Iron Valley Project

Baseline Aquatic Fauna Survey:
Weeli Wolli Creek
Wet Season 2015

November 2015



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EXECUTIVE SUMMARY

BC Iron Limited (BCI) is currently undertaking baseline environmental studies for the proposed below water table (BWT) development of the Iron Valley Project ("the Project") in the East Pilbara region of Western Australia. Groundwater dewatering will be required to mine BWT, which could potentially require the discharge of excess water into the regionally significant Weeli Wolli Creek (WWC). This would add to the cumulative impacts of existing dewatering discharge operations on WWC, with several mines (RTIO HD1, RTIO Yandicoogina and BHPBIO Yandi) located upstream. Existing dewatering discharge operations upstream currently provide permanent surface flows extending approximately 25 – 30 km along the main channel of WWC.

Surface water discharge has numerous implications for the ecology of WWC, in terms of changes in extent and duration of surface water flows, creekline hydrology in general, and cumulative impacts to the creekline at a local level. Therefore, BCI commissioned Wetland Research and Management (WRM) to undertake baseline aquatic fauna and water quality sampling of WWC adjacent to the Project, in order to document the ecological condition of the creekline, identify current ecological values (i.e. rare, listed fauna, new species) and develop a baseline dataset to which future monitoring can be compared.

The objectives of the baseline study were to:

I. Systematically sample aquatic fauna (macroinvertebrates, microinvertebrates, hyporheic fauna, fish & other vertebrate fauna, if present) and water quality (*in-situ*, ions, dissolved metals, nutrients, TSS & turbidity) at sites within and adjacent to WWC during the wet season 2015;
II. Report water quality data against default ANZECC/ARMCANZ (2000) water quality guidelines for the protection of aquatic ecosystems (95% & 99% species protection), and assess spatial variability in results;
III. Identify invertebrate specimens to species level, where possible;
IV. Analyse fauna data to assess spatial variability, with consideration to species occurrence at 'reference' (off-channel) and potentially exposed (main channel) sites;
V. Assess the conservation status of recorded aquatic fauna, with focus on species occurring in potentially exposed sites.

The key findings of the baseline survey were:

I. Rainfall in the weeks prior to sampling likely resulted in increased surface flows adjacent to, and downstream of the Project, with newly inundated pools observed at the time of sampling (evidenced by a lack of in-stream habitat; A.Harman, pers. comm). Short residence time of surface waters (either flowing or pools) at downstream sites along WWC likely provided insufficient time for a number of aquatic invertebrates to establish populations prior to sampling.

II. *In situ* spot measurements indicated surface waters were generally circum-neutral to slightly alkaline, relatively fresh (however, one site, WWOCR3, was considered brackish), with dissolved oxygen concentrations ranging from low to supersaturated.

III. Nitrogen oxides exceeded ANZECC/ARMCANZ (2000) eutrophication trigger values (TVs) at all main channel sites, and toxicity TVs at WWC8. Total nitrogen and total phosphorous also exceeded eutrophication TVs at WWOCR3 and several main channel sites. Elevated nutrients were likely due to a number of factors; unrestricted livestock access to WWC from pastoral stations nearby, first flushing catchment runoff, and unknown water quality entering WWC from dewatering discharge activities upstream.

IV. Microinvertebrate fauna was diverse and abundant at off-channel pools WWOCR1 and WWOCR2. In comparison, microinvertebrates were depauperate at main channel sites, particularly those receiving high surface flows. Multivariate analysis indicated that species assemblages were significantly different between off-channel and main channel sites.

V. Microinvertebrate taxa of scientific value (regionally restricted taxa, uncommon taxa or potential new species) included *Australoeucyclops karaytugi, Mesocyclops holynskae, Simocephalus* spp., cf. *Anthalona* sp. and *Boeckella fluvialis*.

VI. Hyporheic sampling revealed the presence of three short range endemic (SRE) amphipod species of conservation significance: Paramelitidae sp. B, Paramelitidae sp. D, and *Chydaekata* sp.

VII. There was evidence of a longitudinal gradient in macroinvertebrate taxa richness along the main channel of WWC upstream and adjacent to the Project. Taxa richness was greatest upstream at WWC1, declining with increasing distance downstream to WWC6. Regression analysis indicated a significant linear relationship between in-stream habitat diversity and macroinvertebrate richness within the main channel, with richness decreasing with lower habitat diversity.

VIII. Macroinvertebrate diversity was relatively low at off-channel sites, compared to main channel sites. This was somewhat unexpected, given the documented habitat-species richness patterns observed along the main channel, and considering habitat diversity at off-channel sites was more diverse (macrophytes, algae etc) than main channel sites. Low diversity may in part reflect hydrology and water quality at off-channel sites (i.e. low dissolved oxygen, lack of surface flows, elevated ions & metals, etc.), with flowing water in the main channel providing additional habitats (e.g. riffle zones) for lotic (flow-adapted) species.

IX. Multivariate analysis indicated macroinvertebrate assemblages at off-channel and main channel sites were significantly different from one another, with a number of flow-adapted taxa (e.g. mayflies and caddisflies) either absent, or recorded in reduced abundance at off-channel sites. This reflected the standing nature of pools, and lack of surface flow at off-channel sites.

X. No conservation listed (IUCN Red List or DPaW priority) macroinvertebrate species were recorded in the study area. However, one SRE amphipod (Paramelitidae sp. B), and four Pilbara endemic Coleoptera (aquatic beetle) species were recorded, including *Limbodessus occidentalis* and the recently described *Haliplus fortescueensis.*

XI. Three native fish species were recorded in the study area; the western rainbowfish *Melanotaenia australis,* the spangled perch *Leiopotherapon unicolor*, and the Hyrtl's tandan (eel-tailed catfish) *Neosilurus hyrtlii.* Diversity and abundance of fish species at sites reflected in-stream habitat diversity, permanence of flow, and effects of predation.

XII. Although a number of stygobitic, SRE hyporheic and Pilbara endemic microinvertebrate and macroinvertebrate taxa were recorded in the current study, the majority of these taxa have known local and/or regional distributions outside the Project area.

