia albiceps* and the caddisfly *Triplectides ciuskus seductus* (**Table 3-12**).

However, three separate invertebrate assemblages to the main grouping were detected by SIMPROF, reflected in the nMDS:

- All four downstream discharge sites during the dry season (BCD1, BCD2, ORD1 and RD2), and BCD1 during the wet season (approximately 35% assemblage similarity);
- Groundwater dependent upstream reference sites ORU1 and ORU2 during the dry season (approximately 33% assemblage similarity); and
- Brumby Creek discharge sites BCD2 and upstream reference site ORU1 during the wet season (approximately 35% assemblage similarity) (**Figure 3-17A, B**).

The distinction of these sites from the main grouping is likely related to hydrological regime, with each of these sites subject to perennial flows and stable habitat and water quality, and hosting assemblages which favour these conditions. For example, the grouping of the four downstream discharge sites during the dry season, as well as BCD1 during the wet season, was primarily due to the presence of lotic taxa, such as *Cheumatospche wellsae* and the mayfly *Offadens* sp. G1WA2 (Dean 2001; Pinder *et al.* 2010). Similarly, discharge site BCD2 and ORU1 during the wet season shared several taxa common to flowing riffle zones, such as the caddisflies *Cheumatopsyche wellsae*, *Chimarra* sp. AV17, the mayfly *Offadens* sp. G1WA2, and the riffle beetle *Austrolimnius* sp. (Gooderham and Tsyrlin 2002; Pinder *et al.* 2010; Webb and Suter 2011), which were typically absent or rare at semi-permanent riverine and temporary pool sites.

Table 3-12: Summary aquatic invertebrates (total abundance) recorded at downstream discharge, upstream reference and temporary pool sites during the Study.

Invertebrate Taxa	Dry Season								Wet Season											
	Upstream Reference				Downstream Discharge				Upstream Reference				Downstream Discharge				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Arachnida																				
Trombidiformes																				
Acarina spp.						1			1	1	4		34	7	18	60		17		200
Bivalvia																				
Cyrenidae																				
Corbicula australis				2			20			1		28			1	9				
Branchiopoda																				
Diplostraca																				
Cladocera sp.							1													
Daphniidae																				
Ceriodaphnia cornuta													1							13
Daphnia lumholtzi												50								
Simocephalus heilongjiangensis															1					
Macrothricidae																				
Macrothrix spinosa																				1
Moinidae																1				
Moina sp.																1				
Gastropoda																				
Lymnaeidae																				
Bullastra vinosa	16	4	4		1					2		2		1						
Ferrissia petterdi																1				
Planorbidae																				
Ferrissia petterdi														1						
Amerianna spp.		1									3									
Gyraulus sp.	30	7	30	30	1	16	3		1			2						1		
Thiaridae																				
Melanoides tuberculata					1	7						8								
Thiara spp.				16																
Insecta																				
Coleoptra																				
Dytiscidae																				
Allodessus bistrigatus																2				
Antiporus bakewelli																1				
Cybister tripunctatus											1									
Eretes australis														1						
Hydroglyphus godeffroyi																				1
Hydroglyphus grammopterus														3	1	3	2	1	11	
Hydroglyphus orthogrammus					1	1	6			1									15	
Hydroglyphus leai														1						
Hyphydrus elegans	1						2							1						
Hyphydrus lyratus							1							1	2	1			2	
Laccophilus clarki															1					
Laccophilus sharpi														2	1	2				
Limbodessus compactus																		2		
Necterosoma regulare							3													
Necterosoma sp. (L)														1						
Neobidessodes denticulatus					2		1										2	2		
Sternopriscus pilbaraensis							1				1									
Tiporus sp. (L)														1						
Tiporus tambreyi							7										5	11		
Elmidae																				
Austrolimius spp.			1		1					1			2	1						
Austrolimnius spp. (L)	1	8								1			3							
Hydraenidae																				
Hydraena spp.													5					10	1	6
Limnebius spp.														1						2
Octhebius spp.															1		5			
Hydrochidae																				
Hydrochus sp.				3	2	8			1					5	8	1		2	1	4
Hydrophilidae																				
Berosus dallasae				1			3	6						1	1					
Berosus nutans															1					
Berosus sp. (L)								1							1					
Enochrus deserticola						2													1	
Helochares sp. (L)						1								2						
Paracymus sp. (L)				1																
Paracymus spenceri						4				1				1				1		

Invertebrate Taxa	Dry Season								Wet Season											
	Upstream Reference				Downstream Discharge				Upstream Reference				Downstream Discharge				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Regimbartia attenuata	1				1															
Sternolophus immarginatus																		1		
Scirtidae																				
Scirtidae sp. (L)			1		4	4														
Diptera																				
Ceratopogonidae																				
Ceratopogoninae sp.						1			1	1		2		1		9			7	
Dasyheleinae sp.			1			6			2	3					1					
Chironomidae																				
Chironomidae spp. (imm/dam)	2	13					3													
Tanypodinae sp. (eyeless)										2										
Ablabesmyia hilli						1							7	10						
Cladopelma curtivala							1	2							5					
Cladotanytarsus spp.							2				3				6	48	40	140		10
Coelopynia pruinosa											3	32				300	240			
Corynoneura spp.													15							
Cricotopus spp.											3									
Cryptochironomus griseidorsum		1	3						7			1			2		10			10
Dicrotendipes sp. 1	2	1					2	1	28	4			15		3	16	10	10		
Dicrotendipes sp. 2					2		7													
Harnischia spp.										8	6									
Larsia albiceps		2	3	1	1	5	4	1	3	29	3	4		17	5				2	50
Microchironomus spp.																	40			
Nilotanypus sp.											3		7							
Parachironomus spp.													225							
Paracladopelma 'M3'										8			45	5						
Paramerina sp.		1	5		2	3			5	11			15	12						10
Parametriocnemus spp.																	1			
Paraskusella 'Genus K2'			11																	
Paratanytarsus spp.		1					2				16							10	4	100
Polypedilum leei													15			8				
Polypedilum nr *watsoni*									7	44										
Polypedilum nubifer		3																		
Polypedilum spp.												1								
Procladius spp.	1		3	2		4		1	1	8		14					60	1	3	20
Rheocricoctopus spp.		2											113	1	1					
Rheotanytarsus spp.		3				4			32		6	8		30						
Skusella subvittata						1				4										
Stenochironomus sp.						1														
Tanytarsus spp.			1			1	21			12	6	2		15	3	8		40	2	10
Thienemanniella spp.			1							2										
Culicidae																				
Anopheles spp.						2	1	1						2	1					
Culex spp.														2	2					
Dolichopodidae																				
Dolichopodidae spp.		1																		
Simuliidae																				
Simuliidae sp.			1										40							
Stratiomyidae																				
Stratiomyidae spp.														2						1
Ephemeroptera																				
Baetidae																				
Baetidae spp. (imm/dam)	2	2	1				5		3	19				4	3					
Cloeon spp. (imm/dam)						2										2		2		
Cloeon fluviatile		1				3						1		3		2		1		
Cloeon sp. RedStripe	6		1	11			18	30	2	19	3	13		11	7	4		2	1	
Offadens sp. G1WA2	6	6							2	12			2							
Pseudocloeon hypodelum	8	1											1							
Caenidae																				
Caenidae spp. (imm/dam)										3						10				
Tasmanocoenis spp. (imm/dam)	4	5	7						1		13	5		2				12		5
Tasmanocoenis sp. M			2				3													
Tasmanocoenis sp. P/arcuata	2	4	2			3	3		1	3	3	13	3	9	2	13	3	48		30
Wundacaenis dostini		1														10				
Hemiptera																				
Belostomatidae																				
Belostomatidae sp. (imm/dam)						2				1										
Diplonychus eques														2		1				
Corixidae																				

Invertebrate Taxa	Dry Season								Wet Season											
	Upstream Reference				Downstream Discharge				Upstream Reference				Downstream Discharge				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Corixidae sp. (imm/dam)				1																
Gerridae																				
Gerridae spp. (imm/dam)											2		2	8	2					
Limnogonus fossarum gilguy														1						
Limnogonus luctuosus						1							1							
Rhagadotarsus anomalus						1														
Hydrometridae																				
Hydrometra papuana														1						
Mesoveliidae																				
Mesovelia vittigera	1																			
Micronectidae																				
Micronectidae spp. (imm/female)	1		1					22	2		11	20			46		1	11	1	38
Austronecta micra								1			7	50		1	60	200	1	7	1	2
Micronecta adelaidae								4				25								
Micronecta annae								5			1	5			45		1			
Micronecta ludibunda			1																	
Nepidae																				
Ranatra diminuta														1						
Nepidae																				
Laccotrephes tristis						1									1					
Ranatra diminuta																		1		
Notonectidae																				
Anisops spp. (imm/female)																	1			
Notonectidae sp. (imm/dam)								3												
Pleidae																				
Paraplea brunni			3	3		2	16	8	1	1	10	2		20	1	10	7		7	
Veliidae																				
Veliidae spp. (imm/dam)									1				1	9	1					
Microvelia peramoena														2			1			
Lepidoptera																				
Crambidae																				
Acentropinae spp. (imm/dam)		1			1															
Margarosticha sp. 3		1							1				2							
Parapoynx sp.	4						1		10	1	4									
Odonata																				
Epiproctophora sp. (imm/dam)	11		2	4	1	1	2		6		2		1	6	3	2				
Zygoptera sp. (imm/dam)	6	2	4	4			1	1	8		4	2		1	5	5				
Coenagrionidae																				
Agriocnemis rubescens	1					2														
Argiocnemis sp.	1																			
Ischnura aurora	3		13	3				2				1								
Ischnura heterosticta				1																
Corduliidae																				
Hemicordulia koomina							1													
Gomphidae																				
Austrogomphus gordoni							2						1		1	10	1	14	1	
Isostictidae																				
Eurysticta coolawanyah	1												2			1	2	2		
Coenagrionidae	3			1					2							1				
Pseudagrion aureofrons	1			1					2							1				
Pseudagrion microcephalum	2																			
Libellulidae																				
Diplacodes bipunctata	7																			
Diplacodes haematodes	12	1	1	9			3	1												
Orthetrum caledonicum	2		1	3																
Trichoptera																				
Ecnomidae																				
Ecnomus sp.		1	1												1	1	1	5		3
Hydropsychidae																				
Cheumatopsyche wellsae		5	7						1	200			200	1						
Hydroptilidae																				
Orthotrichia sp.							1													
Leptoceridae																				
Leptoceridae sp. (imm/dam)	1													29						
Oecetis sp.									2					13	3	9	4	1		3
Trianodes sp.						1								4						
Triplectides australis														8						
Triplectides ciuskus seductus	5	7	11		7	2				7	3	3	6	46	1		2	4		
Philopotamidae																				

Invertebrate Taxa	Dry Season								Wet Season											
	Upstream Reference				Downstream Discharge				Upstream Reference				Downstream Discharge				Temporary Pools			
	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	BCD1	BCD2	ORD1	ORD2	ORU1	ORU2	ORU3	ORU4	WWC1	MCP1	MCP2	NP
Chimarra sp. AV17			8							3			80							
Polycentropodidae																				
Paranyctiophlyax sp. AV5			4		1					1			11							
Maxillopoda																				
Copepoda sp.															50	15				
Calanoida																				
Diaptomidae																				
Calanoida sp.							3													
Eudiaptomus lumholtzi						2						4						50	2	
Cyclopoida																				
Cyclopidae																				
Cyclopidae spp.																				
Mesocyclops spp.															48					
Eucyclops australiensis											1									
Mesocyclops brooksi							50													
Mesocyclops darwini								1												
Mesocyclops notius		4	1	2				48				40	15	50		45		3	38	50
Microcyclops varicans		1			1	6		1												
Paracyclops chiltoni	2																			
Thermocyclops decipiens						2														
Tropocyclops confinis				1																
Poecilostomatoida																				
Ergasilidae																				
Ergasilidae sp.				1										1	2	2				
Monogononta																				
Flosculariacea																				
Filiniidae																				
Filinia sp.																		20		
Ostracoda																				
Ostracoda spp (imm/dam)	31																			
Podocopida																				
Cyprididae																				
Cyprididae sp.	1			2																
Cypretta sp.	4																			
Darwinulidae																				
Darwinulidae sp.									2											
Vestalenula marmonieri	1			2		2														
Diversity	36	30	32	24	17	36	34	20	29	32	26	27	30	52	41	37	23	31	18	22
Abundance	183	91	136	105	30	106	200	140	136	414	122	338	870	361	348	815	440	432	100	569

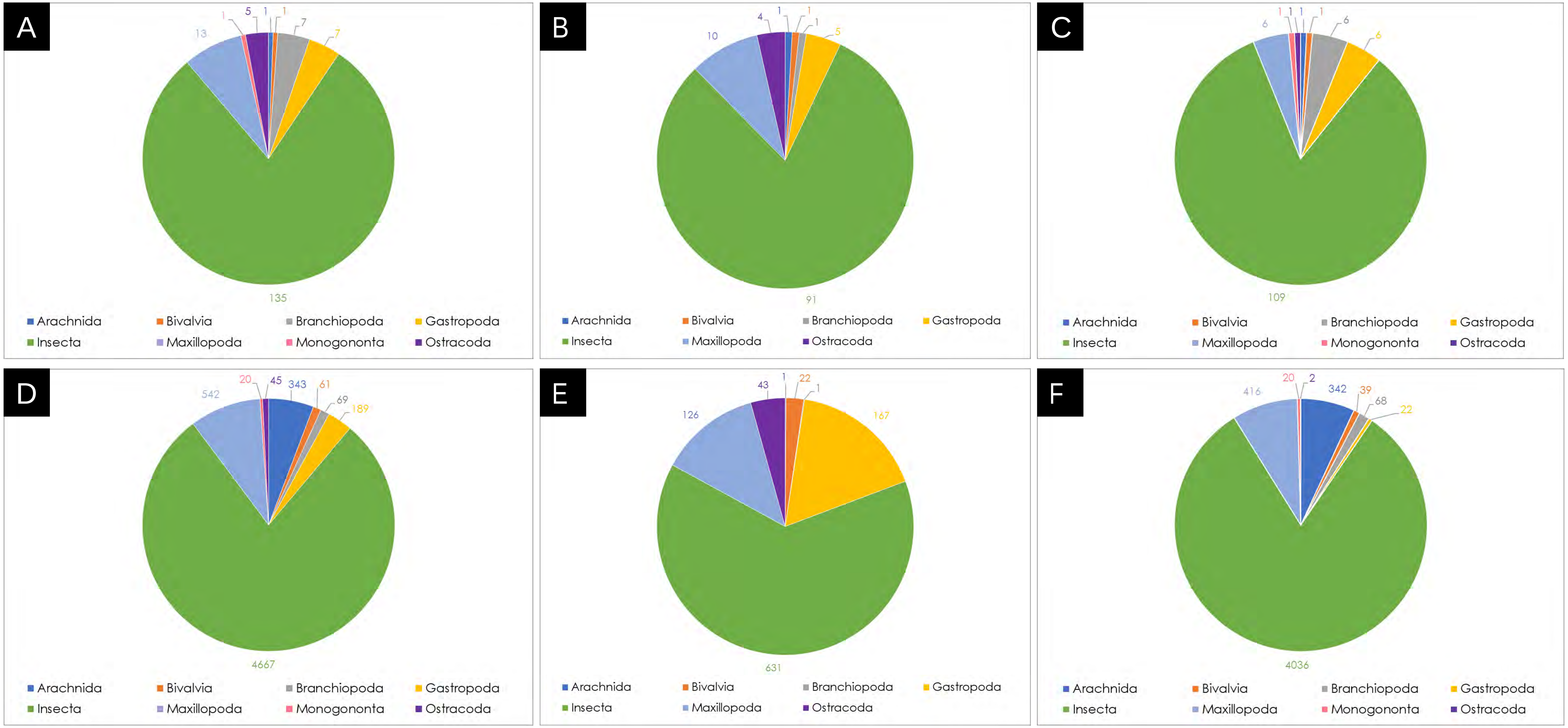


Figure 3-15: Pie charts summarising (A) overall diversity, (B) dry season diversity and (C) wet season diversity of aquatic invertebrates, and (D) overall abundance, (E) dry season abundance and (F) wet season abundance of aquatic invertebrates recorded during the Study.