1 INTRODUCTION

1.1 Background

BC Iron Limited (BCI) is currently undertaking baseline environmental studies for the proposed below water table (BWT) development of the Iron Valley Project (hereafter referred to as “the Project”) in the East Pilbara region of Western Australia. The Project is located in the Weeli Wolli Creek (WWC) catchment, within the vicinity of a number of existing iron ore mines, including the Fortescue Metals Group (FMG) Nyidinghu operation (15 km to the north), Rio Tinto Iron Ore’s (RTIO) Yandicoogina (10 km to the west) and Hope Downs 1 operations (30 km to the south west), and the BHP Billiton Iron Ore (BHPBIO) Yandi operation (25 km to the west).

Groundwater dewatering will be required to mine BWT, which could potentially require the discharge of excess water into WWC if dewatering volumes are surplus to operational requirements. Further, it is likely the Project will require a provision for emergency discharge into WWC in the event of high rainfall periods. Surface water discharge has numerous implications for the ecology of WWC, in terms of changes in surface water flows, creekline hydrology, and cumulative impacts to the creekline at a local level (WRM 2015).

In March 2015, WRM were commissioned by BCI to undertake baseline aquatic fauna and water quality sampling of WWC adjacent to the Project, in order to document the ecological condition of the creekline, identify current ecological values (i.e. rare, listed fauna, new species), and develop a baseline dataset to which future monitroing can be compared.

This report provides sampling methodology and all aquatic fauna and water quality baseline data from the March 2015 survey.

1.2 Legislative framework

A number of State and Commonwealth acts and policies are relevant to the proposed development in terms of environmental protection and legislation.

At a State level, aquatic fauna are protected under the *Wildlife Conservation Act 1950* (WC Act) and their environment is protected under the *Environmental Protection Act 1986* (EP Act). This includes freshwater turtles, frogs, fish and invertebrates (including hyporheic and stygal invertebrates). Hyporheic invertebrates (collectively referred to as “hyporheos”) inhabit subsurface interstitial spaces in coarse creek bed sediments. Stygal invertebrates are obligate groundwater-dwelling species known to be present in a variety of rock types, and are often also present in the hyporheos.

The WC Act provides for species and ecological communities to be protected and listed as either ‘threatened’, because they are under identifiable threat of extinction, or ‘priority’, because they are rare, or otherwise in need of protection. This encompasses species with small distributions (occupying an area of less than 10,000 km^2) defined as short range endemics, or SREs (Harvey 2002, EPA 2009). The majority of stygal invertebrates are also SREs. The Environmental Protection Authority of Western Australia (EPA) expects that environmental impact assessments will consider the conservation of SRE species (EPA 2004).

The Department of Parks and Wildlife (DPaW) uses the *International Union for Conservation of Nature* (IUCN) Red List criteria for assigning species and communities to threat categories under the WC Act. Not all Western Australian species listed by the IUCN are also listed by DPaW.

At a Federal level, the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides for native fauna and their habitats to be specially protected and listed as nationally or internationally important.

Relatively few aquatic species in Western Australia are listed as threatened or endangered under the WC or EPBC acts. Aquatic invertebrates in particular have historically been under-studied. Lack of knowledge of their distributions often precludes aquatic invertebrates for listing as threatened or endangered. The *State Environmental Protection Authority* (EPA) has stated that listing under legislation should therefore not be the only conservation consideration in environmental impact assessment (EPA 2004).

Other relevant state legislation for the protection of water and native fauna species include the *Rights in Water and Irrigation Act 1914* (RIWI Act) and the *Fish Resources Management Act 1994*. The Department of Water (DoW) administers the RIWI Act, which provides for the sustainable use and development of the State's water resources, the protection of natural ecosystems and the control of activities that may be detrimental to ecosystem condition. Part 4 of the RIWI Act 1914 provides:

> *(1) The objects of this Part [Control of Water Resources] are —*
>
> > *(a) to provide for the management of water resources, and in particular —*
> >
> > *(i) for their sustainable use and development to meet the needs of current and future users; and*
> >
> > *(ii) for the protection of their ecosystems and the environment in which water resources are situated.*

Under this Act, licences are required for groundwater abstraction and permits required for any interference with the bed and banks of proclaimed watercourses; all watercourses in the Pilbara are proclaimed under the RIWI Act. All native fish and their habitats are protected under the *Fish Resources Management Act 1994*.

The current baseline dataset, together with the prior desktop assessment (WRM 2015) constitute a Level 1 survey for environmental impact assessment, as described under the EPA Environmental Assessment Guideline (EAG) No. 12 (EPA 2013), and in accordance with EAG No. 8 (EPA 2015) with the focus on hydrological processes and ecosystem maintenance.

1.3 Study objectives

The objectives of the baseline water quality and aquatic fauna study were to:

I. Systematically sample aquatic fauna (macroinvertebrates, microinvertebrates, hyporheic fauna, fish & other vertebrate fauna, if present) and water quality (*in-situ*, ions, dissolved metals, nutrients, TSS & turbidity) at sites within and adjacent to WWC during the wet season 2015;
II. Report water quality data against default[1] ANZECC/ARMCANZ (2000) water quality guidelines for the protection of aquatic ecosystems (95% and 99% species protection), and assess spatial variability in results.
III. Identify invertebrate specimens to species level, where possible;

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[1] Default TVs are to be applied to systems for which there are no baseline data or where baseline data are insufficient to adequately describe the natural or existing seasonal or annual fluctuations in water quality. Local conditions are naturally variable between river systems and because of this, ANZECC/ARMCANZ (2000) recommend that TVs should be 'tailored' to local conditions through the development of 'local guideline levels'. It is recommended historic (baseline) data are used to derive local (i.e. site-specific) TVs in accordance with ANZECC/ARMCANZ (2000) protocols.

IV. Analyse fauna data to assess spatial variability, with consideration to species occurrence at 'reference' (off-channel) and potentially exposed (main channel) sites;

V. Assess the conservation status of recorded aquatic fauna, with focus on species occurring in potentially exposed sites.