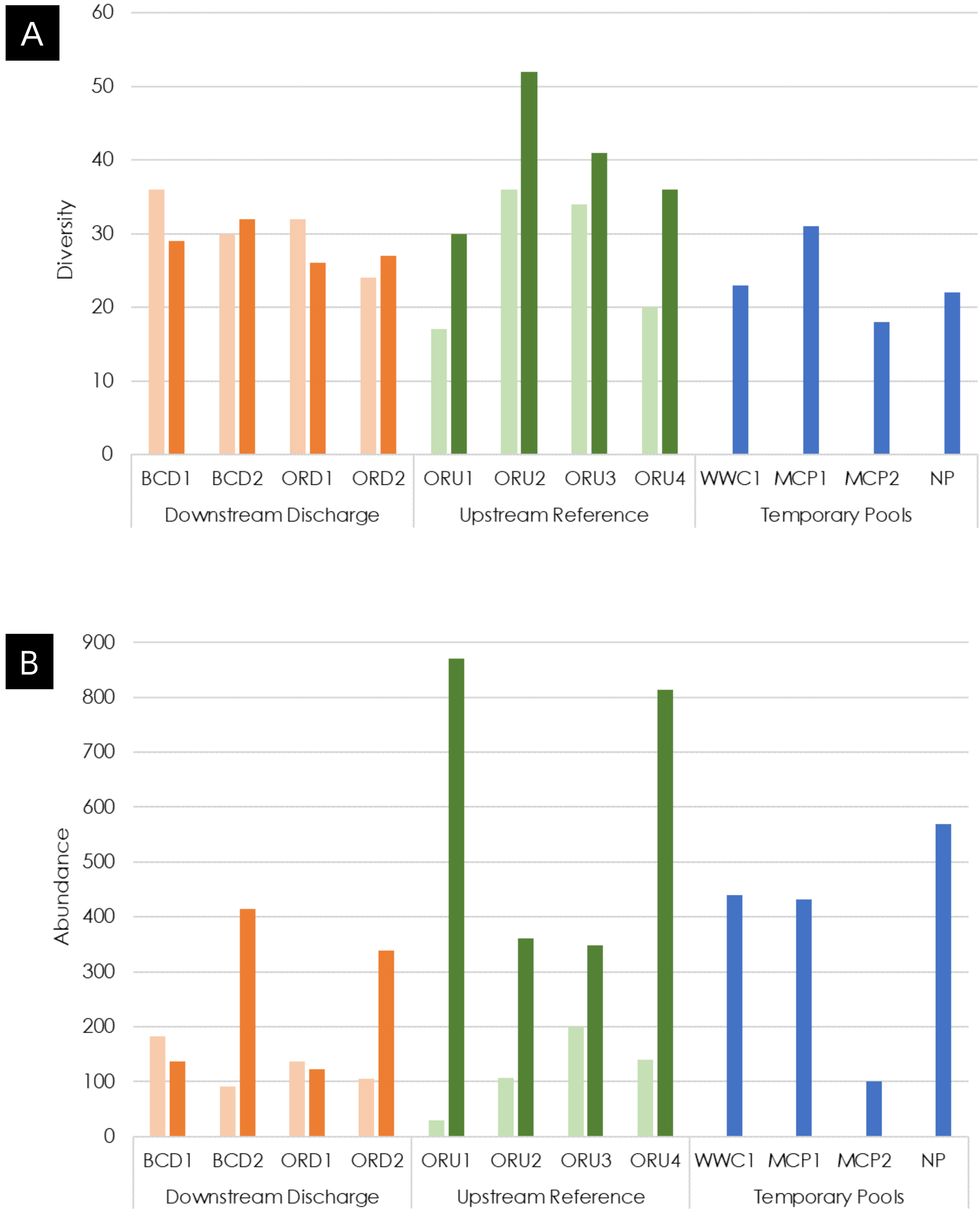
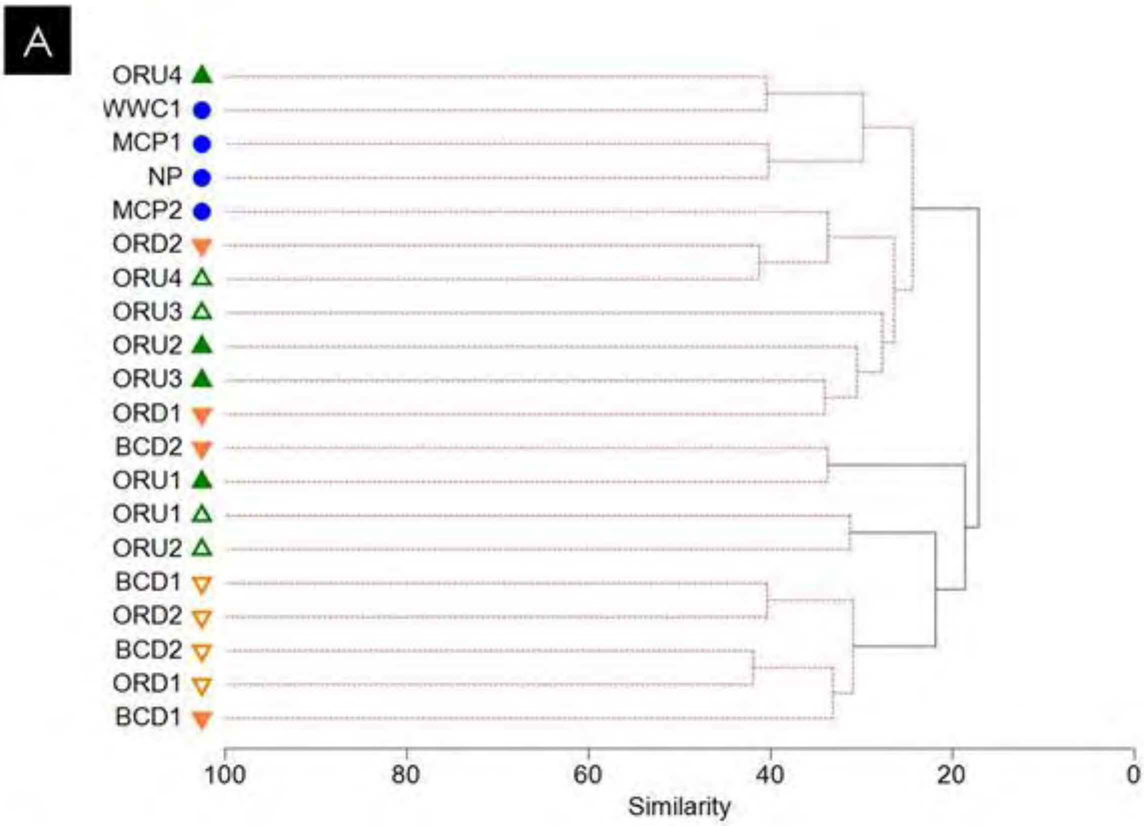


Figure 3-16: Aquatic invertebrate diversity (A) and abundance (B) of downstream discharge, upstream reference and temporary pool sites (■■ = dry season, ■■ = wet season and ■ = temporary pools).



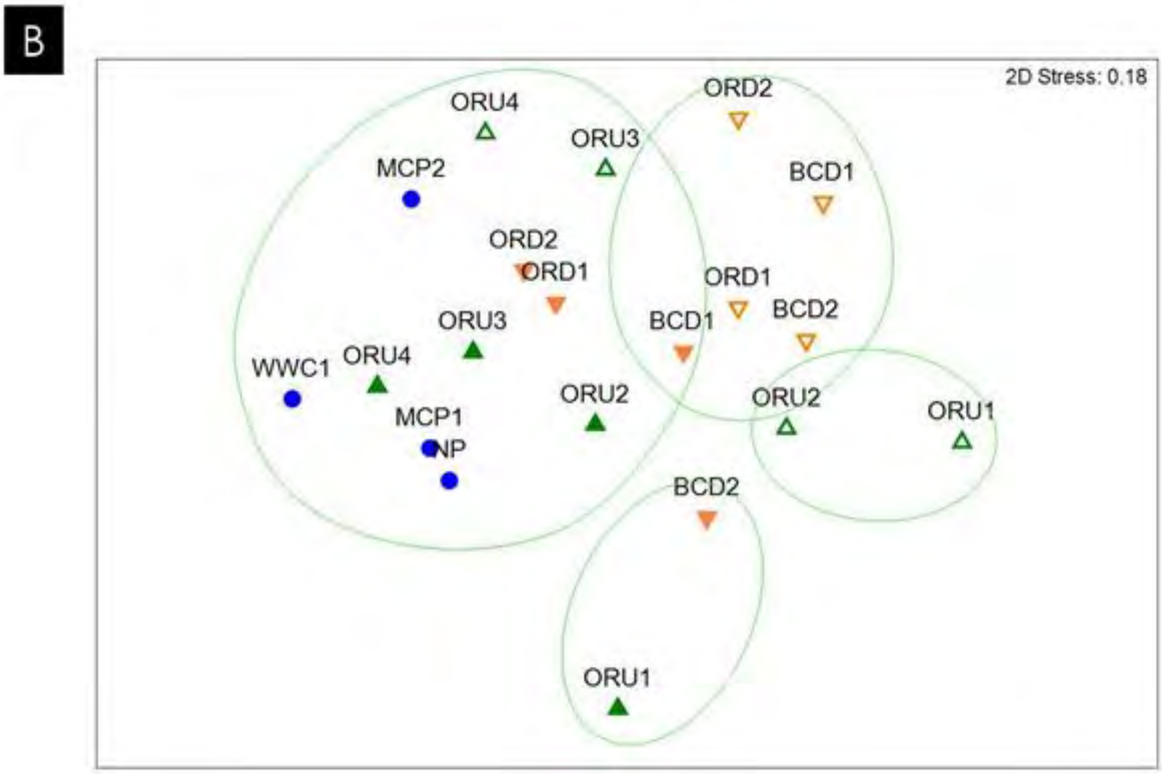


Figure 3-17: Cluster dendrogram and nMDS of aquatic invertebrate samples of downstream discharge, upstream reference and temporary pool sites (▲ = upstream reference wet season, △ = upstream reference dry season, ▼= downstream discharge wet season, ▽ = downstream discharge dry season, • = temporary pools). Green circles demonstrate significantly different clusters, as determined by SIMPROF.

3.2.6 Fish

Australia has a relatively depauperate freshwater fish fauna, particularly given the size of the continent, which is likely a reflection of the arid conditions in most areas (Allen *et al.* 2002). There is a high degree of endemism, particularly in Western Australia (Allen *et al.* 2002; Morgan *et al.* 2014a; Morgan *et al.* 2014b). The fish fauna have varying aquatic requirements, with some species occurring exclusively in freshwater habitats, and others typically inhabiting estuarine or marine habitats, yet still requiring freshwater for some stage of their life cycle (Allen *et al.* 2002). The importance of permanent waterbodies, particularly those that provide both shallow and deep areas, as refugia for freshwater and estuarine species in the Pilbara has been well established (Beesley and Prince 2010; Braimbridge 2010; Dobbs and Davies 2009a; Morgan *et al.* 2009). Groundwater intrusion has been identified as a key factor in this regard, which provides buffering from adverse temperature, salinity and dissolved oxygen levels (Morgan *et al.* 2009).

A total of 13 freshwater fish species are known from the Pilbara bioregion, six of which have been recorded from the Oakover River; *Melanotaenia australis* (western rainbowfish), *Leiopotherapon unicolor* (spangled perch), *Craterocephalus cuneiceps* (Murchison River hardyhead), *Neosilurus hyrtlii* (Hyrtl's tandan catfish), *Arius graeffei* (lesser salmon catfish) and *Nematalosa erebi* (bony bream) (Allen *et al.* 2002; Morgan *et al.* 2014a; Morgan and Gill 2004; Morgan *et al.* 2014b). Additionally, two marine/estuarine vagrant species, *Megalops cyprinoides* (oxeye herring) and *Mugil cephalus* (sea mullet) have been recorded from the Oakover River (Morgan and Gill 2004). During the Study, all six freshwater fish species known from the Oakover River, and one of the estuarine/marine vagrants (*Megalops cyprinoides*) were recorded, from a total of 2,071 individuals (**Table 3-13**).

Leiopotherapon unicolor (**Plate 3-3A**) and *Melanotaenia australis* (**Plate 3-3B**) were the most common and widespread species, recorded from all sites during both the wet and dry seasons (**Table 3-13**). *Nematalosa erebi* (**Plate 3-3E**) was also relatively widespread, recorded at three of the four discharge sites (BCD2, ORD1 and ORD2), all four reference sites (ORU1-4) and WWC1 among the temporary pool sites (**Table 3-13**). These species were also the most abundant taxa, together typically comprising over 75% of all fish captured or observed at each site in both seasons (**Table** 3-13). *Melanotaenia australis, Leiopotherapon unicolor* and *Nematalosa erebi* are among the most ubiquitous species in the Pilbara region, known from the majority of major river systems (Morgan *et al.* 2014a; Morgan *et al.* 2009; Morgan and Gill 2004). More broadly, *Leiopotherapon unicolor* and *Nematalosa erebi* are two of Australia's most widespread fish species, with distributions spanning drainages of the Kimberley, Northern Territory, Queensland, Murray-Darling basin and Lake Eyre (Morgan *et al.* 2014b). This can be ascribed to their ability to withstand extreme variations in water quality, and high fecundity, with protracted spawning periods extend over many months (Allen *et al.* 2002; Morgan and Gill 2004).

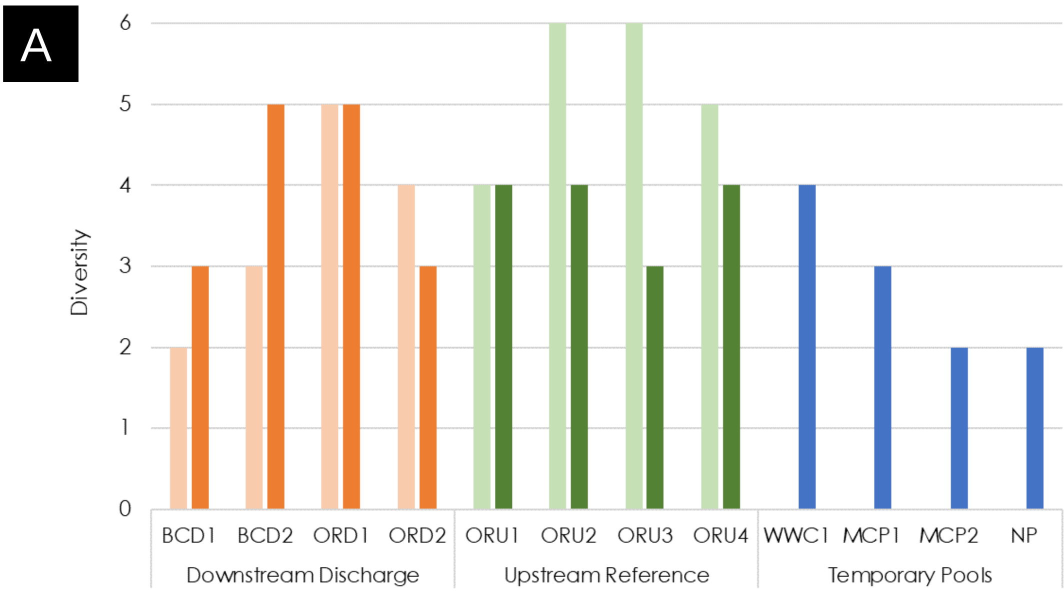
Of the remaining fish species, *Neosilurus hyrtlii* (**Plate 3-3D**) and *Arius graeffei* (**Plate 3-3F**) were recorded from seven and six sites, respectively, with *Neosilurus hyrtlii* recorded from multiple discharge, upstream reference and temporary pool sites (**Table 3-13**). *Arius graeffei* was typically associated with larger pools on the Oakover River, both upstream (ORU2, ORU3 and ORU4) and downstream (ORD1) of discharge, although one specimen was observed in a deep pool at Brumby Creek discharge site BCD2 during the dry season (**Table 3-13**). *Neosilurus hytlii* is a widespread species across the Pilbara region, and more broadly across northern Australia (Morgan *et al.* 2014a; Morgan *et al.* 2009; Morgan and Gill 2004). The larger *Arius graeffei* is also widely distributed across northern Australia, although is more commonly associated with the lower estuarine reaches of Pilbara drainage systems (Morgan and Gill 2004), typically recorded in lower densities in upstream riverine pools such as those sampled during the Study.

Craterocephalus cuneiceps (**Plate 3-3C**) was only recorded from four sites (BCD2, ORD1, ORD2 and ORU4) in relatively low abundances (<12 individuals per site) (**Table 3-13**), while the estuarine/marine vagrant *Megalops cyprinoides* was only present at two upstream reference sites on the Oakover River; ORU3 and ORU4, with a maximum recorded abundance of four individuals (ORU2 in the dry season) (**Table 3-13**). *Craterocephalus cuneiceps* is endemic to Western Australia, and has a unique distribution in the Pilbara, being only known from the region's southernmost rivers (Greenough, Hutt, Murchison and Gascoyne), as well as its northernmost river (De Grey) (Allen *et al.* 2005), where it is relatively uncommon (Morgan and Gill 2004). *Megalops cyprinoides* is a common inhabitant of large riverine pools in the Pilbara region, such as those on the Oakover River, which are primarily used as nursery habitat. However, adults of this species are also known to spend extended periods in the freshwater reaches of river systems (Morgan and Gill 2004).

Between sites, diversity was relatively consistent, and was highest at upstream reference sites ORU2 and ORU3 during the dry season (six taxa each) (**Figure 3-18A**). At the time of sampling, these were very clear riverine pools, representing optimal conditions for counting and identifying fish by visual observation, with both sites comprising a combination of freshwater and marine/estuarine vagrent species. Diversity was lower at both sites during the wet season, which was attributable to the increase in size of the pools, as well as increased turbidity, resulting in sub-optimal conditions for fish capture and visual observation. Overall, lowest diversity occurred at temporary pools MCP2 and NP (two taxa each) (**Figure 3-18A**), associated with the ephemeral nature of these pools, with only *Melanotaenia australis* and *Leiopotherapon unicolor* present. Both species are strongly adapted to the ephemeral regimes of Pilbara river systems, being able to persist in small, temporary pools for extended periods due to their tolerances of a wide range of salinities, oxygen levels and temperatures (Morgan *et al.* 2014a; Morgan and Gill 2004; Rogers and Ralph 2011).

Fish abundance was more variable between sites, with greatest abundance recorded at WWC1 (200 individuals), followed by ORU1 (wet season; 188 individuals), MCP1 (160 individuals) and BCD1 (wet season; 160 individuals) (**Figure 3-18B**). High abundance at these sites was primarily due to high numbers of *Leiopotherapon unicolor*, which are known to school in large numbers, particularly in their juvenile stages (Rogers and Ralph 2011). Comparatively, lowest abundance was recorded at ORU4 (wet season; 40 individuals), followed by ORD2 (wet season; 46 individuals) (**Figure 3-18B**). This was attributable to fish sampling methods being rendered relatively ineffective due to very great size (>500 m) and depth (>1 m) of these pools.

Overall, the fish fauna encountered during the Study comprised common, ubiquitous species with broader distributions across the Pilbara region. Greatest diversity was recorded at semi-permanent and permanent riverine pools on the Oakover River, which provide a variety of habitat types, stable water quality and refugia for both freshwater and marine/estuarine vagrant species between wet season flow events. The perennial reach of Brumby Creek downstream of the W12 outfall also supports all six freshwater fish species known from the Oakover River system, which were utilising the permanent habitat and relatively good water quality generated by the discharge. Despite drying completely during the dry season, the temporary pools within and adjacent to the Development Envelope support hardy species, such as *Melanotaenia australis* and *Leiopotherapon unicolor,* which are strongly adapted to dispersing, spawning and persisting in ephemeral rivers and creeklines (Morgan *et al.* 2014a; Morgan and Gill 2004; Rogers and Ralph 2011).



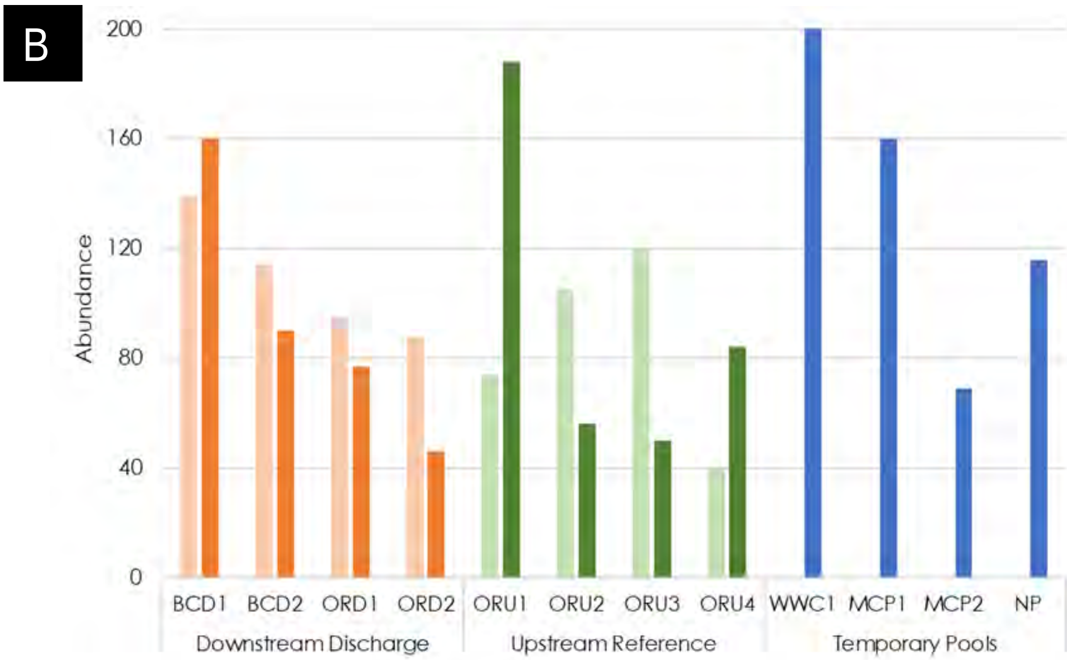


Figure 3-18: Fish diversity (A) and abundance (B) of downstream discharge, upstream reference and temporary pool sites during the Study (■■ = dry season, ■■ = wet season and ■ = temporary pools).

Table 3-13: Summary fish recorded at downstream discharge, upstream reference and temporary pool sites during the Study.

Scientific Name	Common Name	Downstream Discharge								Upstream Reference								Temporary Pools			
		BCD1		BCD2		ORD1		ORD2		ORU1		ORU2		ORU3		ORU4		WWC1	MCP1	MCP2	NP
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet				
Freshwater Fishes																					
Ariidae (Fork-Tailed catfishes)																					
Arius graeffei	Lesser salmon catfish			1		7	1					6	1	17		1	5				
Atherinidae (Hardyheads)																					
Craterocephalus cuneiceps	Murchison River hardyhead				1	12	1	8								1					
Clupeidae (Herrings)																					
Nematalosa erebi	Bony bream				21	2	16	2	26	14	43	45	6	19	1		10	29			
Plotosidae (Eel-tailed catfishes)																					
Neosilurus hyrtlii	Hyrtl's tandan		5		1					1	3		4	3		1		1	2		
Melanotaeniidae (Rainbowfishes)																					
Melanotaenia australis	Western rainbowfish	102	94	31	39	40	29	20	1	35	38	32	25	25	35	2	37	124	4	23	1
Terapontidae (Grunters)																					
Leiopotherapon unicolor	Spangled perch	37	61	82	28	34	30	58	19	24	104	18	19	53	14	35	32	46	154	46	115
Marine/Estuarine Fishes																					
Megalopidae (Tarpon)																					
Megalops cyprinoides	Oxeye herring											4	1	3							
Abundance		**139**	**160**	**114**	**90**	**95**	**77**	**88**	**46**	**74**	**188**	**105**	**56**	**120**	**50**	**40**	**84**	**200**	**160**	**69**	**116**
Total Abundance		**2,071**																			
Diversity		**2**	**3**	**3**	**5**	**5**	**5**	**4**	**3**	**4**	**4**	**5**	**6**	**6**	**4**	**5**	**4**	**4**	**3**	**2**	**2**
Total Diversity		**7**																			

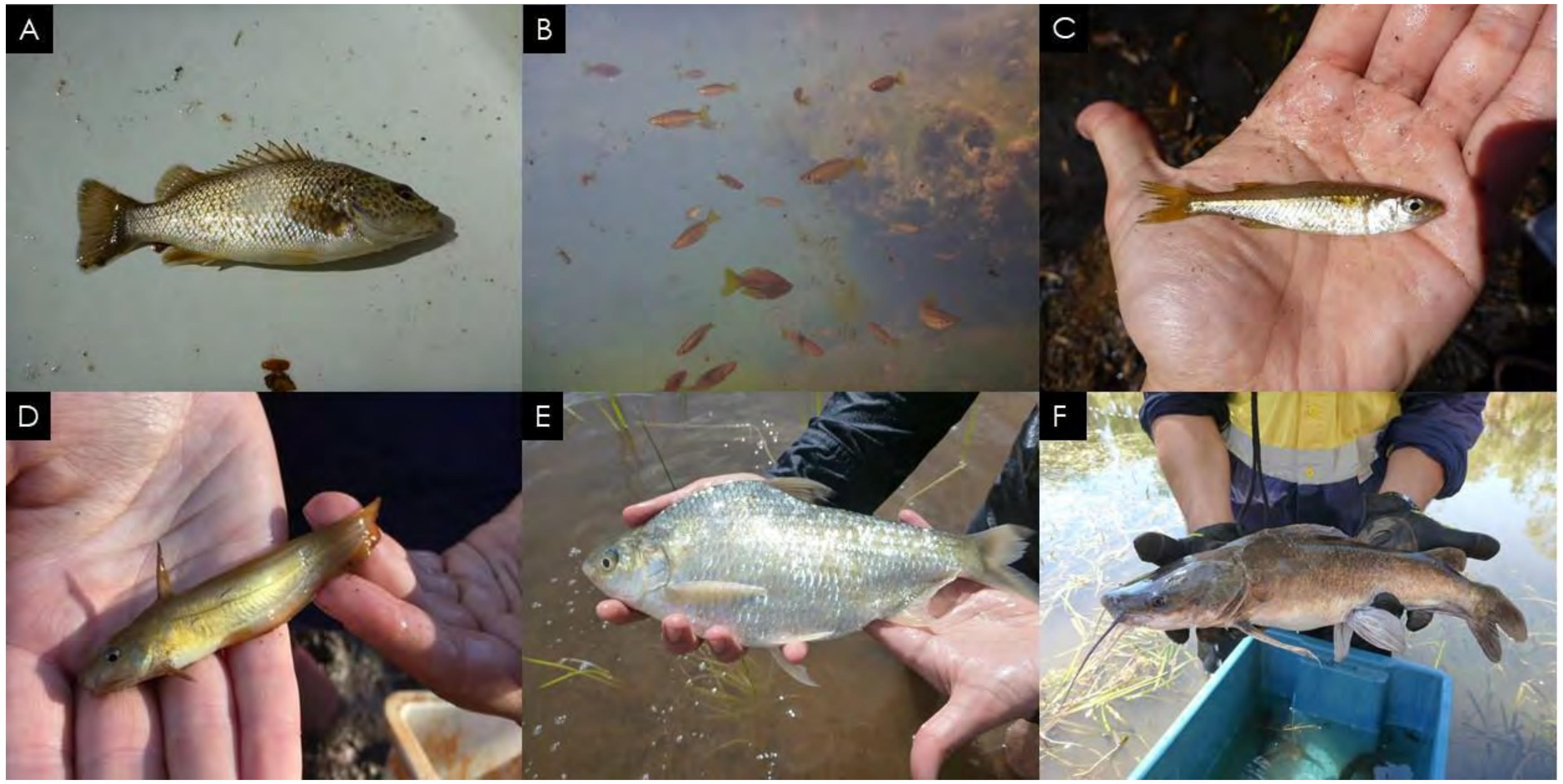


Plate 3-3: Examples of freshwater fish recorded during the Study, including (A) Spangled perch, (B) Western rainbowfish (C) Murchison River hardyhead, (D) Hyrtl's tandan, (E) Bony bream and (F) Lesser salmon catfish.

3.2.7 Waterbirds

Pilbara riverine habitats, particularly those with permanent/semi-permanent pools and riparian vegetation supported by groundwater, are recognised as important habitats for avifauna (Johnstone *et al.* 2013). The inland waterbodies provide refugia for both waterbirds and terrestrial birds, particularly over the dry season, with coastal floodplains, mudflats and claypans hosting a diverse array of migratory and nomadic species (Johnstone *et al.* 2013). The resident waterbirds of the Pilbara region are typically opportunistic in their feeding and breeding strategies, and disperse over wide areas following large wet season rainfall events (Masini 1988). However, during low-rainfall years, permanent and semi-permanent riverine pools such as those of the Oakover River can host large concentrations of waterbirds, as they provide shelter, breeding habitat among emergent macrophytes, and a food source in the form of invertebrates, fish and submerged macrophytes (Masini 1988).

A total of 12 waterbird species from nine families, were recorded from during the Study (**Table 3-14**). The most common and widespread species were the black-fronted dotterel (*Charadrius melanops*) and Pacific black duck (*Anas superciliosa*), recorded from three sites each (**Table 3-14**). The black-fronted dotterel was the only species recorded during both wet and dry seasons at a given site (downstream discharge site ORD2). These birds are ubiquitous species in the Pilbara region, known from many lentic and lotic water bodies including artificial habitats (Bell *et al.* 2014). They are usually seen in ones or twos (as was the case during the Study) or occasionally as small flocks up to 21 within the region (Storr 1984). Black-fronted dotterels are considered to have benefited from increased feeding opportunities in artificial aquatic habitats in the Pilbara region (Johnstone *et al.* 2013). Breeding of this species has been reported during most of the year, especially January to July and then August and September. The Pacific black duck is nomadic in the Pilbara and mostly comprise visitors from other parts of Australia, but do occasionally breed within Pilbara (Johnstone *et al.* 2013).

Both the black swan (*Cygnus atratus*) and little pied cormorant (*Phalacrocorax melanoleucos*) were recorded from two sites each (**Table 3-14**). Both species are widespread in the Pilbara region and inhabit a range of aquatic systems across all major river systems (Johnstone *et al.* 2013). The little pied cormorant is a resident species within the Pilbara region, and are more abundant in the northern Pilbara, where they congregate at river pools such as those of the De Grey River system (Johnstone *et al.* 2013).The black swan was formerly a scarce visitor to the Pilbara region, but since the 1970s, has become progressively more common, attributed to the increase of artificial habitats, including water supply dams and permanent habitats created by discharge (Johnstone *et al.* 2013). Occasionally, large flocks of over 580 individuals have been sighted (Storr 1984), although such congregations are typically associated with large claypans (such as the Fortescue Marsh) following major flooding (Johnstone *et al.* 2013). During the Study, black swans were observed in pairs at each site, which is more typical for the species at river pools (Johnstone *et al.* 2013).

Of interest within the avifauna was the record of a pair of black-necked storks (*Ephippiorhynchus asiaticus australis*) from ORD1 during the wet season (**Plate** 3-4). This species was formerly rare in the Pilbara region and probably was only a vagrant from the Kimberley (Storr 1984). However, in the last 50 years, they have gradually increased in numbers within the region, although records are still largely restricted to the north and east regions of the Pilbara (Johnstone *et al.* 2013). The white-bellied sea-eagle (*Haliaeetus leucogaster*), recorded at discharge site ORD2, is also of interest as this species is largely restricted to the northern coastline of Pilbara, and is only an occasional visitor to inland waterbodies (Johnstone *et al.* 2013). The other six species reported (eastern great egret, white-faced heron, white-necked heron, whiskered tern, Australian pelican and darter; **Table 3-14**), are common waterbird species within the Pilbara region, and more broadly across Australia (Johnstone *et al.* 2013).

During the Study, the majority of waterbirds were associated with large, semi-permanent and permanent riverine pools, such as ORD1, ORD2 and ORU4, compared to the temporary pools or Brumby Creek. Two discharge sites (BCD2 and ORD1), two reference sites (ORU1 and ORU2) and three temporary pools (WWC1, MCP1 and NP) did not contain any waterbirds at the time of sampling. Between sites, diversity was highest at ORD2, with eight of the 12 species recorded (six species during the dry season and three during the wet season) (**Table 3-14**). This site comprises a large, deep pool supplying a permanent water and food source, with a large, rocky cliff face, providing shelter and nesting habitat. The reference site ORU4 reported four species, all recorded only during the dry season. The higher number of records during the dry season is likely due to the concentration of feeding opportunities at remnant and receding pools. Contrastingly however, ORD1 and ORU3 only contained birds during the wet season, likely related to greater habitat availability and overall productivity following flooding. Generally, the waterbirds encountered during the Study comprised a suite of common, representative, ubiquitous species with known broader distributions across the Pilbara or in the broader area surrounding Oakover River.

Table 3-14: Summary waterbirds recorded at downstream discharge, upstream reference and temporary pool sites during the Study.

Scientific Name	Common Name	Downstream Discharge								Upstream Reference								Temporary Pools			
		BCD1		BCD2		ORD1		ORD2		ORU1		ORU2		ORU3		ORU4		WWC1	MCP1	MCP2	NP
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet				
Accipitridae																					
Haliaeetus leucogaster	White-bellied sea-eagle								●												
Anatidae																					
Cygnus atratus	Black swan							●							●						
Anas superciliosa	Pacific black duck	●														●				●	
Anhimidae																					
Anhinga melanogaster novaehollandiae	Darter															●					
Ardeidae																					
Ardea modesta	Eastern great egret							●													
Ardea novaehollandiae	White-faced heron							●													
Ardea pacifica	White-necked heron								●									●			
Charadriidae																					
Charadrius melanops	Black-fronted dotterel						●	●	●							●					
Ciconiidae																					
Ephippiorhynchus asiaticus australis	Black-necked stork						●														
Laridae																					
Sterna hybrida javanica	Whiskered tern																				
Pelecanidae																					
Pelecanus conspicillatus	Australian pelican							●													
Phalacrocoracidae																					
Phalacrocorax melanoleucos	Little pied cormorant							●								●					
Diversity		**1**	**0**	**0**	**0**	**0**	**2**	**6**	**3**	**0**	**0**	**0**	**0**	**0**	**1**	**4**	**0**	**1**	**0**	**1**	**0**
Total Diversity		**12**																			

Plate 3-4: Black-necked storks (photograph not taken during the Study).

3.2.8 Other Fauna

No frogs, freshwater turtles, or Pilbara olive pythons were observed during the Study. The Pilbara olive python, *Liasis olivaceus barroni*, is listed as Vulnerable under both the BC Act and the EPBC Act, and has a strong affinity to rocky escarpments and gorges, often along watercourses (Wilson and Swan 2010), as well as to permanent/semi-permanent pools where they ambush prey such as kangaroos and wallabies (Tutt et al. 2002). This species has previously been observed utilising temporary pools within the Development Envelope following inundation (Western Wildlife 2020). It is also likely that this species utilises permanent/semi-permanent pools of the Oakover River. As the Pilbara olive python is primarily nocturnal, the absence of the species during the Study is likely reflective of field surveys being undertaken during the daytime, as well as the inherent cryptic nature of the species.