2 STUDY AREA

2.1 Description

The Project is situated in the East Pilbara region of Western Australia, within Mining Lease M47/1439 and a small area of Exploration Licence E47/1385. The co-ordinates of M47/1439 are as follows:

NW Corner	22° 42' 05"S 119° 19' 02"E
NE Corner	22° 43' 02"S 119° 20' 30"E
SE Corner	22° 46' 33"S 119° 17' 56"E
SW Corner	22° 45' 35"S 119° 16' 28"E

The Project is located within the Marillana (pastoral) Station, with land-use in the area comprising predominately of pastoral activities and more recently, mining. The regional topography of the Eastern Pilbara is dominated by the Chichester Ranges in the north and the Hamersley Plateau to the south, with these features being divided by the Fortescue Valley. The main drainage system in the area is the Fortescue River, which flows north and then northwest into the Fortescue Marsh.

A section of the regionally significant WWC flows adjacent to the Project. Approximately 70 km in length, and with a catchment area of 4100 km^2, WWC is fed in its mid-reaches by Weeli Wolli Spring, located approximately 20 km upstream (south) of the Project. Owing to the historical permanency of Weeli Wolli Spring, WWC is of high ecological, cultural and social significance. Prior to dewatering discharge from RTIO's Hope Downs 1 (HD1) mine, Weeli Wolli Spring provided perennial surface flows of around 2 km along WWC. However, due to a number of mines (RTIO Hope Downs 1, BHPBIO Yandi, and RTIO Yandicoogina) located on Marillana Station commencing dewatering discharge operations within the last decade, approximately 25 - 30 km of Weeli Wolli Creek is now influenced by surface flows (A.W. Storey, pers. comm.). Cumulative impacts from dewatering discharge on WWC are likely to intensify with time, as construction is currently underway at RTIO's Billiards Project (south of the WWC and Marillana Creek confluence), and planned for mid-2016 is FMG's Nyidinghu Project (directly downstream of the Project tenement). Both projects have substantial ore deposits BWT. BHPBIO also have intentions to develop additional BWT deposits on WWC upstream of RTIO's HD1 mine. Therefore, it is likely that cumulative dewatering discharge will result in permanent/semi-permanent surface and subsurface flows adjacent to the Project in the near future.

Flowing to the north, WWC drains into the Fortescue River via the Fortescue Marsh. The two systems are only connected during flooding associated with intense cyclonic events (Kendrick 2001). The Fortescue Marsh, an episodically inundated samphire marsh, approximately 100 km long and 10 km wide (Kendrick 2001, DEC 2009), is located 25 - 30 km downstream, and to the north-east, of the Project. The Marsh is described as an extensive, irregularly inundated inland floodplain system, and is considered to be a highly unique wetland landform in Western Australia (Environment Australia 2001). It is listed on the national Directory of Important Wetlands of Australia (WA066), and is a Priority 1 Priority Ecological Community (PEC) under the DPaW list of Priority Ecological Communities (DPaW 2014). It is also acknowledged that if nominated, the Marsh meets the criteria for listing as a Wetland of International Importance under the Ramsar Convention (Jaensch & Watkins 1999). The Fortescue Marsh and surrounding pastoral leases are earmarked for reservation by DPaW when leases are up for renewal in 2015 (FMG 2011). Current and potential threats to the Marsh include changes to hydrology, overgrazing by cattle, and pollution of surface inflow water from mine sites (Environment Australia 2001).

2.2 Climate and hydrology

2.2.1 General

The climate of the Pilbara is semi-arid, with relatively dry winters and hot summers. Most rainfall occurs during the summer months (November to March) and is mainly associated with cyclonic events or thunderstorms, when flooding frequently occurs along creeks and rivers (BOM 2015). Due to the nature of cyclonic events and thunderstorms, total annual rainfall in the region is highly unpredictable and individual storms can contribute several hundred millimetres of rain at one time. However, average annual pan evaporation in the Pilbara is ten times greater than rainfall (BOM 2015).

Two Department of Water (DoW) gauging stations are located in the vicinity of the Project, including one on WWC, downstream of the confluence with Marillana Creek (Waterloo Bore GS), and one on Marillana Creek, upstream of all mining operations (Flat Rocks GS; DoW 2015). The Waterloo Bore GS lies approximately 3.5 km downstream of the current wetting front (extent of surface flow from cumulative dewatering discharge operations located upstream). Flows at this station, however, will likely become more influenced by discharge operations in the future.

Long-term average rainfall at Flat Rocks and Waterloo Bore was 382.9 mm and 395.7 mm, respectively. Total annual rainfall varies greatly between years. Between 2006 and 2010, rainfall at both gauging stations was regularly below the long-term average. Recently (i.e. since 2010), rainfall has been above the long-term average at Waterloo Bore. Rainfall at Flat Rocks was above the long-term average in 2012 and 2013. Rainfall during the wet of 2011 was influenced by the La Niña event, which contributed to numerous and significant floods throughout northern Australia. In January 2011, Tropical Cyclone Bianca brought heavy rain across the Pilbara (BOM 2015).

Like rainfall, streamflow is also highly seasonal and variable. Flows occur as a direct response to rainfall, with peak flows tending to occur within 24 hours of a major rainfall event and continuing for several days. The Flat Rocks gauging station is located upstream of all mining operations and as such is not influenced by additional inputs from discharge or reductions in flow due to dewatering. The highest flow on record was 144,472 ML in 1975, when total annual rainfall was 717 mm, well above the long-term average (392.60 mm). At Waterloo Bore, seven zero-flow years were recorded between 1986 and 2012 (1986, 1989, 1991, 1996, 2005, 2007 & 2010). The greatest flow recorded was 215,473 ML in 2000. At this time, rainfall was 753.1 mm; almost twice the long-term average. The long-term average flow at these stations ranged from 10,514.92 ML at Flat Rocks to 33,542.63 ML at Waterloo Bore.

2.2.2 Rainfall prior to March 2015 sampling

The Project area experienced a major rainfall event just prior to March 2015 sampling by WRM. The Bureau of Meteorology’s Marillana Gauging Station, located approximately 14 km north-east of the Project, recorded 51 mm of rainfall in the six days (21st – 26th March 2015) prior to sampling (44 mm of which was recorded between the 24th and 25th of March; Figure 1). Total rainfall recorded in March 2015 (134.7 mm) was also well above the Marillana Gauging Station long-term March average (49.7 mm; Figure 2).