3.2.9 Summary of Ecological Values

The rivers and creeklines sampled during the Study were found to support a diverse and abundant aquatic biota community. In total, nine aquatic macrophyte, 71 phytoplankton, 64 diatom, 170 aquatic invertebrate, seven fish and twelve waterbird taxa were recorded at downstream discharge, upstream reference and temporary pool sites across both the dry and wet seasons. During dry conditions, the permanent or semi-permanent pools on the Oakover River (both upstream and downstream of discharge), as well as the perennial reach of Brumby Creek influenced by existing discharge from Woodie Woodie, provide refuge for aquatic biota in an otherwise arid landscape. In the wet season, expansion of riverine pools following flooding, and associated increases in habitat availability and favorable water quality, leads to enhanced productivity of primary producers (algae and macrophytes) and increased diversity of aquatic invertebrates, supporting higher order consumers such as fish and waterbirds.

Sites influenced by the existing discharge were found to support comparable macrophyte, algal, invertebrate fish diversity, abundance and composition, to permanent reference sites upstream during the Study. This was associated with the perennial hydrological regime created by discharge, as well as discharge water quality characterised by relatively low salinity, turbidity and metals. In contrast, opportunistic, transient invertebrate taxa, and hardy and adaptable fish species (*Melanotaenia australis* and *Leiopotherapon unicolor*), were characteristic of temporary pools within and adjacent to the Development Envelope, while aquatic macrophytes and waterbirds were depauperate.

The majority of macrophyte, algal, invertebrate and vertebrate taxa recorded during the Study have broader distributions throughout the Pilbara, northern-Australia, or Australia. Exceptions included the dragonfly *Hemicordulia koomina,* and the damselfly *Eurysticta coolawanyah*, which are endemic to the Pilbara region, and are listed as Vulnerable on the IUCN Red List of Threatened Species. *Eurysticta coolawanyah* was widely distributed in the local area, recorded from discharge, upstream reference and temporary pool sites, while *Hemicordulia koomina* was only recorded from one upstream reference site, reflecting the cryptic nature of this species.

Additionally, database records suggest that the semi-permanent and permanent pools of the Oakover River downstream of the discharge intermittently support significant migratory waterbird species, including *Actitis hypoleucos* (common sandpiper), *Tringa glareola* (wood sandpiper), *Pandion cristatus* (osprey) and *Plegadis falcinellus* (glossy ibis). There are also records of *Liasis olivaceus barroni* (Pilbara olive python) and the migratory waterbird *Calidris canutus* (red knot) from temporary waterbodies within the Development Envelope. However, both taxa are only likely to visit these pools following inundation during the wet season.

A summary of the abiotic and biotic characteristics and ecological values of the various waterbodies within the Development Envelope, based on the findings of this Study is provided in **Table 3-15.** At the local and regional scale, permanent, groundwater-fed pools, such as ORU1 and ORU2, are considered to be of significant importance to arid-zone aquatic ecosystem function (Howe and Pritchard 2007). Maintenance of pool size and depth by groundwater limits diurnal and seasonal fluctuations in water quality, buffering aquatic biota from changes in water temperature, dissolved oxygen and salinity, which may cause mortality (Loomes and Braimbridge 2010). Water permanency at groundwater-fed pools also provides refuge and migratory routes for fauna, with maintenance of fish populations inherently linked to water permanence (Morgan *et al.* 2009).

The semi-permanent riverine pools in Oakover River, such as ORU3 and ORU4, are expansive and highly productive during the wet season, supporting a diverse array of primary producers, aquatic invertebrates and waterbirds. However, these pools contract substantially during the dry season, corresponding with a decrease in the diversity of diatoms and aquatic invertebrates observed during this Study. This was associated with degraded water quality (increased salinity, turbidity and nutrients), attributed to unrestricted livestock access and evapoconcentration. Therefore, the permanent and semi-permanent pools of the Oakover River upstream of discharge are considered to be of **moderate to high** ecological value within the local area.

Within the reach of Brumby Creek downstream of the W12 outfall (BCD1 and BCD2), the discharge provides stable water quality and habitat for aquatic biota during both the wet and dry seasons, including *Eurysticta coolawanyah*. Downstream of the Brumby Creek confluence, the riverine habitats of the Oakover River influenced by discharge also provide permanent refuge for a range of algal, invertebrate, fish and waterbird taxa, which includes historic records for several migratory waterbirds. However, the overall productivity within these waterbodies, and particularly Brumby Creek, which does not host any natural permanent pools, is expected to decrease following the eventual cessation of discharge. Therefore, the reach of Brumby Creek downstream of the W12 outfall is considered to be of **moderate** ecological value, while the downstream Oakover River pools are considered to be of **moderate to high** ecological value, with higher value associated with historic (pre-discharge) permanent pools (such as ORD2).

The temporary pools (WWC1, NP, MCP1 and MCP2) support a variety of transient aquatic biota able to rapidly colonise waterbodies when inundated during the wet season. They also provide temporary habitat for conservation listed species such as *Liasis olivaceus barroni*, *Eurysticta coolawnyah* and migratory waterbirds such as *Calidris canutus*. However, these pools only hold surface water for a short period (weeks to months) and are subject to declining water quality towards the end of the hydroperiod. This contrasts to the favourable conditions and refugia provided by permanent pools of the Oakover River and Brumby Creek downstream of the discharge. Therefore, the temporary pools within and adjacent to the Development Envelope are considered to be of **low to moderate** ecological value, within a local context.

Table 3-15: Summary of ecological values of upstream reference, downstream discharge and temporary pool sites during the Study.

Reach / Waterbody	Hydrology / Habitat	Water Quality	Sediment Quality	Primary Producers	2nd and 3rd Order Consumers	Conservation Significant Taxa (Desktop and Baseline Study)	Ecological Value
Upstream Reference	• Large permanent, spring-fed riverine pools • Semi-permanent riverine pools, which are expansive in the wet season, and contract substantially during the dry season.	• Fresh water (EC < 5,000 µS/cm), neutral to alkaline pH, generally low metals levels. • Elevated nutrient concentrations due to groundwater influence (spring-fed pools) • Salinity, nutrients and turbidity increase at semi-permanent pools during the dry season due to evapoconcentration and cattle impacts	• Low salinity, nutrients and metals levels • Salinity and nutrients increase at semi-permanent pools during the dry season due to evapoconcentration • Some naturally elevated metals at spring-fed pools (e.g. nickel and chromium)	• Eight aquatic macrophytes, 54 phytoplankton, 43 diatoms, all with Pilbara wide/cosmopolitan distribution • Increased diatom productivity during the wet season and semi-permanent pools expand and water quality increases	• 130 invertebrate taxa, seven fish species and five waterbirds • Increased richness and abundance of aquatic invertebrates during the wet season, associated with greater habitat availability and higher overall productivity	• *Hemicorulia koomina* (dragonfly) (IUCN Vulnerable) • *Nososticta pilbara* (damselfly) (BC Act P2) – record likely erroneous	**Moderate to High**
Downstream Discharge (Brumby Creek)	• Flows perennially due to discharge • Historically ephemeral creekline, • Perennial regime, and overall productivity expected to decrease following cessation of discharge	• Fresh water (EC < 5,000 µS/cm), alkaline pH, generally low metals levels • Elevated nitrogen concentrations due to discharge of enriched groundwater • Seasonally homogenous water quality	• Low salinity and metals levels • Elevated total nitrogen (BCD2 in the dry season), related to elevated concentrations in discharge water	• Eight aquatic macrophytes, 34 phytoplankton, 28 diatoms, all with Pilbara wide/cosmopolitan distribution • Diverse macrophyte assemblage associated with water permanency and morphological heterogeneity, with deep pools, shallow backwaters and areas of flow	• 75 invertebrate taxa, six fish species and one waterbird • Consistent aquatic invertebrate diversity between seasons, due to homogenous conditions created by discharge • Invertebrate assemblage at BCD2 comparable to permanent spring ORU1 on the Oakover River, reflecting perennial flow regime	• *Eurysticta coolawanyah* (damselfly) (IUCN Vulnerable)	**Moderate**
Downstream Discharge (Oakover River)	• Large permanent riverine pools maintained by discharge • Limited change in pool size or depth between seasons due to discharge influence	• Fresh water (EC < 5,000 µS/cm), alkaline pH, generally low nutrient and metals levels • Relatively consistent water quality between seasons, due to discharge maintaining pool size and depth over the dry season	• Low salinity and metals levels • Higher nutrient concentrations during the wet season, likely due to catchment inflows and distribution of nutrients following flooding	• Seven aquatic macrophytes, 33 phytoplankton, 30 diatoms, all with Pilbara wide/cosmopolitan distribution • Increased diatom productivity during the wet season and semi-permanent pools expand and water quality increases	• 67 invertebrate taxa, five fish species and nine waterbirds • High waterbird diversity at ORD2, with this site supplying a permanent water and food source, with a large, rocky cliff face, providing shelter and nesting habitat	• *Actitis hypoleucos* (common sandpiper) (Migratory) • *Tringa glareola* (wood sandpiper) (Migratory) • *Plegadis falcinellus* (glossy ibis) (Migratory) • *Pandion cristatus* (osprey) (Migratory)	**Moderate to High -**
Temporary Pools	• Small, ephemeral pools, typically located at the base of small rocky gorges • Hydrology influenced exclusively by rainfall • Short hydroperiod; only hold water for a period of weeks to months during the wet season	• Fresh water (EC < 5,000 µS/cm), alkaline pH, generally low nutrient and metals levels • Elevated turbidity, nutrients and some metals at some sites associated with impacts from unrestricted livestock access and evapoconcentration	• Generally low salinity and metals levels • Elevated total nitrogen and total phosphorous levels, likely related to the breakdown of animal waste from unrestricted livestock access, along with evapoconcentration effects	• One aquatic macrophyte, 28 phytoplankton, 19 diatoms, all with Pilbara wide/cosmopolitan distribution • Low diversity of macrophytes and diatoms related to ephemeral regime • High abundance of phytoplankton recorded, associated with large numbers of the colonial green alga *Pediastrum* sp. and the dinoflagellate *Peridinium* sp.	• 51 invertebrate taxa, four fish species, two waterbirds • Invertebrate assemblages comprising transient and opportunistic taxa, able to rapidly colonise waterbodies following inundation • Fish fauna comprising species with high dispersal capabilities and tolerance of a wide range of environmental conditions (e.g. *Melanotaenia australis* and *Leioptherapon unicolor*).	• *Liasis olivaceus barroni* (Pilbara olive python) (BC Act and EPBC Act Vulnerable) • *Eurystica coolawanyah* (damselfly) (IUCN Vulnerable) • *Calidris canutus* (red knot) (BC Act and EPBC Act Endangered)	**Low to Moderate**

3.3 Impact Assessment

Based on the findings from the Study, and the ecological value of waterbodies (considering significant species records), the following aquatic ecological impact assessment has been developed. The impact assessment provides a description of the relevant threatening processes associated with the WCOP, the potential impacts of these threatening processes on the aquatic biota of receiving environments, potential management and mitigation measures, and the subsequent determination of potential risk.

The two key threatening processes associated with the WCOP that may potentially impact the aquatic ecology of waterbodies in the local area are:

- Discharge of excess mine pit dewatering to creeklines or rivers, causing the alteration of hydrology and water quality within receiving environments; and
- Groundwater drawdown from mine pit dewatering, resulting in changes to groundwater quantity and subsequent impacts to groundwater-supported surface waters.

The threatening processes, potential impacts and management and mitigation measures are discussed in more detail below and are summarised in **Table 3-17**.

3.3.1 Discharge

3.3.1.1 Quantity and Extent

To enable below water table mining during the WCOP, it is anticipated that the overall dewatering discharge volume required will increase from approximately 10 GL/annum to a maximum of 40 GL/annum over the life of operations. The increase in discharge will occur in two stages:

- **Stage 1 (Topvar outfall only):** This will involve increasing the discharge volume from the existing W12 (Topvar) outfall, with the total 40 GL/annum discharged directly to Brumby Creek for the majority of the WCOP.
- **Stage 2 (Canyon-Topvar outfalls):** This will involve the installation of second discharge outfall (Canyon) on Warri Warri Creek within the southern section of the Development Envelope as mining progress to the south. It is expected that 75% of excess water (approximately 30 GL/annum) will be discharged from Canyon to Warri Warri Creek, with the remaining volume discharged from W12.

During Stage 1, current modelling (Cardno 2021) suggests the discharge water will influence a maximum of 122 km downstream from the W12 discharge outfall, including a further 91 km of the Oakover River downstream of the current discharge extent (**Figure 3-19**). During Stage 2, the modelled footprint is predicted to extend approximately 116 km downstream of W12 and influence a further 85 km of the Oakover River downstream of the current extent (**Figure 3-19**). Additionally, during Stage 2, approximately five to 10 km of Warri Warri Creek will also to be influenced by the discharge prior to its confluence with Brumby Creek (**Figure 3-19**).

3.3.1.2 Quality

Groundwater quality within the Development Envelope has been monitored at various locations since 1993, with long-term data available for pH, salinity (TDS and EC), nitrate, Kjeldahl Nitrogen, total nitrogen (TN), cadmium, lead, manganese, zinc, calcium, sodium and magnesium. In addition, turbidity, total phosphorous (TP), and several metals have recently been sampled at a monitoring bore (WWMB17) within the Development Envelope. These data are used to provide a general indication of the water quality that can be expected within discharge and are summarised in **Table 3-16**. The ranges for each parameter recorded from local surface waters (upstream reference, downstream discharge and temporary pools) during the Study are also provided in **Table 3-16**, along with the ANZG (2018) DGVs (95% species protection), where available, for comparison.

Groundwater quality can be characterised as freshwater (EC <1,100 µS/cm, TDS 350 to 850 mg/L), neutral to alkaline (pH 7.2 to 8.5), and with turbidity, nutrient and metals concentrations within the ranges typically recorded from local surface waters, and/or below respective ANZG (2018) DGVs (**Table 3-16**). Exceptions were TN and nitrate, with respective maximum values in groundwater (4.9 and 8 mg/L), above local surface water ranges and ANZG (2018) DGVs. Naturally elevated TN in groundwater mostly occurring as nitrate, is common throughout the Pilbara region, and is primarily derived from nitrogen-fixing vegetation (Appleyard 2000).

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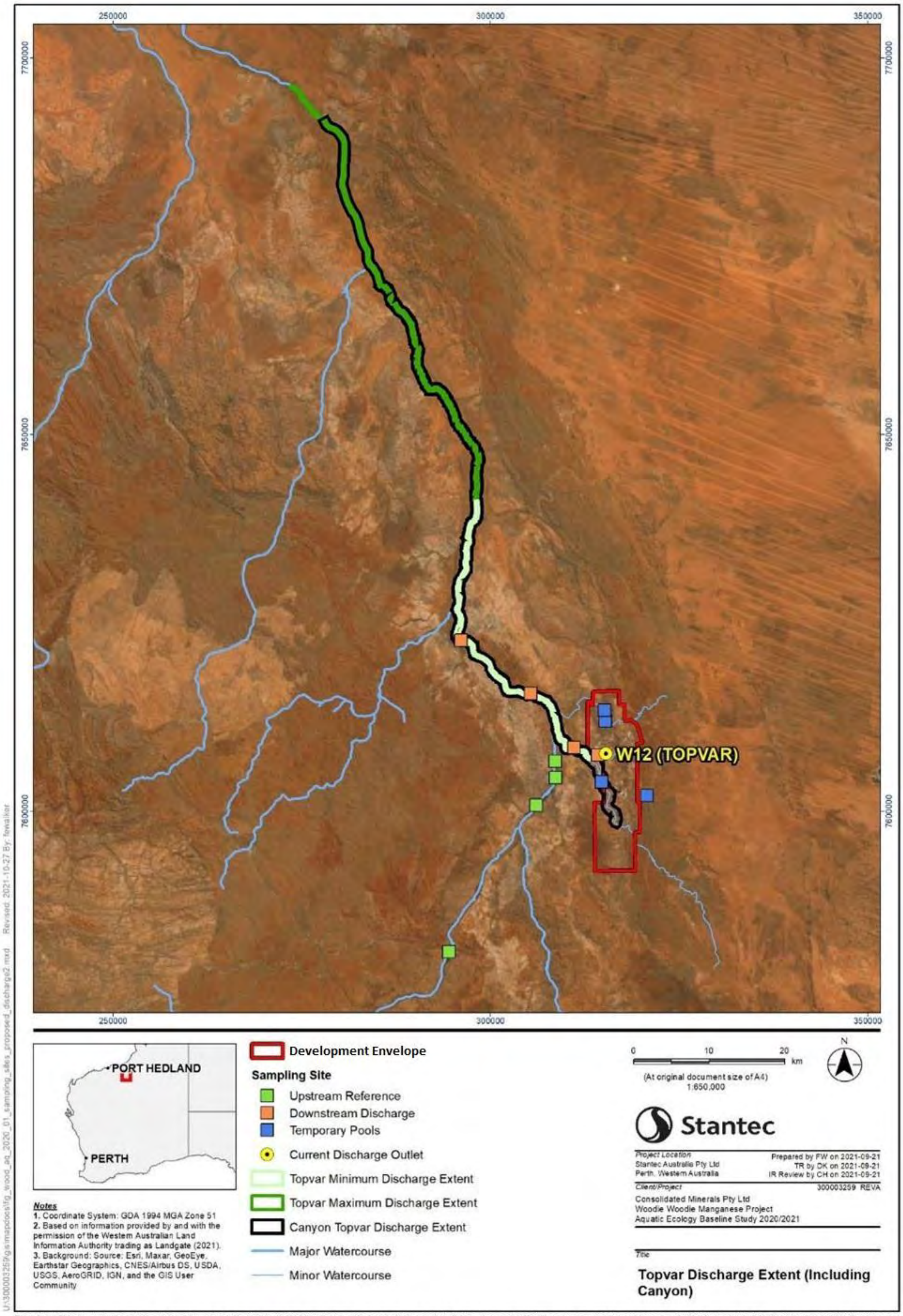

Figure 3-19: Figure showing maximum modelled discharge extent under discharge Stage 1 (Topvar Maximum Discharge Extent) and Stage 2 (Canyon Topvar Discharge Extent), with 2020/2021 sampling sites for context.

Table 3-16: Summary of long-term groundwater quality from the Development Envelope (ConsMin 2020b) and metals concentrations from monitoring bore WWMB17 (sampled 22/07/2021). The ranges for each parameter recorded from local surface waters during the Study are also provided, along with the ANZG (2018) DGVs (95% species protection), where available (units in mg/L unless stated).

Parameter	Minimum	Maximum	Range Recorded within Surface Waters (2020 – 2021)	ANZG DGV
pH (units)	7.2	8.5	7.29 – 9.25	6.5 – 8.0
Turbidity (NTU)		15*	<0.1 - 962	15
TDS	350	850	176 – 4,190	-
EC (µS/cm)		1,100*	313 – 4,214	250
Nitrate	0.21	8	<0.01 – 2.99	0.7 – 2.1
Kjeldahl Nitrogen	<0.01	1.3	<0.01 - 13	-
TN	0.53	4.9	<0.1 - 3.3	0.3
TP		0.01	<0.01 – 1.36	0.01
Aluminum		<0.01*	<0.005 – 0.02	0.055
Arsenic		<0.001*	<0.0002 – 0.0013	0.024
Boron		0.24*	0.06 - 1.04	0.94
Barium		0.017*	0.0001 – 1.25	-
Cadmium	<0.0001	<0.002	<0.00005	0.002
Cobalt		<0.001	<0.0001 - 0.0007	-
Chromium		<0.001	<0.0002 – 0.0006	0.00031
Copper		<0.001	<0.0005 - 0.0016	0.0014
Iron		0.59*	<0.002 – 0.032	0.7
Lead	<0.0001	<0.002	<0.0001	0.0034
Manganese	<0.001	1.9*	0.0005 - 0.86	1.9
Mercury		<0.00005*	<0.00004	0.0006
Molybdenum		<0.001*	0.0003 - 0.001	-
Nickel		<0.001*	<0.0005 - 0.0014	0.011
Selenium		<0.001*	<0.0002 – 0.0014	0.011
Uranium		<0.0005*	<0.0005 - 0.0019	-
Vanadium		<0.001*	0.0007 – 0.0064	-
Zinc	<0.005	0.03	<0.001 – 0.014	0.008
Calcium	18.3	54	14 - 66	-
Sodium	39	220	23 - 854	-
Magnesium	24.5	55	13 - 66	-

Note: *indicates 2021 record from WWMB17.

3.3.1.3 Potential Impacts and Predicted Outcomes

In addition to the reaches of Brumby Creek and Oakover River that are subject to existing discharge (considered to be of **moderate** and **moderate to high** ecological value, respectively), the following receiving environments occur within the predicted discharge extents:

Stage 1 (Topvar Outfall Only): Approximately 91 km of the Oakover River downstream of the existing discharge extent. Based on satellite imagery (Sentinel), this reach appears to host several isolated, semi-permanent riverine pools (**Figure 3-20**

Figure 3-20: Examples of semi-permanent pools on the Oakover River (satellite imagery insets; dated 17/11/21) within the modelled discharge extents.

-) similar to the Oakover River upstream reference pools, considered to be of **moderate to high** ecological value, based on the results of this Study.
- **Stage 2 (Canyon-Topvar Outfalls)**: Approximately 85 km of the Oakover River downstream of the existing discharge extent and a short section (8 to 10 km) of Warri Warri Creek downstream of the proposed Canyon outfall, prior to its confluence with Brumby Creek. During the Study, this reach contained one small, temporary pool (WWC1) during the wet season, considered to be of **low to moderate** ecological value.

The increase in discharge volume under both stages may potentially cause the following impacts to the receiving environments:

- Creation of perennial, albeit temporary (for the life of operations) flows, leading to a decrease in seasonal variation in hydrology, water quality and ecological processes;

- Increases in habitat availability and colonisation by aquatic biota, similar to the reaches of Brumby Creek and the Oakover River within the existing discharge extent; and
- Elevated TN and nitrate levels, which may lead to increased algal/cyanobacterial growth (blooms), and adversely affect aquatic biota via toxicity, or indirectly through reduced oxygen levels (ANZG 2018; Carmargo *et al.* 2005; Pinder *et al.* 2010).

Additionally, based on the findings of the desktop assessment and field surveys, the following conservation significant species have been recorded within the receiving environments that may potentially affected by discharge (**Figure 3-21**):

- *Eurysticta coolawanyah* (Pilbara pin damselfly), listed as vulnerable under the IUCN Red List of Threatened Species);
- *Actitis hypoleucos* (common sandpiper), listed as Migratory under the BC and EPBC Act;
- *Pandion cristatus* (osprey), listed as Migratory under the BC and EPBC Act*;*
- *Tringa glareola* (wood sandpiper), listed as Migratory under the BC and EPBC Act; and
- *Plegadis falcinellus* (glossy ibis), listed as Migratory under the BC and EPBC Act.

It is expected that during both stages, the discharge will pose a ***low*** risk to the aquatic biota (including conservation significant species) of the downstream receiving environments (**Table 3-17**). This is due to the following:

- Results from the Study demonstrated that the existing discharge is not adversely impacting aquatic biota, with water and sediment quality, and diversity and community composition of aquatic biota within the receiving environments (Brumby Creek and the Oakover River), generally comparable to reference sites upstream;
- The aquatic biota of the Pilbara region are naturally resilient to variability in flow regimes, water quality, and habitat availability (Pinder and Leung 2009; Pinder *et al.* 2010; Timms *et al.* 2009), with life strategies that allow them to persist during adverse conditions (e.g. as pools contract during the dry season), and disperse rapidly to when conditions are favourable (Pinder and Leung 2009; Pinder *et al.* 2010; Timms *et al.* 2009);
- The aquatic biota are likely to be inherently resilient to elevated nitrogen concentrations. At the regional scale, TN and nitrate concentrations above ANZG (2018) are known, particularly as pools recede and are subject to evapoconcentration (Biologic 2020; WRM 2009). Additionally, the ANZG (2018) DGVs generally considered conservative for the Pilbara environment (Dobbs and Davies 2009b);
- Elevated nitrogen will likely be localised within the immediate downstream receiving environments, with TN and nitrates being utilised or fixed by primary producers (algae and macrophytes), and/or are diluted within the broader Oakover River channel. Within the existing discharge, TN and nitrate are highest at the discharge outfall, and decrease with distance downstream;
- *Eurysticta coolawanyah* is widely distributed within the local area, including within the existing discharge (**Figure** 3-21), as well as more broadly across the Pilbara region (Biologic 2020; Pinder *et al.* 2010; WRM 2017). The record of this species within the existing discharge suggests this taxon may exploit any increased water permanency and habitat availability; and
- The migratory waterbirds *Actitis hypoleucos, Tringa glareola*, *Pandion cristatus* and *Plegadis falcinellus,* given their transient nature, are likely to frequent the Oakover River only temporarily within the predicted discharge extent, and may benefit from the increased regime, due to increased water and foraging habitat.

However, the risk determinations were ascertained based on the following assumptions, in relation to the proposed discharge:

- The immediate receiving environments (Warri Warri Creek/Brumby Creek) have the adequate storage and flow capacity for the increased discharge volume; and
- Any additional discharge outfall will be designed and positioned appropriately, to minimise erosion from the discharge within the river channel.

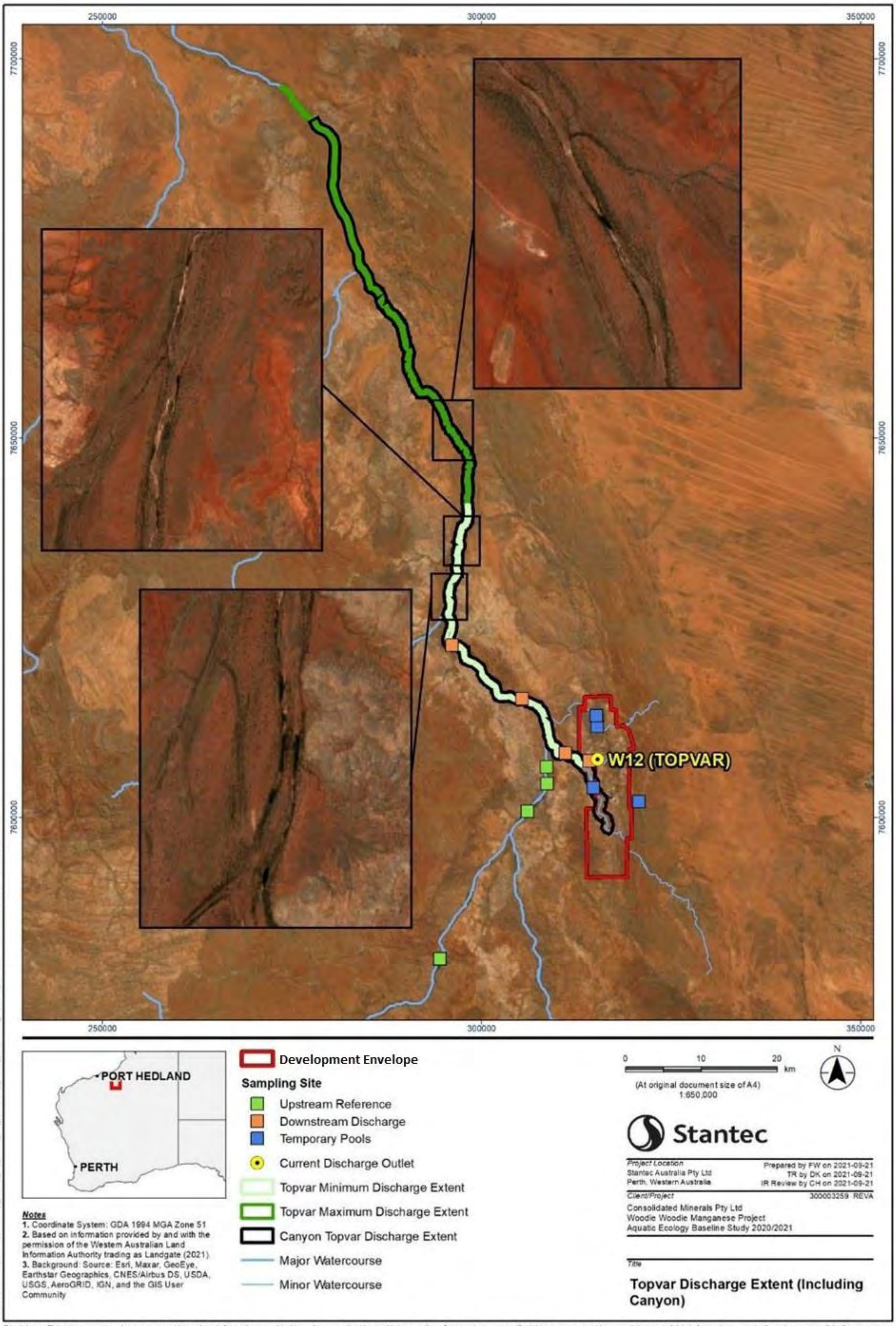

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Figure 3-20: Examples of semi-permanent pools on the Oakover River (satellite imagery insets; dated 17/11/21) within the modelled discharge extents.

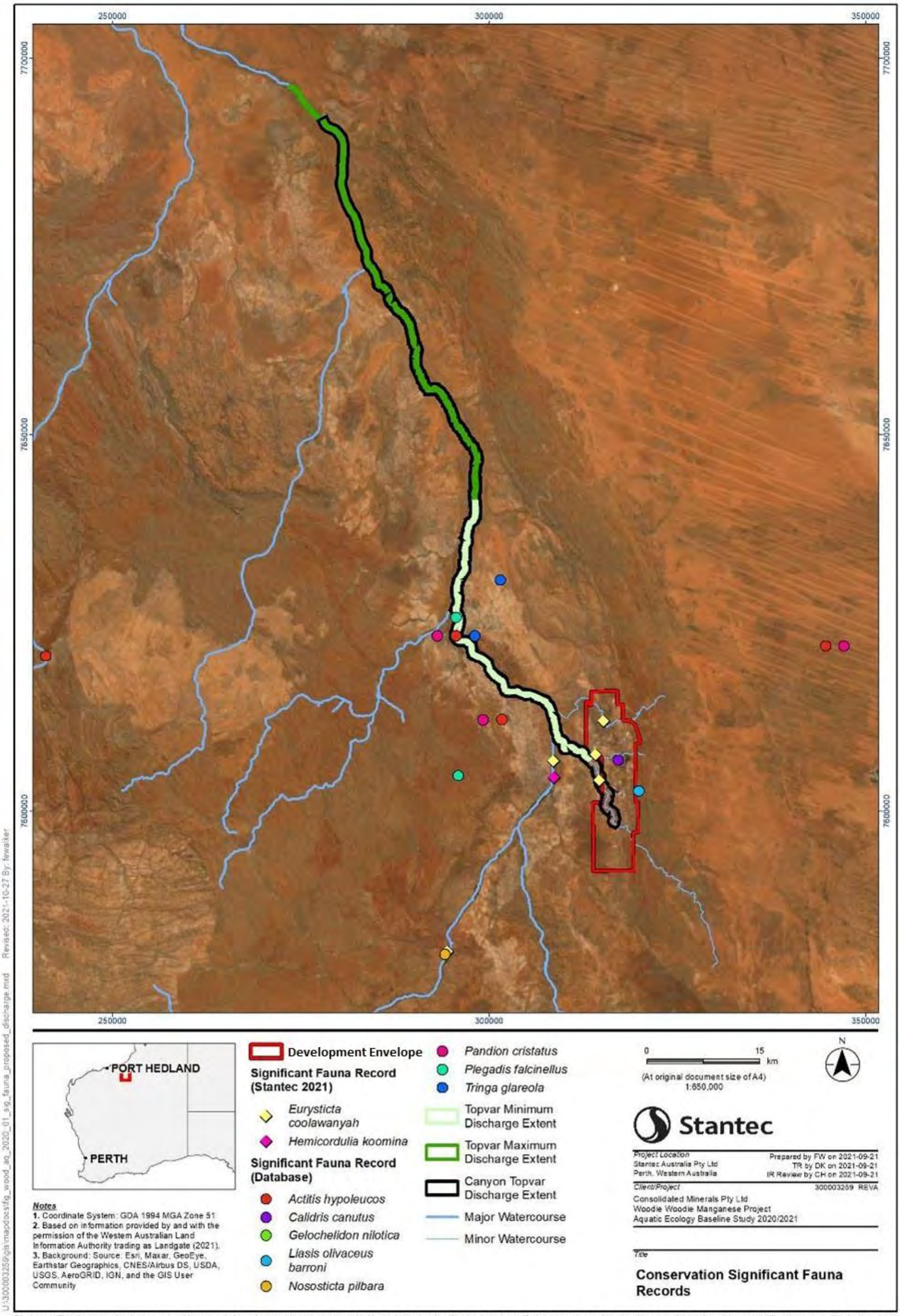

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Figure 3-21: Conservation significant taxa recorded within the modelled discharge extents.

3.3.2 Drawdown

3.3.2.1 Drawdown Extents

Depth to groundwater in the Development Envelope currently ranges from 10 to 200 m (**Figure 1-6**), with depth to groundwater greater in the northern section of the Development Envelope (typically 80 to 200 m), due to historic and ongoing dewatering of BWT pits (ConsMin 2020b; Rockwater 2021). In the southern section of the Development Envelope, where dewatering is less, depth to groundwater typically ranges from 10 to 100 m, with the shallowest depth to groundwater (<20 m) associated with the Warri Warri Creek drainage channel (**Figure 1-6**).

Groundwater modelling has been undertaken for the Development Envelope (Rockwater 2021), with the predicted extent of drawdown (from current depth to groundwater) to 2028 and 2030 shown in **Figure 3-22** and **Figure 3-23**, respectively. The modelling shows that in 2028, cones of depression will be steep (up to 70 m) within the northern and central sections of the Development Envelope, with limited drawdown (<1 m) expected to occur outside of the Development Envelope. Predicted drawdown patterns are similar in 2030, with some drawdown (up to 10 m) within the southern portion of the Development Envelope as further pits are accessed, although there is limited drawdown (<1 m) outside of the Development Envelope. The regional drawdown is largely constrained to within the Development Envelope due to the presence of numerous low permeability faults and geological units (ConsMin 2020b; Rockwater 2021).

3.3.2.2 Potential Impacts and Predicted Outcomes

Under the 2028 and 2030 modelling scenarios, the following receiving environments occur within the predicted extent drawdown:

- Temporary pools within ephemeral creeklines (Mungarathuna Creek, Warri Warri Creek) traversing the Development Envelope, considered to be of **low to moderate ecological value** in the local area. There are no known permanent, groundwater dependent waterbodies within the Development Envelope (ConsMin 2020b).