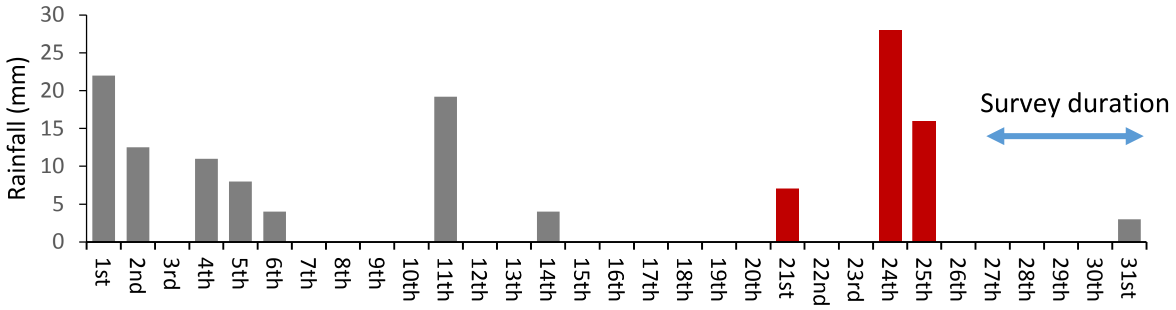

Figure 1. Daily rainfall (mm) recorded at Marillana Gauging Station during March 2015. Columns highlighted in red represent rainfall recorded in the seven days prior to sampling. Survey duration is shown by blue arrow.

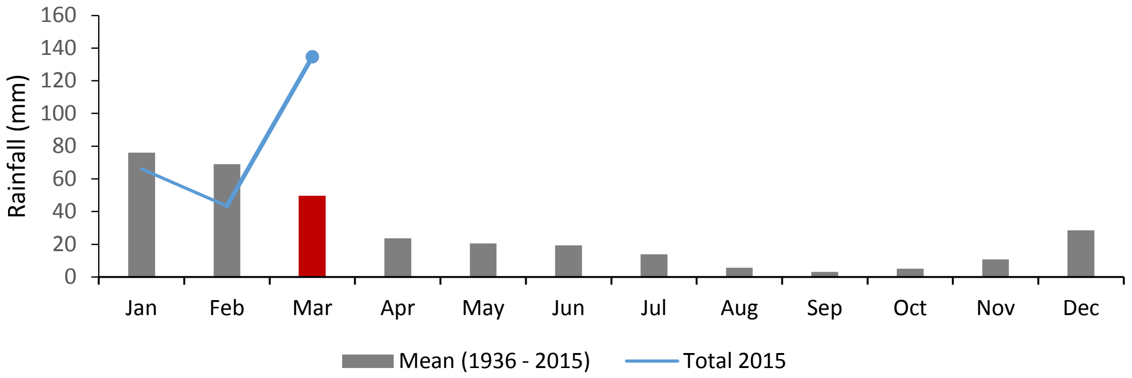

Figure 2. Long-term average rainfall and total 2015 monthly rainfall recorded at Marillana Gauging Station. Column highlighted in red indicates month of sampling.

Therefore, gauging station data indicate rainfall during the weeks leading up to the field trip appears substantially greater than the long term average. Consequently, streamflow at WWC adjacent to the Project was high at the time of sampling, with channel width, depth and flow greater than normally observed at this time of year (A. Harman, pers. comm.). The reach of WWC downstream of the Project is ephemeral in nature, and was likely completely dry prior to the rainfall event, however, the reach held large pools on the first afternoon when visited. Of note was the rate at which surface water (pools and connected flowing reaches) receded over the course of field sampling (n = 5 days), predominantly at downstream reaches.

3 SURVEY METHODS

3.1 Compliance

Baseline field surveys employed sampling design, methods and general approaches consistent with the following:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000);
- EPA Guidance No. 20, Sampling of Short Range Endemic Invertebrate Fauna for Environmental Impact Assessment in Western Australia (EPA 2009);
- EPA Position Statement No. 3, Terrestrial Biological Surveys as an Element of Biodiversity Protection (EPA 2002);

- EPA Guidance No. 56, Terrestrial Fauna Surveys for Environmental Impact Assessment in Western Australia (EPA 2004).

Aquatic fauna sampling by WRM is consistent with methodology used by government and universities for similar surveys, including the Pilbara Biological Survey (Pinder *et al.* 2010).

This study was conducted under Fisheries licence EXEM 2314 (Instruments of Exemption to the Fish Resources Management Act 1994 for Scientific Research Purposes) and DPaW licence SF010240 (Reg. 17; Licence to Take Fauna for Scientific Purposes). As a condition of these licences, taxa lists and reports are required to be submitted to the respective authorities.

3.2 Sites and sampling design

The survey took place during the late-wet season, between 27th and 31st March, 2015. In order to accurately document the water quality and composition and distribution of aquatic fauna of WWC adjacent to the Project, sampling targeted two main ecosystem types: pools/riffle zones within the main channel of WWC, and off-channel pools, which are most likely perched permanent/semi-permanent pools, which are elevated above, and to the west of, the main channel of WWC (and therefore not likely to be influenced by cumulative discharge operations upstream).

Statistical analyses rely on adequate replication to characterise variability within and between groups in a given parameter (e.g. species richness, assemblage composition). Adequate replication provides the necessary statistical power to test for differences between groups (e.g. reference vs. potential impact sites), and thereby detect statistically significant differences should they exist. Therefore, to obtain adequate statistical robustness, nine replicate sites (n = 9) were sampled along the main channel of WWC. Additionally, three replicate off-channel 'reference' sites (n = 3) were sampled. This design allows spatial comparisons of faunal assemblages between off-channel 'reference' sites (WWOCR1, WWOCR2 & WWOCR3), and potentially impacted main channel WWC sites (WWC1 to WWC9). GPS co-ordinates for sampling locations, and a map of the survey area are provided in Figure 3 and Table 1, respectively. Site photographs are provided in Appendix 1.