The drawdown of groundwater may potentially cause the following impacts to these receiving environments:

- Reduction in the hydroperiod and/or loss of pools, due to groundwater drawdown.

Additionally, based on the findings of this Study the following conservation significant species have been recorded within the predicted zone of groundwater drawdown (**Figure 3-24**):

- *Liasis olivaceus barroni* (Pilbara olive python), listed as Vulnerable under the BC Act and EPBC Act;
- *Eurysticta coolawanyah* (Pilbara pin damselfly), listed as vulnerable under the IUCN Red List of Threatened Species); and
- *Calidris canutus* (red knot), listed as Endangered under the BC Act and EPBC Act.

It is expected that drawdown, based on groundwater modelling, will pose a ***negligible*** risk to the aquatic biota (including conservation significant species) of the receiving environments (**Table 3-17**). This is due to the following:

- Depth to groundwater in the drawdown zone typically ranges between 80 to 200 m, due to current and historic dewatering. Therefore, it is likely that there is no connection between temporary pools and the underlying aquifer, with drawdown anticipated to have no impact on the surface hydrology or aquatic biota; and
- Temporary pools within the Development Envelope are considered to be of **low to moderate** ecological value, supporting aquatic biota for a short period during the wet season, in comparison to the nearby permanent/semi-permanent pools of the Oakover River.

However, the risk determination was ascertained based on the following assumptions, in relation to the proposed drawdown:

- Drawdown will largely be constrained to within the east and west boundaries of the Development Envelope, due to the presence of low permeability faults and geological units, and will not impact the aquifers that support groundwater-dependent pools of the Oakover River.

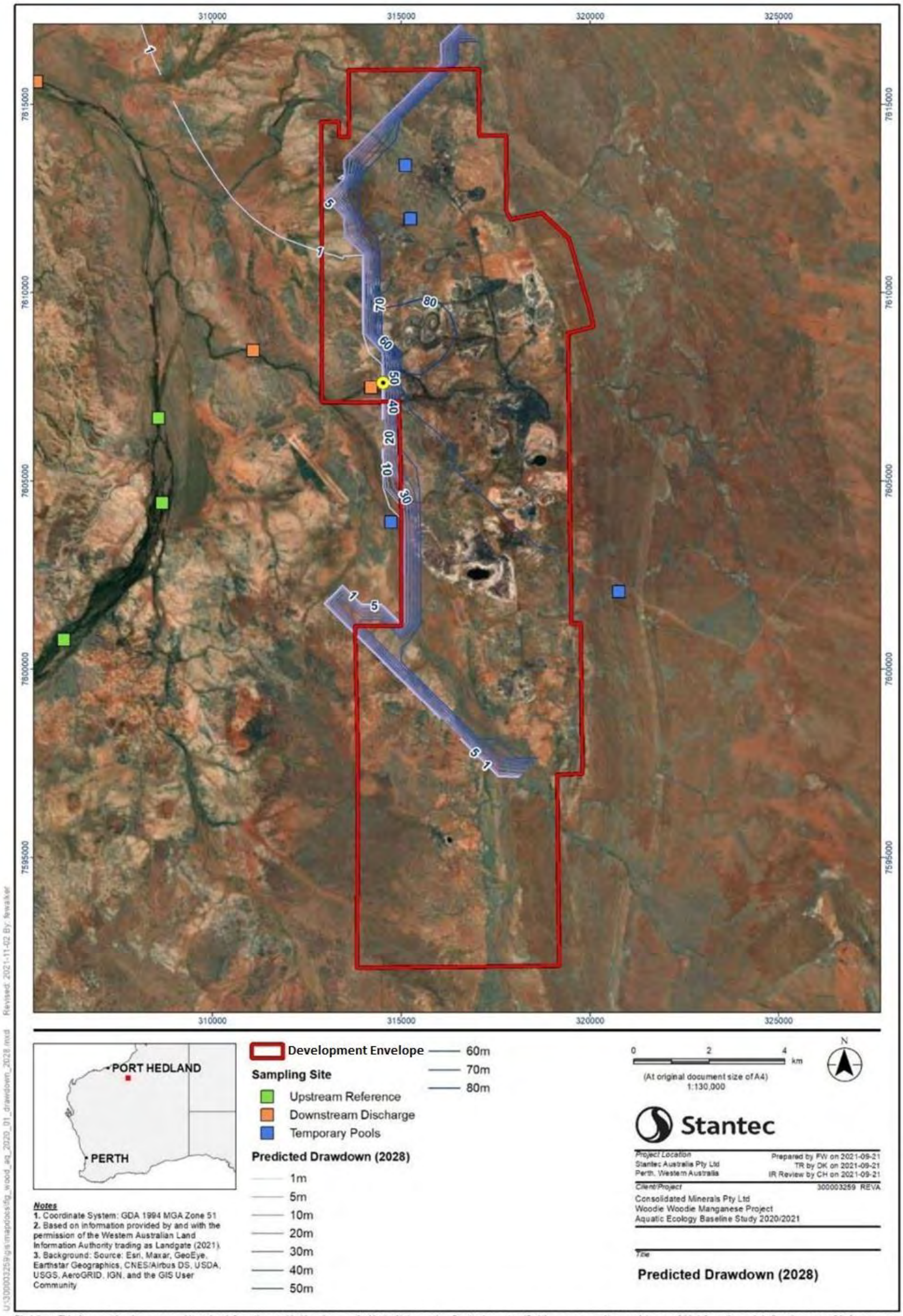

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Figure 3-22: Modelled predicted extent of groundwater drawdown to 2028 (Rockwater 2021).

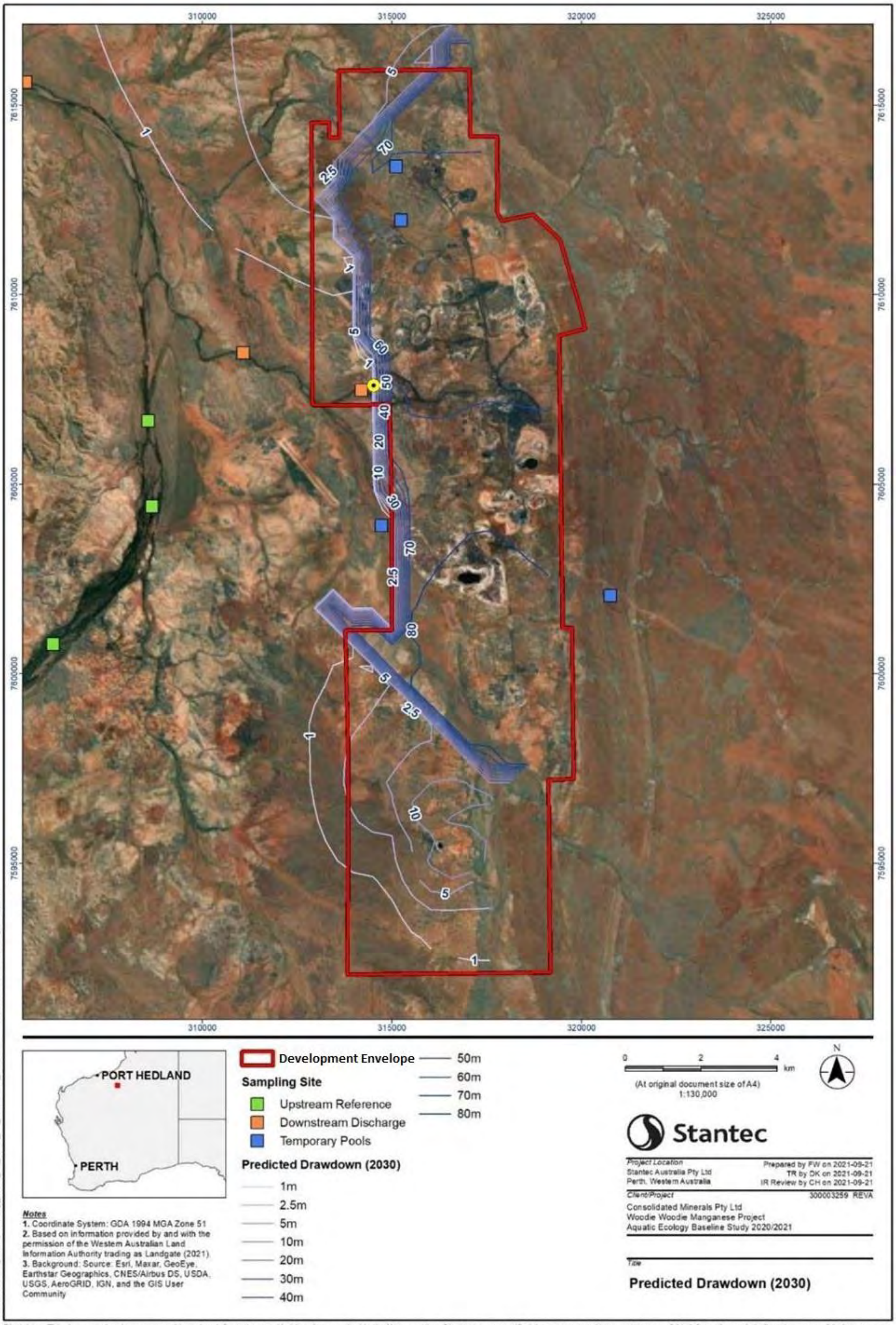

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Figure 3-23: Modelled predicted extent of groundwater drawdown to 2030 (Rockwater 2021).

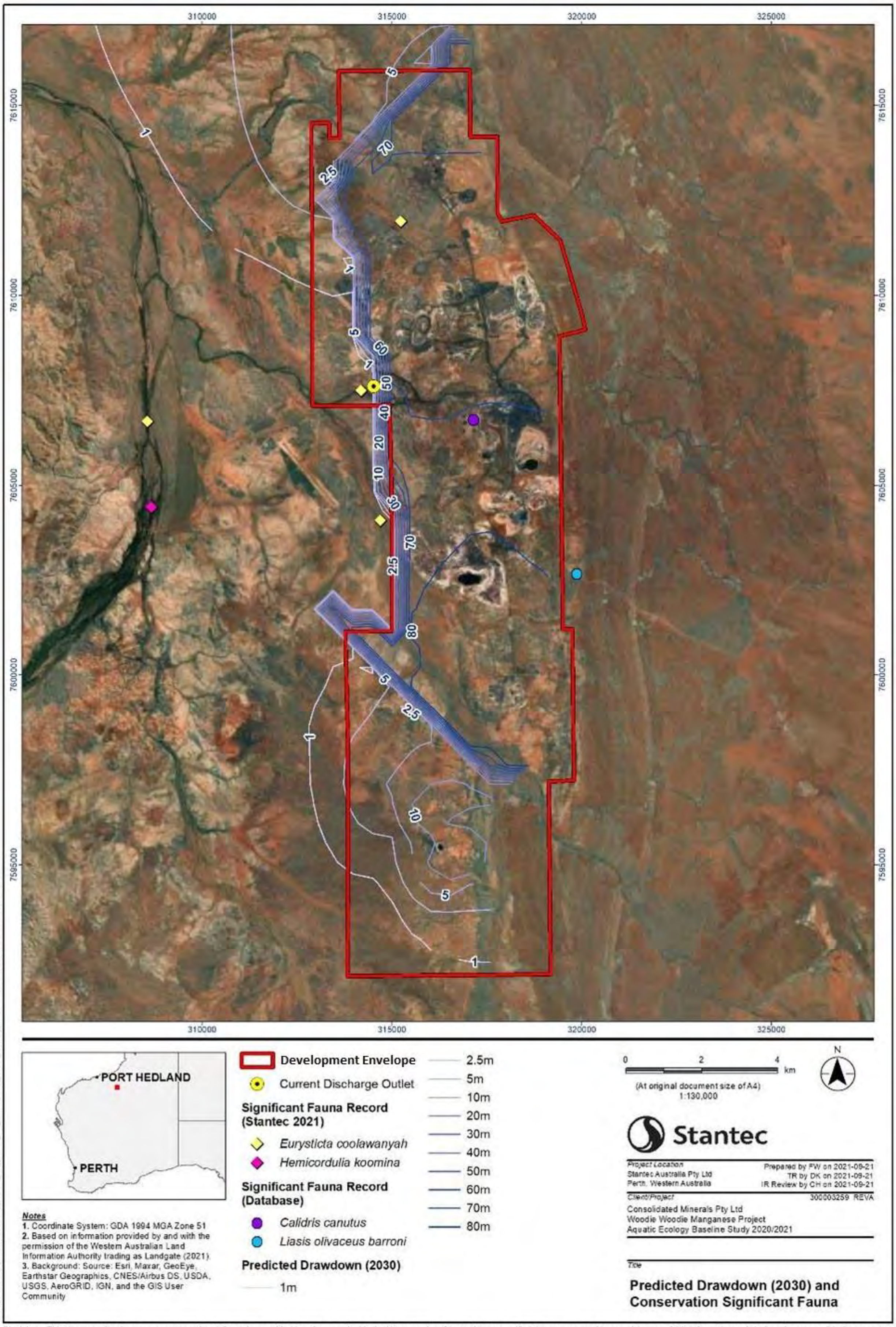

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Figure 3-24: Conservation significant taxa recorded within the predicted drawdown extent (2030).

Table 3-17: Summary of threatening processes and potential impacts to receiving environments associated with the WCOP.

Threatening Process	Receiving Environments	Conservation Significant Taxa Records Within Receiving Environments	Potential Impacts	Risk to Aquatic Biota, Justification and Key Assumptions
Discharge of excess groundwater to creeklines	• Ephemeral section of Warri Warri Creek prior to Brumby Creek confluence • Reach of Brumby Creek subject to current discharge • Oakover River within and downstream of current discharge extent	• *Eurysticta coolawanyah* (Pilbara pin damselfly) (IUCN Vulnerable) • *Actitis hypoleucos* (common sandpiper) (BC and EPBC Act Migratory) • *Pandion cristatus* (osprey) (BC and EPBC Act Migratory) • *Tringa glareola* (wood sandpiper) (BC and EPBC Act Migratory) • *Plegadis falcinellus* (glossy ibis) (BC and EPBC Act Migratory)	• Creation of perennial, albeit temporary (for the life of operations) flows, leading to a decrease in seasonal variation in hydrology, water quality and ecological processes • Increases in habitat availability and colonisation by aquatic biota • Increased algal/cyanobacterial growth (blooms), and/or direct toxicity to aquatic biota, due to elevated TN and nitrates	***Low*** • Aquatic ecosystems and biota likely naturally resilient to changes in hydrology, including increased, perennial flows during discharge operations, and declining flows upon cessation of discharge • Waterbodies subject to existing discharge (e.g. Brumby Creek, Oakover River downstream) host diverse and productive aquatic biota assemblages • Pilbara aquatic biota are likely inherently resilient to elevated TN and nitrate concentrations • Elevated TN and nitrate are likely to be localised within the immediate receiving environment of discharge • Appropriate outfall design will prevent physical impacts to creeklines • The immediate receiving environments have the adequate storage and flow capacity for the increased discharge volume
Groundwater drawdown from mine pit dewatering	• Temporary pools on ephemeral creeklines (Mungarathuna Creek, Warri Warri Creek) traversing the Development Envelope	• *Liasis olivaceus barroni* (Pilbara olive python) (BC and EPBC Act Vulnerable) • *Eurysticta coolawanyah* (Pilbara pin damselfly) (IUCN Vulnerable) • *Calidris canutus* (red knot) (BC and EPBC Act Endangered)	• Reduction or loss of pools within the predicted zone of groundwater drawdown	***Negligible*** • Groundwaters of the Development Envelope are already subject to historic drawdown • Ephemeral creeklines/temporary pools within the drawdown zone are not groundwater dependent and are unlikely to be affected by further declines in groundwater levels • Temporary pools within the Development Envelope are considered to be of low to moderate ecological value, in comparison to the nearby permanent/semi-permanent pools of the Oakover River • Drawdown will largely be constrained to within the east and west boundaries of the Development Envelope, due to the presence of low permeability faults and geological units,

Low: impact on a localised or temporary scale, with no irreversible damage to the aquatic ecosystem expected.
Negligible: No impact expected to aquatic ecosystem.

4 Conclusions

The rivers and creeklines sampled during the Study were found to support a diverse and abundant aquatic biota community. During dry conditions, the permanent or semi-permanent pools on the Oakover River (both upstream and downstream of discharge), as well as the perennial reach of Brumby Creek influenced by discharge, provide refuge for aquatic biota in an otherwise arid landscape. In the wet season, expansion of riverine pools following flooding, and associated increases in habitat availability and favorable water quality, leads to enhanced productivity of primary producers (diatoms), as well as aquatic invertebrates.

Sites influenced by existing discharge were found to support comparable macrophyte, algal, invertebrate and fish diversity, abundance and assemblage composition, to permanent reference sites upstream. This was associated with the perennial hydrological regime created by discharge, as well as water quality characterised by relatively low salinity, turbidity and metals levels. In contrast, opportunistic, transient invertebrate taxa, as well as hardy and adaptable fish species, were characteristic of temporary pools within and adjacent to the Development Envelope, although aquatic macrophytes and waterbirds were depauperate. This was attributable to the short residence time of surface water, and declining water quality as the hydroperiod progresses.

The majority of macrophyte, algal, invertebrate and vertebrate taxa recorded during the Study have broader distributions throughout the Pilbara, northern-Australia, or Australia. Exceptions included the dragonfly *Hemicordulia koomina,* and the damselfly *Eurysticta coolawanyah*, which are endemic to the Pilbara region, and are listed as Vulnerable on the IUCN Red List of Threatened Species. Additionally, database records found that the semi-permanent and permanent pools of the Oakover River downstream of discharge intermittently support significant migratory waterbird species, including *Actitis hypoleucos* (common sandpiper), *Pandion cristatus* (osprey), *Tringa glareola* (wood sandpiper) and *Plegadis falcinellus* (glossy ibis). Meanwhile, *Liasis olivaceus barroni* (Pilbara olive python) and the migratory waterbird *Calidris canutus* (red knot) have been reported at temporary pools within the Development Envelope.

Based on the findings of the Study, discharge from the WCOP will likely pose a ***low*** risk to aquatic biota (including conservation significant species), despite discharge waters potentially being elevated in TN and nitrates. This was primarily due to the limited impact of the current discharge on aquatic biota, as well as the likely natural resilience of aquatic biota of the region to variation in hydrology and water quality. Additionally, discharge may potentially benefit many taxa, by providing increased habitat and perennial flows for the life of operations.

The potential risk of drawdown to aquatic biota was classified as ***negligible***, as temporary pools within the zone of drawdown unlikely to be linked to the underlying aquifer due to current and historic drawdown, with further lowering of groundwater not likely to affect surface hydrology and aquatic biota.

However, the risk determinations were ascertained based on the following assumptions, in relation to the proposed discharge and drawdown:

- The immediate receiving environments (Warri Warri Creek/Brumby Creek) have the adequate storage and flow capacity for the increased discharge volume;
- Any additional discharge outfall will be designed and positioned appropriately, to minimise erosion from the discharge within the river channel; and
- Drawdown will largely be constrained to within the east and west boundaries of the Development Envelope, due to the presence of low permeability faults and geological units, and will not impact the aquifers that support groundwater-dependent pools of the Oakover River.

5 References

Alba-Tercedor, J. and Suter, P. J. (1990). A new species of Caenidae from Australia: *Tasmanocoenis arcuata* sp.m. (Insecta, Ephemeroptera). *Aquatic Insects* 12(2): 85-94.

Allen, G. R., Midgley, S. H. and Allen, M. H. (2002). Field Guide to the Freshwater Fishes of Australia. Western Australian Museum, Perth.

Allen, M. G., Morgan, D. L. and Gill, H. S. (2005). Distribution, zoogeography and biology of the Murchison River hardyhead (*Craterocephalus cuneiceps* Whitley, 1944), an atherinid endemic to the Indian Ocean (Pilbara) Drainage Division of Western Australia. *Ecology of Freshwater Fish* 14: 209-224.

ANZG (2018). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra ACT, Australia. . Available online at www.waterquality.gov.au/anz-guidelines.

Appleyard, S. J. (2000). Preliminary Assessment: Discharge of Nitrogen by Groundwater to the Marine Environment in the Pilbara Region. WRC, Perth, Western Australia.

Australian Government. (2018). Australian Government 2018, Charter: National Water Quality Management Strategy (NWQMS), Department of Agriculture and Water Resources.

Beesley, L. S. and Prince, J. (2010). Fish community structure in an intermittent river: the importance of environmental stability, landscape factors and within-pool habitat descriptors. *Marine and Freshwater Research* 61: 605-614.

Bell, D. T., Agar, P. K., Luyer, J. R. and Robertson, H. M. (2014). Winter bird assemblages of the Fortescue Marshes and surrounding vegetation, Pilbara Region, Western Australia. Amytornis. Available online at.

Bellinger, E. G. and Sigee, D. C. (2010). Freshwater Algae. Identification and Use as Bioindicators. Wiley-Blackwell, Oxford, UK.

Biologic. (2020). Greater Paraburdoo Iron Ore Hub: Aquatic Fauna Survey. Interim Report: Dry Season 2019., Perth, Western Australia.

Bird, M. S., Mlambo, M. C., Wasserman R.J., Dalu, T., Holland, A. J., Day, J. A., Villet, M. H., Bilton, D. T., Barber-James, H. M. and Brendonck, L. (2019). Deeper knowledge of shallow waters: reviewing the invertebrate fauna of southern African temporary wetlands. *Hydrobiologia* 827: 89-121.

Blinn, D. W. (1995). Diatom community structure along salinity gradients in Australian lakes: biogeographic comparisons with other continents. In: J. P. Kociolek and M. J. Sullivan (eds) A Century of Diatom Research in North America: A Tribute to the Distinguished Careers of Charles W. Reimer and Ruth Patrick. Koeltz Scientific Books, Illinois, USA

Boulton, A. J. and Brock, M. A. (1999). Australian Freshwater Ecology: processes and management. Cooperative Research Centre for Freshwater Ecology, Adelaide, South Australia.

Braimbridge, M. (2010). Yule River: ecological values and issues. Department of Water, 18, Western Australia.

Brock, M. A., Capon, S. J. and Porter, J. L. (2006). Disturbance of plant communities dependent on desert rivers. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, New York, pp 100-132

Bunn, S. E. (1995). Biological monitoring of water quality in Australia: Workshop summary and future directions. *Australian Journal of Ecology* 20: 220-227.

Bunn, S. E., Balcombe, S. R., Davies, P. M., Fellows, C. S. and McKenzie-Smith, F. J. (2006). Aquatic productivity and food webs of desert river ecosystems. In: R. Kingsford (ed) Ecology of Desert Rivers. Cambridge University Press, Cambridge, UK, pp 76-99

Cairns Jnr., J. and Pratt, J. R. (1993). A history of biological monitoring using benthic macroinvertebrates. In: D. M. Rosenberg and V. H. Resh (eds) Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman & Hall, New York

Campagna, V. S. (2007). Limnology and biota of Lake Yindarlgooda - an inland salt lake in Western Australia under stress. Doctoral Thesis. Curtin University of Technology.

Cardno. (2021). CW1154400-WA-REP-001 Rev A, Title: Woodie Woodie Mine Site Waterway Discharge Assessment.

Carmargo, J. A., Alonso, A. and Salamanca, A. (2005). Nitrate toxicity to aquatic animals: a review with new data for freshwater invertebrates. *Chemosphere* 58(9): 1255-1267.

Casanova, M. T. (2005). An overview of Chara L. in Australia (Characeae, Charophyta). *Australian Systematic Botany* 18: 25-39.

Chakrapani, G. J. (2002). Water and sediment geochemistry of major Kumaun Himalayan lakes, India. . *Environmental Geology* 43(1-2): 99-107.

Clarke, K. R. and Warwick, R. M. (2001). Change in marine communities: An approach to statistical analysis and interpretation, 2nd edition. PRIMER-E, Plymouth.

Connell, D. W. (2005). Basic Concepts of Environmental Chemistry. CRC Press, Taylor and Francis Group, Boca Raton, Florida.

ConsMin. (2020a). Monitoring of Point Source Emissions to Surface Water, October 2018 to September 2019. Western Australia.

ConsMin. (2020b). Woodie Continued Operations Project EPA Referral Supporting Document. Western Australia.

Cooper, V. C. (1996). Microalgae: Microscopic Marvels. Riverside Books, Hamilton, New Zealand.

Coops, H. (2002). Ecology of Charophytes. *Aquatic Botany* 72: 205-208.

Cornette, R., Gusev, O., Nakahara, Y., Shimura, S., Kikawada, T. and Okuda, T. (2015). Chironomid midges (Diptera, Chironomidae) show extremely small genome sizes. *Zoological Science* 32(3): 248-254.

DAWE (2020). Directory of Important Wetlands in Australia: De Grey River - WA065. Available online at http://www.environment.gov.au/cgi-bin/wetlands/report.pl?smode=DOIW;doiw_refcodelist=WA065.

DBCA. (2020). Priority Ecological Communites for Western Australia - Version 28.

Dean, J. C. (2001). New species of Hydropsychidae (Insecta: Trichoptera) from Northern Australia. *Memoirs of the Museum of Victoria* 58(2): 231-246.
Dills, G. and Rogers Jnr, D. T. (1974). Macroinvertebrate community structure as an indicator of acid mine pollution. *Environmental Pollution* 6: 239-262.
Dobbs, R. and Davies, P. M. (2009a). Long Term Ecological Research on a Pilbara River System - Analysis of Long Term Robe River Aquatic Monitoring Dataset. Centre of Excellence in Natural Resource Management, University of Western Australia.
Dobbs, R. and Davies, P. M. (2009b). Long Term Ecological Research on a Pilbara River System. Analysis of Long Term Robe River Aquatic Monitoring Dataset. *Centre of Excellence in Natural Resource Management, the University of Western Australia* (CENRM Report 11/05).
Dunlop, J., McGregor, G. and Horrigan, N. (2005). Potential impacts of salinity and turbidity in riverine ecosystems: Characterisation fo impacts ad a discussion of regional target setting for riverine ecosystems in Queensland.
Entwisle, T. J., Sonneman, J. A. and Lewis, S. H. (1997). Freshwater algae in Australia - a guide to the conspicuous genera*.* Sainty and Associates, Potts Point.
EPA (2018). Environmental Factor Guideline: Inland Waters EPA, Western Australia. Available online at.
Foged, N. (1978). Diatoms in Eastern Australia. *Bibliotheca Phycologica* 41: 1-242.
Förstner, U. (1977). Mineralogy and geochemistry of sediments in arid lakes of Australia. *Geologische Rundschau* 66: 146-156.
Gooderham, J. and Tsyrlin, E. (2002). The Waterbug Book. A Guide to the Freshwater Macroinvertebrates of Temperate Australia*.* CSIRO Publishing, Victoria, Australia.
Gorham, E. (1961). Factors influencing supply of major ions to inland water, with special reference to the atmosphere. *Geological Society of America* 72: 795-840.
Gregory, S. J. (2008). The classification of inland salt lakes in Western Australia. Minerals and Energy Research Institute of Western Australia, Perth, Western Australia.
Hart, B. T. and McKelvie, I. D. (1986). Chemical limnology in Australia. In: P. W. De Dekker, W. D. (ed) Limnology in Australia, vol IV. Australian Society for Limnology, CSIRO, pp 3-32
Hazelton, P. and Murphy, B. (2007). Interpreting Soil Test Results. What do all the numbers mean. CSIRO Publishing, Collingwood, Victoria.
Hellawell, J. M. (1986). Biological Indicators of Freshwater Pollution and Environmental Management*.* Elsevier Applied Science Publishers, London.
Howe, P. and Pritchard, J. (2007). Project REM1 - A Framework for assessing the Environmental Water Requirements of Groundwater Dependent Ecosystsmes Report 3 Implementation. Resource & Environmental Management Pty Ltd, Kent Town, SA.
IUCN. (2021a). Anguilla bicolor. International Union for Conservation of Nature. Available online at http://www.iucnredlist.org/details/178824/0. Accessed on 03/08/2021.
IUCN. (2021b). Eurysticta coolawanyah. International Union for Conservation of Nature. Available online at http://www.iucnredlist.org/details/178824/0. Accessed on 03/08/2021.
IUCN. (2021c). Hemicordulia koomina. International Union for Conservation of Nature. Available online at http://www.iucnredlist.org/details/178824/0. Accessed on 03/09/2021.
John, J. (1998). Diatoms: Tools for bioassessment of river health, a model for south-western Australia. Land and Water Resources Research and Development Corp., Project UCW 3, Canberra.
John, J. (2000). A guide to diatoms as indicators of urban stream health. National River Health Program, Urban Sub Program, Report No. 7. LWRRDC Occasional Paper 14/99*.* Land and Water Resources and Development Corporation, Canberra.
Johnstone, R. E., Burbidge, A. H. and Darnell, J. C. (2013). Birds of the Pilbara region, including seas and offshore islands, Western Australia: distribution, status and historical changes. *Records of the Western Australian Museum* 78: 343-441.
Kendrick, P. and McKenzie, N. L. (2003). Pilbara 1 (PIL1 Chichester subregion). In: J. E. May and N. L. McKenzie (eds) A Biodiversity Audit of Western Australia's 53 Biogeographical Subregions in 2002 Department of Conservation and Land Management, Kensington, WA, pp 547-558
Krejci, M. E. and Lowe, R. L. (1986). Importance of sand grain mineralogy and topography in determining micro-spatial distribution of epipsammic diatoms. *Journal of the North American Benthological Society* 5(3): 211-220.
Loomes, R. and Braimbridge, M. (2010). Lower De Grey River: Ecological Values and Issues. Environmental Water Report Series, Report No. 12. Department of Water, Government of Western Australia, Perth.
Lyons, M. N. (2015). The riparian flora and plant communities of the Pilbara region of Western Australia. *Records of the Australian Museum* Supplement 78: 485-513.
Masini, R. J. (1988). Inland Waters of the Pilbara, Western Australia. Part 1. Technical Series No. 10. Environmental Protection Authority, Nedlands.
Masini, R. J. and Walker, B. A. (1989). Inland Waters of the Pilbara, Western Australia. Part 2. Technical Series No. 24. Environmental Protection Authority, Nedlands.
McComb, A. J. and Qui, S. (1998). The effects of drying and reflooding on nutrient release from wetland sediments. In: W. D. Williams (ed) Wetlands in a Dry Land: Understanding for Management. Environment Australia Biodiversity Group, Canberra, pp 147-159.
McKenzie, N., Jacquier, D., Isbell, R. and Brown, K. (2004). Australian Soils and Landscapes: an illustrated compendium*.* CSIRO Publishing, Collingwood, Victoria.
McKenzie, N. L., May, J. E. and McKenna, S. (2003). Bioregional Summary of the 2002 Biodiversity Audit for Western Australia: A Contribution to the Development of Western Australia's Biodiversity Conservation Strategy. Department of Conservation and Land Management.

McKenzie, N. L., van Leeuwen, S. and Pinder, A. M. (2009). Introduction to the Pilbara Biodiversity Survey, 2002-2007. *Records of the Western Australian Museum Supplement 78*: 3-89.
Montoya, H. (2009). Algal and cyanobacterial saline biofilms of the Grande Coastal Lagoon, Lima, Peru. *Natural Resouces and Environmental Issues* 15(23).
Morgan, D. L., Allen, M. G., Beatty, S. J., Ebner, B. C. and Keleher, J. J. (2014a). A field guide to the freshwater fishes of Western Australia's Pilbara province. Freshwater Fish Group & Fish Health Unit; Murdoch Univeristy, Perth.
Morgan, D. L., Ebner, B. and Beatty, S. (2009). Fishes in groundwater dependant pools of the Fortescue and Yule Rivers; Pilbara, Western Australia. Freshwater Fish Group, Centre for Fish & Fisheries Research, Murdoch University, Perth.
Morgan, D. L. and Gill, H. S. (2004). Fish fauna in inland waters of the Pilbara (Indian Ocean) Drainage Division of Western Australia - evidence for three subprovinces. *Zootaxa* 636: 1-43.
Morgan, D. L., Unmack, P. J., Beatty, S. J., Ebner, B. C., Allen, M. G., Keleher, J. J., Donaldson, J. A. and Murphy, J. (2014b). An overview of the 'freshwater fishes' of Western Australia. *Journal of the Royal Society of Western Australia* 97: 263–278.
Pinder, A. and Leung, A. (2009). Conservation Status and Habitat Associations of Aquatic Invertebrates in Pilbara Coastal River Pools. Science Division, Department of Environment and Conservation.
Pinder, A. M., Halse, S. A., Shiel, R. J. and McRae, J. M. (2010). An arid zone awash with diversity: patterns in the distribution of aquatic invertebrates in the Pilbara region of Western Australia. *Records of the Western Australian Museum* Supplement 78: 205-246.
Porter, J., Kingsford, T. and Brock, M. A. (2007). Seed banks in arid wetlands with contrasting flooding, salinity and turbidity regimes. *Plant Ecology* 188: 215-234.
Pulford, I. and Flowers, H. (2006). Environmental Chemistry at a Glance. Blackwell Publishing, Oxford, United Kingdom.
Reddy, K. R. and DeLaune, R. D. (2008). Biogeochemistry of Wetlands. Science and Applications. CRC Press, Boca Raton, Florida.
Rockwater. (2021). Woodie Woodie - Detailed Hydrogeological Assessment and Modelling Report.
Rogers, K. and Ralph, T. J. (2011). Floodplain Wetland Biota in the Murray-Darling Basin: Water and Habitat Requirements. CSIRO Publishing, Collingwood, Victoria.
Sainty, G. R. and Jacobs, S. W. L. (2003). Waterplants in Australia. A Field Guide. Sainty and Associates, Potts Point, New South Wales.
Schütte, K. H. and Elsworth, J. F. (1954). The significance of large pH fluctuations observed in some South African vleis. *Journal of Ecology* 42(1): 148-150.
Simpson, S. L., Batley, G. E., Chariton, A. A., Stauber, J. L., King, C. K., Chapman, J. C., Hyne, R. V., Gale, S. A., Roach, A. C. and Maher, W. A. (2005). Handbook for Sediment Quality Assessment CSIRO, Bangor, NSW.
Storr, G. M. (1984). Birds of the Pilbara Region, Western Australia. Western Australian Museum,
Szlauer-Lukaszewska, A. and Pesic, V. (2020). Habitat factors differentiating the occurance of Ostracoda (Crustacea) in the floodplain of a small lowland River Krapiel (N-W Poland). *Knowledge and Management of Aquatic Ecosystems* 421(23): 11.
Taukulis, F. E. (2007). Diatom communities in lakes and streams of varying salinity from south-west Western Australia: distribution and predictability. Doctoral Thesis. Curtin University of Technology.
Thackway, R. and Cresswall, I. D. (1995). An interim biogeographic regionalisation for Australia: a framework for setting priorities in the national reserves system cooperative. Department of the Environment and Water Resources. Available online at http://www.environment.gov.au/land/nrs/science/ibra. Accessed on 20/10/2017.
Theischinger, G. and Hawking, J. (2006). The Complete Field Guide to Dragonflies of Australia. CSIRO Publishing, Australia.
Timms, B. V., Pinder, A. M. and Campagna, V. S. (2009). The biogeography and conservation status of the Australian endemic brine shrimp *Parartemia* (Crustacea, Anostraca, Parartemiidae). *Conservation Science Western Australia* 7(2): 413-427.
Tina Liu, H. T. and Resh, V. H. (1997). Abundance and microdistribution of freshwater gastropods in three streams of Moorea, French Polynesia. *International Journal of Limnology* 33(4): 235-244.
van Dam, R., Storey, A., Humphrey, C., Pidgeon, B., Luxon, R. and Hanley, J. (2005). Bulgarene Borefield (De Grey River) Port Hedland Water Supply Aquatic Ecosystems Study. National Centre for Tropical Wetland Research, Darwin.
Van Vreeswyk, A. M. E., Payne, A. L., Leighton, K. A. and Hennig, P. (2004). An inventory and condition survey of the Pilbara Region, Western Australia. Department of Agriculture, Perth, Western Australia.
Webb, J. M. and Suter, P. J. (2011). Identification of Larvae of Australia Baetidae. *Museum Victoria Science Reports* 15: 1-24.
Western Wildlife. (2020). Woodie Woodie Mine: Targeted Pilbara Olive Python Survey 2020. Mahogany Creek, Western Australia.
Williams, W. D. (1983). Life in Inland Waters. Blackwell Scientific Publications, Melbourne.
Williams, W. D. (1998a). Biodiversity in salt lakes. In: A. J. McComb and J. A. Davies (eds) Wetlands for the Future. Gleneagles Publishing, Adelaide, pp 161-166
Williams, W. D. (1998b). Salinity as a determinant of the structure of biological communities in salt lakes. *Hydrobiologia* 381: 191-201.
WRM. (2009). API Aquila: Baseline Aquatic Ecosystem Surveys. Western Australia.
WRM. (2015). Iron Valley Project: Baseline Aquatic Fauna Survey: Weeli Wolli Creek, Wet Season 2015. Western Australia.
WRM. (2017). Mesa B and C Project: Baseline Aquatic Ecosystem Survey, Wet Season Sampling 2016. Western Australia.