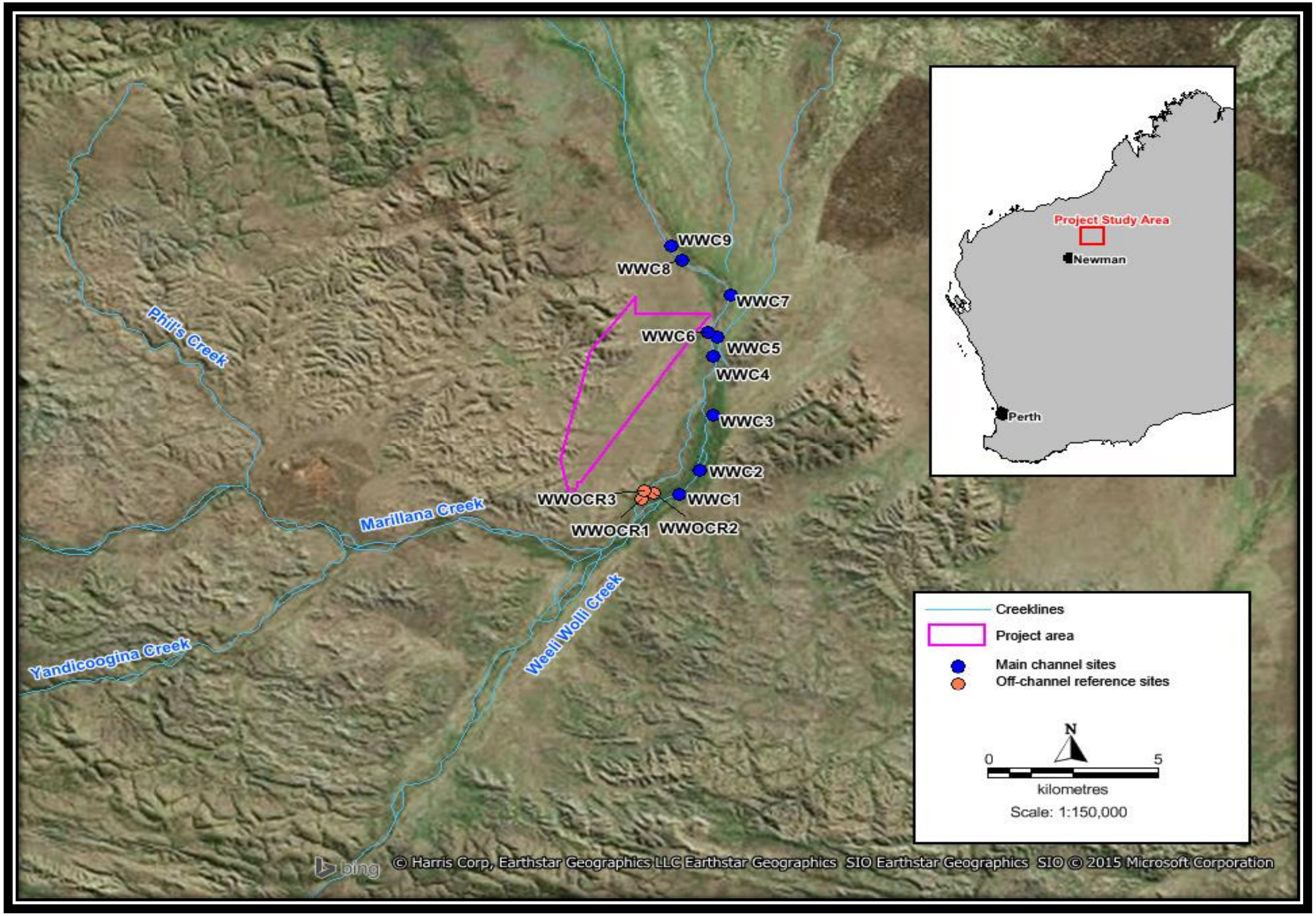

Figure 3. Overview of baseline survey sites along Weeli Wolli Creek, sampled in March 2015. Main channel sites are blue, and off-channel reference sites are orange. The Projec tenement is denoted by pink outline.

Table 1. Aquatic fauna and water quality sampling sites and reaches, showing date sampled in March 2015, and GPS coordinates for each site.

Reach	Site	Date	GPS Co-ordinates		
			Zone	Easting	Northing
Main channel	WWC1	29/03/2015	50 K	739105	7480029
	WWC2	29/03/2015	50 K	739726	7480812
	WWC3	29/03/2015	50 K	740156	7482620
	WWC4	30/03/2015	50 K	740199	7484539
	WWC5	29/03/2015	50 K	740309	7485174
	WWC6	30/03/2015	50 K	740032	7485325
	WWC7	31/03/2015	50 K	740719	7486557
	WWC8	27/03/2015	50 K	739338	7487739
	WWC9	30/03/2015	50 K	739011	7488199
Off-channel	WWOCR1	28/08/2015	50 K	738016	7479866
	WWOCR2	28/03/2015	50 K	738352	7480071
	WWOCR3	28/03/2015	50 K	738095	7480149

3.3 Field sampling

3.3.1 Water quality

At each site, *in situ* measurements of dissolved oxygen (DO; % and mg/L), water temperature (°C) and pH were taken using portable hand-held Wissenschaftlich-Technische-Werkstätten (WTW) field meters. Water depth was measured using a graduated pole. In addition, undisturbed water samples were collected for laboratory analyses of major ions, alkalinity, dissolved metals, nutrients, TSS and turbidity. Water samples for nutrients and dissolved metals were filtered in the field through 0.45 µm millipore nitrocellulose filters. To avoid contamination, all sample bottles and filtering equipment were acid-washed (0.1% nitric acid) prior to use. Water samples for dissolved metals were taken using nitrile gloves, with sample bottles wrapped in polyethylene bags after collection. All water samples were kept cool in an esky while in the field, and either refrigerated (ions & metals), or frozen (nutrients) as soon as possible for subsequent transport to the laboratory. All laboratory analyses were conducted by ChemCentre, Bentley, WA (a NATA accredited laboratory). All water quality variables measured are summarised in Table 2.

3.3.2 Habitat characteristics

Qualitative visual observations of habitat characteristics were made at each site, which assist in explaining patterns in faunal assemblages. Habitat assessments were based on the Australian Monitoring River Health AusRivAS protocol, a standardised rapid method for the collection of data on geomorphological, physical and riparian habitat (Parsons *et al.* 2002, Parsons *et al.* 2004). WRM have standard worksheets for this task so that recordings between sites remain as comparable as possible. Recorded habitat characteristics included proportional (%) cover by inorganic sediment, submerged macrophyte, floating macrophyte, emergent macrophyte, algae, large woody debris, detritus, roots and trailing vegetation. Details of substrate composition were also recorded, and included percent cover by bedrock, boulders, cobbles, pebbles, gravel, sand, silt and clay.