Appendices

We design with community in mind

Appendix A DBCA Threatened Fauna Database Records

Taxa	Common Name	BC Listing	EPBC Listing	Latitude	Longitude
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.4986	120.5013
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.4986	121.5013
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.4153	121.0847
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.582	121.0847
Actitis hypoleucos	Common Sandpiper	MI	MI	-22.082	121.918
Actitis hypoleucos	Common Sandpiper	MI	MI	-22.082	121.918
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.4986	121.5013
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.4817	121.028
Actitis hypoleucos	Common Sandpiper	MI	MI	-21.482	121.0274
Plegadis falcinellus	Glossy ibis	MI	MI	-21.4825	121.0278
Plegadis falcinellus	Glossy ibis	MI	MI	-21.4811	121.0289
Plegadis falcinellus	Glossy ibis	MI	MI	-21.4153	121.0847
Plegadis falcinellus	Glossy ibis	MI	MI	-21.6492	121.0283
Plegadis falcinellus	Glossy ibis	MI	MI	-21.4811	121.0289
Falco hypoleucos	Grey falcon	VU		-22.4153	120.7513
Falco hypoleucos	Grey falcon	VU		-21.2239	120.4974
Falco hypoleucos	grey falcon	VU		-21.1319598	120.518
Gelochelidon nilotica	Gull-billed tern	MI	MI	-21.8184	121.866
Pezoporus occidentalis	Night parrot	CR	EN	-21.2486	120.418
Pandion cristatus	Osprey, eastern osprey	MI	MI	-21.4811	121.0289
Pandion cristatus	Osprey, eastern osprey	MI	MI	-21.4986	121.5013
Pandion cristatus	Osprey, eastern osprey	MI	MI	-21.4153	121.0847
Pandion cristatus	Osprey, eastern osprey	MI	MI	-21.4153	121.0847
Pandion cristatus	Osprey, eastern osprey	MI	MI	-21.582	121.0847
Pandion cristatus	Osprey, eastern osprey	MI	MI	-21.4153	121.0847
Falco peregrinus	Peregrine falcon	OS		-21.8184	121.866
Falco peregrinus	Peregrine falcon	OS		-21.5738	121.223
Liasis olivaceus barroni	Pilbara olive python	VU	VU	-21.6406	120.2242
Liasis olivaceus barroni	Pilbara olive python	VU	VU	-22.0794	120.5932
Liasis olivaceus barroni	Pilbara olive python	VU	VU	-21.6683	121.8842
Liasis olivaceus barroni	Pilbara olive python	VU	VU	-21.6702422	121.25922
Nososticta pilbara	Pilbara threadtail	P2		-21.8631	121.0081
Calidris canutus	Red knot	EN	EN	-21.6333	121.2333
Calidris canutus	Red knot	EN	EN	-21.6333	121.2333
Tringa glareola	Wood sandpiper	MI	MI	-21.4825	121.0278
Tringa glareola	Wood sandpiper	MI	MI	-21.8753	120.4442
Tringa glareola	Wood sandpiper	MI	MI	-21.4153	121.0847
Tringa glareola	Wood sandpiper	MI	MI	-21.8739	120.4455

Appendix B WAM Invertebrate Database Search Results

ORDER	FAMILY	GENUS	SPECIES	LATITUDE	LONGITUDE
Insecta					
Blattodea	Blaberidae	*Calolampra*	*irrorata*	21°10`22"S	121°11`30"E
Blattodea	Blattidae	*Anamesia*		21°29`S	121°02`E
Blattodea	Blattidae	*Anamesia*		21°29`S	121°02`E
Blattodea	Blattidae	*Melanozosteria*	*barrominensis*	21°29`S	121°02`E
Coleoptera	Tenebrionidae	*Helea*	type 8	21°17`24"S	121°01`12"E
Coleoptera	Hydrophilidae	*Berosus*	*dallasae*	21°29`S	121°02`E
Coleoptera	Carabidae			21°20`20.7"S	120°46`06.0"E
Coleoptera	Carabidae			21°17`18"S	121°14`15"E
Coleoptera	Trogidae	*Omorgus*	*rotundulus*	21°17`24"S	121°01`12"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°20`15.7"S	120°46`10.9"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°20`15.7"S	120°46`10.9"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°17`18"S	121°14`15"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°17`18"S	121°14`15"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°17`18"S	121°14`15"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°17`18"S	121°14`15"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°17`18"S	121°14`15"E
Coleoptera	Carabidae	*Phorticosomus*	*gularis*	21°17`44"S	121°15`50"E
Coleoptera	Carabidae	*Phorticosomus*		21°17`18"S	121°14`15"E
Coleoptera	Carabidae	*Phorticosomus*		21°17`18"S	121°14`15"E
Hemiptera	Eurybrachyidae			21°29`S	121°02`E
Hemiptera	Reduviidae	*Oncocephalus*		21°20`S	121°08`E
Hemiptera	Coreidae	*Mictis*	*profana*	21°29`S	121°02`E
Hemiptera	Pentatomidae	*Poecilometis*	*nigriventris*	21°29`S	121°02`E
Hemiptera	Pentatomidae	*Poecilometis*	*nigriventris*	21°29`S	121°02`E
Hemiptera	Pentatomidae	*Poecilometis*	*nigriventris*	21°29`S	121°02`E
Hemiptera	Pentatomidae	*Poecilometis*	*nigriventris*	21°29`S	121°02`E
Hemiptera	Pentatomidae	*Poecilometis*	*nigriventris*	21°29`S	121°02`E
Hemiptera	Pentatomidae	*Cephaloplatus*	*explanatus*	21°29`S	121°02`E
Hymenoptera				21°28`59"S	121°01`59"E
Lepidoptera	Lycaenidae	*Nacabuda*	*biocellata*	21°50`45"S	120°58`40"E
Lepidoptera	Lycaenidae	*Nacabuda*	*biocellata*	21°50`45"S	120°58`40"E
Lepidoptera	Lycaenidae	*Nacabuda*	*biocellata*	21°50`45"S	120°58`40"E
Lepidoptera	Lycaenidae	*Nacabuda*	*biocellata*	21°50`45"S	120°58`40"E
Lepidoptera	Lycaenidae	*Nacabuda*	*biocellata*	21°50`45"S	120°58`40"E
Neuroptera	Myrmeleontidae	*Heoclisis*	*fundata*	21°29`S	121°02`E
Odonata	Coenagrionidae	*Pseudagrion*	*microcephalum*	21°29`S	121°02`E
Odonata	Libellulidae	*Diplacodes*	*bipunctata*	21°29`S	121°02`E
Odonata	Libellulidae	*Diplacodes*	*bipunctata*	21°29`S	121°02`E
Orthoptera	Tettigoniidae	*Caedicia*		21°29`S	121°02`E
Orthoptera	Tettigoniidae	*Caedicia*		21°29`S	121°02`E
Orthoptera	Gryllotalpidae	*Gryllotalpa*	sp. *monanka* group	21°29`S	121°02`E
Orthoptera	Gryllotalpidae	*Gryllotalpa*	*sp. monanka group*	21°29`S	121°02`E
Orthoptera	Gryllotalpidae	*Gryllotalpa*	*sp. monanka group*	21°29`S	121°02`E
Mollusca					
Bivalvia	Corbiculidae	*Corbicula*	sp.	21°40`54.984"S	121°07`31.428"E
Gastropoda	Camaenidae	*Gen. nov.*	cf. `Z` n.sp.	21°41`52.67"S	121°03`33.8"E
Gastropoda	Camaenidae	*Gen. nov.*	n.sp.	21°12`06.085"S	120°40`28.389"E
Gastropoda	Camaenidae	*Rhagada*		21.86308°S	121.01305°E

ORDER	FAMILY	GENUS	SPECIES	LATITUDE	LONGITUDE
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21.86308°S	121.01305°E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21.86308°S	121.01305°E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21.86308°S	121.01305°E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21.86308°S	121.01305°E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°39`53.893"S	121°07`02.644"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°42`28.512"S	121°03`06.85"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°12`06.085"S	120°40`28.389"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°28`15.417"S	121°02`47.404"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°19`44.505"S	121°08`20.4"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°40`53.577"S	121°07`37.196"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°28`11.785"S	121°02`58.555"E
Gastropoda	Camaenidae	*Rhagada*	cf. *richardsonii*	21°28`09.986"S	121°02`54.957"E
Gastropoda	Camaenidae	*Rhagada*	*radleyi*	21°28`S	121°01`E
Gastropoda	Camaenidae	*Rhagada*	*richardsonii*	21°29`02"S	121°02`26"E
Gastropoda	Camaenidae	*Rhagada*	*richardsonii*	21°44`31"S	121°04`50"E
Gastropoda	Camaenidae	*Rhagada*	*richardsonii*	21°35`00"S	121°03`13"E
Gastropoda	Camaenidae	*Rhagada*	*richardsonii*	21°52`S	121°00`E
Gastropoda	Camaenidae	*Rhagada*	sp.	21°52`25"S	121°00`20"E
Gastropoda	Camaenidae	*Rhagada*	sp.	21°52`25"S	121°00`20"E
Gastropoda	Camaenidae	*Rhagada*	sp.	21°52`25"S	121°00`20"E
Gastropoda	Camaenidae	*Rhagada*	sp.	21°52`25"S	121°00`20"E
Gastropoda	Camaenidae	*Rhagada*	sp.	21°18.945`S	121°03.298`E
Gastropoda	Camaenidae	*Rhagada*	`cf. *radleyi*` n.sp.	21°28`15.891"S	121°02`45.234"E
Gastropoda	Camaenidae	*Unidentified*	sp.	21°12`06.085"S	120°40`28.389"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°19`41.593"S	121°08`20.043"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°19`44.505"S	121°08`20.4"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°40`53.577"S	121°07`37.196"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°28`15.417"S	121°02`47.404"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°28`15.891"S	121°02`45.234"E
Gastropoda	Helicodiscidae	*Stenopylis*	*coarctata*	21°28`09.986"S	121°02`54.957"E
Gastropoda	Lymnaeidae			21°23`48.587"S	121°11`41.642"E
Gastropoda	Planorbidae	*cf. Gyraulus*	sp.	21°40`54.984"S	121°07`31.428"E
Gastropoda	Planorbidae	*Gyraulus*	sp.	21°23`48.587"S	121°11`41.642"E
Gastropoda	Pupillidae	*Gastrocopta*	*larapinta*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Pupillidae	*Gastrocopta*	*larapinta*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Pupillidae	*Gastrocopta*	*mussoni*	21°19`44.505"S	121°08`20.4"E
Gastropoda	Pupillidae	*Gastrocopta*	*mussoni*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Pupillidae	*Gastrocopta*	*mussoni*	21°40`53.577"S	121°07`37.196"E
Gastropoda	Pupillidae	*Pupoides*	*beltianus*	21°40`53.577"S	121°07`37.196"E
Gastropoda	Pupillidae	*Pupoides*	*beltianus*	21°28`09.986"S	121°02`54.957"E
Gastropoda	Pupillidae	*Pupoides*	cf. *beltianus*	21°46`37.9"S	121°14`49.1"E
Gastropoda	Pupillidae	*Pupoides*	cf. *beltianus*	21°19`41.593"S	121°08`20.043"E
Gastropoda	Pupillidae	*Pupoides*	cf. *beltianus*	21°23`58.701"S	121°11`41.999"E
Gastropoda	Pupillidae	*Pupoides*	cf. *beltianus*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Pupillidae	*Pupoides*	cf. *beltianus*	21°40`54.984"S	121°07`31.428"E

ORDER	FAMILY	GENUS	SPECIES	LATITUDE	LONGITUDE
Gastropoda	Pupillidae	*Pupoides*	cf. *beltianus*	21°19`44.505"S	121°08`20.4"E
Gastropoda	Pupillidae	*Pupoides*	cf. *eremicolus*	21°39`53.893"S	121°07`02.644"E
Gastropoda	Pupillidae	*Pupoides*	cf. *pacificus*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Pupillidae	*Pupoides*	*eremicola*	21°46`37.2"S	121°14`44.9"E
Gastropoda	Pupillidae	*Pupoides*	*eremicola*	21°46`37.9"S	121°14`49.1"E
Gastropoda	Pupillidae	*Pupoides*	*eremicolus*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Pupillidae	*Pupoides*	*eremicolus*	21°19`44.505"S	121°08`20.4"E
Gastropoda	Pupillidae	*Pupoides*	*eremicolus*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Pupillidae	*Pupoides*	*eremicolus*	21°19`41.593"S	121°08`20.043"E
Gastropoda	Pupillidae	*Pupoides*	*eremicolus*	21°28`09.986"S	121°02`54.957"E
Gastropoda	Pupillidae	*Pupoides*	*pacificus*	21°39`53.893"S	121°07`02.644"E
Gastropoda	Pupillidae	*Pupoides*	*pacificus*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Pupillidae	*Pupoides*	*pacificus*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Subulinidae	*Eremopeas*	*interioris*	21°40`50.301"S	121°07`33.955"E
Gastropoda	Subulinidae	*Eremopeas*	*interioris*	21°40`54.984"S	121°07`31.428"E
Gastropoda	Subulinidae	*Eremopeas*	*interioris*	21°40`53.577"S	121°07`37.196"E
Gastropoda	Succineidae	*Succinea*	sp.	21°40`54.984"S	121°07`31.428"E
Crustacea					
Isopoda				21°13`25"S	120°41`37"E
Isopoda	Microcerberidae			21°18.803`S	121°01.817`E
Isopoda	SUPERFAMILY: Oniscoidea			21°29`00"S	121°02`00"E
Podocopida	Candonidae	*Humphreyscandona*	*capillus*	21°17`51"S	121°08`45"E
Podocopida	Candonidae	*Humphreyscandona*	*capillus*	21°17`51"S	121°08`45"E
Podocopida	Candonidae	*Humphreyscandona*	*capillus*	21°17`51"S	121°08`45"E
Podocopida	Candonidae	*Leicacandona*	*quasihalsei*	21°52`07"S	121°00`26"E

CREATING COMMUNITIES

Communities are fundamental. Whether around the corner or across the globe, they provide a foundation, a sense of belonging. That's why at Stantec, we always **design with community in mind**.

We care about the communities we serve—because they're our communities too. We're designers, engineers, scientists, and project managers, innovating together at the intersection of community, creativity, and client relationships. Balancing these priorities results in projects that advance the quality of life in communities across the globe.

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