When undertaking habitat assessments there can be a small degree of variation in scoring habitat cover. AusRivAS acknowledges this, but generally considers that the variation in habitat scoring is smaller than the differences required to fundamentally affect fauna assemblages. WRM attempt to minimise erroneous variation in scoring between sites by the same person assessing habitat at all sites.

Table 2. Summary of water quality variables measured either *In situ* or from samples collected in the field.

Parameter	Units	Parameter	Units
In situ		***Dissolved metals***	
pH	pH units	Aluminium (Al)	mg/L
Electrical conductivity	µS/cm	Arsenic (As)	mg/L
Redox potential	mV	Boron (B)	mg/L
Dissolved oxygen	% saturation	Barium (Ba)	mg/L
Dissolved oxygen	mg/L	Cadmium (Cd)	mg/L
Water temp	°C	Cobalt (Co)	mg/L
		Chromium (Cr)	mg/L
		Copper (Cu)	mg/L
Ionic composition		Iron (Fe)	mg/L
Sodium (Na)	mg/L	Manganese (Mn)	mg/L
Potassium (K)	mg/L	Mercury (Hg)	mg/L
Calcium (Ca)	mg/L	Molybdenum (Mo)	mg/L
Magnesium (Mg)	mg/L	Nickel (Ni)	mg/L
Chloride (Cl)	mg/L	Lead (Pb)	mg/L
Carbonate (CO_3)	mg/L	Sulfur (S)	mg/L
Hydrogen carbonate (HCO_3)	mg/L	Selenium (Se)	mg/L
Sulfate (SO_4)	mg/L	Uranium (U)	mg/L
Alkalinity	mg/L	Vanadium (V)	mg/L
Hardness	mg/L	Zinc (Zn)	mg/L
Nutrients		***Other***	
Nitrate + nitrite (N_NO$_X$)	mg/L	Total suspended solids (TSS)	mg/L
Ammonia (N_NH$_3$)	mg/L	Turbidity	NTU
Total Nitrogen (total N)	mg/L		
Total Phosphorus (total P)	mg/L		

3.3.3 Invertebrate fauna

Microinvertebrates (i.e. zooplankton) were collected from the water column using a 53 µm mesh pond net to sweep over a standard 15 m distance at each site. Samples were transferred into 250 ml PET vials, preserved in 70% ethanol, and were sent to Dr. Russ Shiel, Adelaide University, for laboratory enumeration and identification. Samples were processed by identifying the first 200-300 individuals encountered in an agitated sample decanted into a 125 mm^2 gridded plastic tray, with the tray then scanned for additional missed taxa, and recorded as 'present'. Specimens were identified to the lowest taxon possible, *i.e.* species or morphotypes, under a high power compound microscope.

Hyporheic fauna were collected using the Karaman-Chappuis method (Delamare-Deboutteville 1960). This involved digging a 30 cm deep x 40 cm diameter hole in alluvial gravels adjacent to the water's edge (see Plate 1). The hole was allowed to fill with water percolating through the gravel, and then was swept with a small 110 µm mesh hand-net (Plate 1). Each sample was transferred to a 250 ml PET vial and preserved in 70% ethanol for laboratory enumeration and identification. Collected specimens were identified in the WRM laboratory to the lowest possible taxonomic level (typically genus or species), under either low power dissecting microscopes, or high power compound microscopes (amphipods, oligochaetes). Taxa were enumerated to $\log_{10}$ scale abundance (*i.e.* 1 = 1 individual, 2 = 2 - 10 individuals, 3 = 11 – 100 individuals, 4 = 101-1,000 individuals, *etc.*).

Benthic macroinvertebrates were collected using a 250 µm mesh pond net (Plate 1). All in-stream habitats, including trailing riparian vegetation, woody debris, open water column and benthic sediments were sampled at each site, to maximise taxa diversity. Each sample was washed through a 250 µm sieve to remove fine sediment, while leaf litter and other debris were carefully washed by hand in the sieve to remove attached macroinvertebrates, and then discarded. Samples were preserved in 70% ethanol for laboratory enumeration and identification. In the WRM laboratory, samples were sifted through a three-tiered sieve system (3.35 mm, 1 mm & 0.25 mm 'fractions'), and specimens were carefully removed from each fraction under low power dissecting microscopes. Collected specimens were then identified to the lowest possible taxonomic level (typically genus or species) using published taxonomic keys, and by reference to WRM's established voucher collection. Taxa were enumerated to $\log_{10}$ scale abundance.

Plate 1. Hyporheic sampling of the Weeli Wolli Creek main channel using the Karaman-Chappuis method (left) and sampling for macroinvertebrates using a 250 µm mesh pond net (right). Photos by WRM ©.

3.3.4 Fish

Fish were sampled using a number of methods, including seine netting, gill nets, dip nets and electrofishing. Electrofishing was conducted with a Smith-Root Model LR24 battery powered backpack electrofisher (see Box 1). Light-weight fine mesh gill nets (10 m net, with a 2 m drop, using 10 mm, 13 mm, 19 mm and 25 mm stretched mesh nets) were used at each site and were set in deeper water for the duration of sampling at that site. Smaller species and juveniles were sampled by beach seine (10 m net, with a 2 m drop and 6 mm mesh) deployed in shallow areas where there was little vegetation or large woody debris. Generally, two hauls of the seine were conducted at each site to maximise the number of individuals caught. Fish were identified in the field, with standard length[2] (SL) measurements taken, and then released alive.

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[2] Standard length (SL) - measured from the tip of the snout to the posterior end of the last vertebra or to the posterior end of the midlateral portion of the hypural plate (i.e. this measurement excludes the length of the caudal fin).

Box 1. Principles of electrofishing.

A DC voltage is passed from a negative electrode (cathode) to a positive electrode (anode) whilst the electrodes are immersed in water. If a fish is caught in the electrical field, a process referred to as 'galvanotaxis' occurs. Galvanotaxis is the involuntary movement of the fish towards the anode, until it reaches an electrical field strong enough to stun ('galvanoarcosis'). Once the current is switched-off, or the fish removed from the electrical field, the fish quickly recovers. The operator of the electrofisher carries the anode (in the form of a modified pond net) whilst trailing the cathode (a stainless steel cable approximately 3.5 m long). The Smith-Root backpack electrofisher has an effective range of approximately 3 m. Galvanotaxis can be used to 'pull' fish out from under debris, logs, boulders and bank undercuts, where conventional netting methods are less effective.

3.4 Data analysis

3.4.1 General analysis

Samples were grouped *a priori* into categories according to ecosystem type (off-channel 'reference' or main channel). Water quality, habitat and species metrics data were plotted to illustrate spatial differences between and within ecosystem types. Where appropriate, water quality parameters were compared against ANZECC/ARMCANZ (2000) trigger values for the protection of 99% and 95% of species in tropical northern Australian waterways (see Appendix 2). Where there appeared to be a linear pattern in macroinvertebrate species metrics, regression analysis was performed using the Data Analysis add-on in Microsoft Excel, in order to determine whether these patterns were significant ($p < 0.05$) and could be explained by variation in habitat variables. Where sufficient numbers of each fish species were collected, length-frequency histograms were plotted.

3.4.2 Multivariate analysis

Spatial variability in water quality parameters, and microinvertebrate and macroinvertebrate species assemblage data was examined using multivariate procedures in the PRIMER v7 software package (Clarke & Gorley 2006). Non-metric Multi-Dimensional Scaling (nMDS) ordination plots (Clarke & Warwick 2001) were constructed to visualise similarity/dissimilarity between and within off-channel and main channel sites. nMDS ordinations were based on Euclidean distance measures for water quality data and Bray-Curtis similarity matrices for species abundance data. Ordinations were depicted as two-dimensional plots.

One-way permutational multivariate analysis of variance (PERMANOVA) was used to test for significant ($p <0.05$) spatial effects on data (Anderson 2001, McArdle & Anderson 2001, Anderson *et al.* 2008). Where there were significant differences in species assemblages, the similarity percentage analysis (SIMPER) routine within PRIMER was used to determine those species contributing most to the similarity/dissimilarity between groupings.

Relationships between species data and environmental data were assessed using BIOENV in PRIMER to calculate the smallest sub-set of environmental variables (habitat characteristics) that explain the greatest percentage of variation in the species ordination patterns, as measured by Spearman rank correlation (ρ) (Clarke & Warwick 2001). Values for environmental variables were based on Euclidean distances.

Unless indicated otherwise, default values or procedures recommended by Clarke and Gorley (2006) or Anderson *et al.* (2008) were employed for all PRIMER and PERMANOVA routines, respectively.

4 RESULTS AND DISCUSSION

4.1 Water quality

4.1.1 Comparison against default ANZECC/ARMCANZ (2000) trigger values

Dissolved oxygen (DO)

Spot measurements of DO (% saturation) ranged between 27% at WWOCR1 and 147% at WWC8 (Figure 4). DO was below the lower ANZECC/ARMCANZ (2000) TV (80%) at WWOCR1, WWOCR2 and WWOCR3 off-channel, and WWC1, WWC3, WWC6 and WWC8 within the main channel (Figure 4). DO was considered particularly low at each of the off-channel reference sites (Figure 4), which is likely a reflection of the hydrological characteristics of these pools (standing water, with little aeration due to lack of surface flows). Additionally, DO depletion in part is likely due to aerobic heterotrophic bacteria utilising water column dissolved oxygen as they decompose organic matter (dead plant material). Emergent and submergent macrophyte was abundant within each off-channel pool (A. Harman pers. obs.). The actual DO depletion experienced will depend upon the biodegradable organic matter loading, microbial activity and the amount of respiration occurring.

While the oxygen needs of aquatic biota differ between species and life history stages, DO concentrations below 20% are known to be lethal to many freshwater macroinvertebrate taxa, and concentrations between 25 - 35% can severely limit recruitment (Connolly *et al.* 2004). Butler and Burrows (2007) reported acute toxicity in six northern Australian fish species at DO concentrations between 25% and 30% (at 23°C - 33°C), while some studies have reported chronic responses in macroinvertebrates and fish to saturation levels below 50% (Butler *et al.* 1970, Davis 1975, Alabaster & Lloyd 1982). Therefore, it is likely DO saturation levels recorded at WWOCR sites in the current study present ecological conditions of 'stress' to resident aquatic fauna.

Conversely, DO was in exceedance of the upper ANZECC/ARMCANZ (2000) TV (120%) at WWC5 and WWC8 (Figure 4), and therefore these sites were considered "supersaturated". Supersaturation occurs in areas of high turbulence (e.g. riffle zones), or when net photosynthesis exceeds total oxygen consumption, and is common where there is high algal and macrophyte growth (Tadesse *et al.* 2004). Supersaturated waterbodies as a result of excess photosynthesis are likely to experience oxygen stress overnight, when respiration by plants, algae and fauna depletes oxygen levels. Supersaturation is also well known to cause gas bubble disease in fish (Bouck 1980). However, it should be noted that dissolved oxygen generally exhibits a diurnal pattern, reflecting the flux between aquatic respiration and photosynthesis, so spot measurements of DO such as these provide only a snapshot of typical daily conditions, which may vary considerably depending on the time of measurement.

pH

Generally, pH was circum-neutral to slightly basic, and ranged from 7.37 (WWC6) to 8.36 (WWC5; Figure 4). pH was slightly in exceedance of ANZECC/ARMCANZ (2000) TVs (pH 6 - 8) at five main channel sites (WWC2, WWC3, WWC4, WWC5 and WWC8; Figure 4). This was not considered to be of ecological concern, given that slightly basic pH has been widely recorded in surface waters across the East Pilbara (Johnson & Wright 2001, WRM unpub. data).

Electrical conductivity (EC)

EC was in exceedance of ANZECC/ARMCANZ (2000) guidelines at all sites, ranging from 449 µS/cm (WWC6) to 1930 µS/cm (WWOCR3; Figure 4). However, most sites were considered "fresh", as defined by the Department of Environment (2003)[3], with the exception of WWOCR3, which was classified as "brackish". Surface waters in arid/semi-arid zones such as the Pilbara naturally exhibit elevated EC levels, particularly in the dry season, due to high evaporation rates and low rainfall. Although some dilution occurs following wet season rains, EC will often remain high due to the variability of flows and flushing of stored salts (Jolly *et al.* 2008). Relatively high EC at WWOCR3 may reflect some saline groundwater influence at this site, which may also explain the persistence of this pool off the main channel. There is a general acceptance that when conductivity is below 1500 µS/cm, freshwater ecosystems experience little ecological stress (Hart *et al.* 1991, Horrigan *et al.* 2005). However, with EC above 1500 µS/cm at WWOCR3 despite good rainfall in the days prior to sampling, it is likely that aquatic fauna will experience some ecological stress during the dry season, when evapo-concentration is expected to further elevate EC.

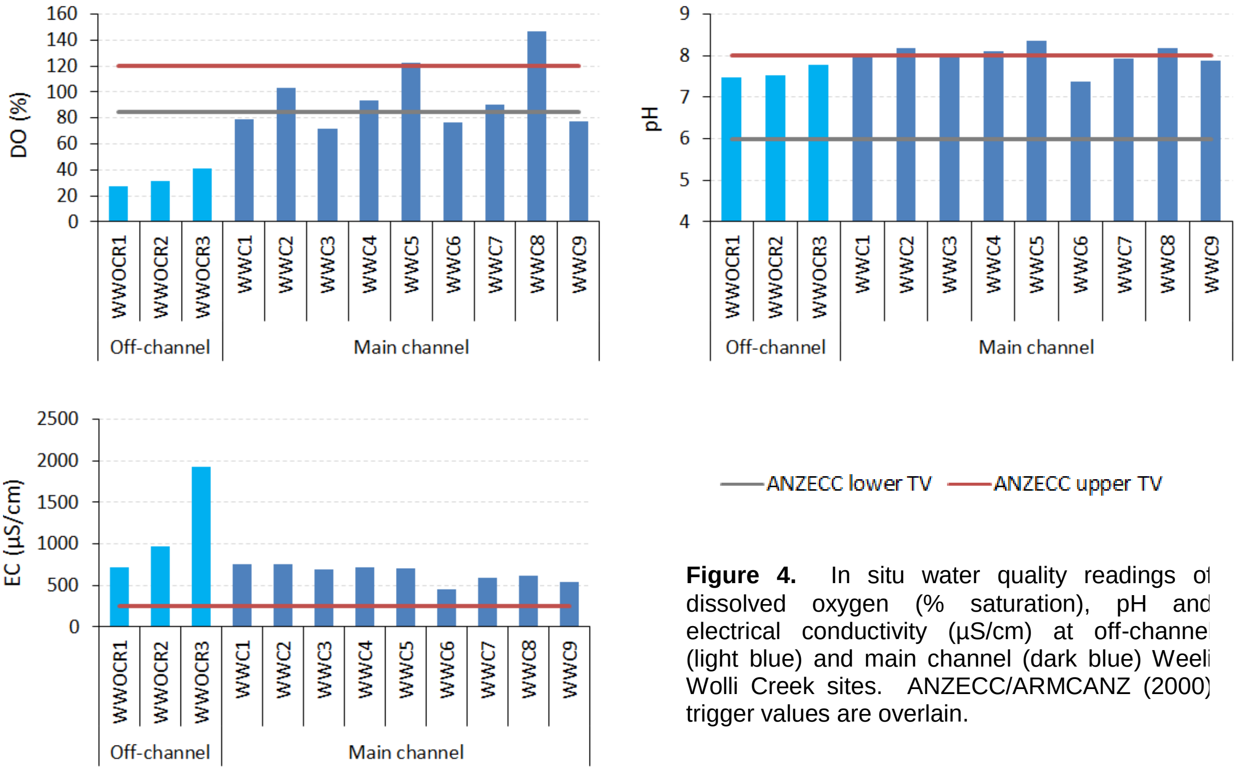

Figure 4. In situ water quality readings of dissolved oxygen (% saturation), pH and electrical conductivity (µS/cm) at off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites. ANZECC/ARMCANZ (2000) trigger values are overlain.

Turbidity and TSS

Turbidity levels were below ANZECC/ARMCANZ (2000) TVs (i.e. > 15 NTU) at all sites. TSS was also relatively low at most sites, though both parameters were slightly elevated at WWOCR3 (Appendix 3). In natural systems, turbidity and TSS can increase during periods of overland flow (runoff), which, coupled with increased streamflow, can cause the erosion of riverbanks and the suspension of finer benthic substrates. However, anthropogenic disturbances, such as livestock activity, can also raise suspended sediment loads *via* physical disturbance of benthic substrates. Slightly raised TSS and turbidity at WWOCR3 likely reflects the disturbance of benthic substrates (predominantly clay and silt; Appendix 3) by heavy livestock activity, causing suspension of fine particulates in the water column.

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[3] Fresh defined as < 1500 µS/cm, Brackish = 1500 – 4500 µS/cm, Saline = 4500 – 50,000 µS/cm, Hypersaline > 50,000 µS/cm (DoE 2003). Classifications were presented as TDS (mg/L) in DoE (2003), so a conversion factor of 0.68 was used to convert to conductivity µS/cm, as recommended by ANZECC/ARMCANZ (2000).

Alkalinity

Alkalinity is an expression of the buffering capacity of waterbodies, and helps protect systems against rapid pH swings. Alkalinity of less than 20 mg/L is considered low, and in poorly buffered waters pH can rise rapidly in response to the removal of carbon dioxide during photosynthesis (Sawyer & McCarty 1978, Romaire 1985, Lawson 2002). Well buffered systems also help neutralise ARD/AMD and help reduce toxicity/bioavailability of dissolved metals (ANZECC/ARMCANZ 2000). Alkalinity in the current study ranged between 148 mg/L (WWC6) and 386 mg/L (WWOCR3; Appendix 3), suggesting the buffering capacities of both off-channel and main channel sites are good.

Ions

Concentrations of most dissolved ions were relatively high at WWOCR3, compared to other off-channel and main channel sites, and reflect elevated EC at this site (Appendix 3). Dissolved chloride (dCl) was particularly elevated at WWOCR3 (374 mg/L), which was more than three times greater than the next highest dCl value recorded off-channel (108 mg/L at WWOCR2), and five times greater than the highest dCl value recorded from main channel sites (74 mg/L at WWC1 & WWC2). Similarly, dissolved potassium (dK) and dissolved sodium (dNa) from WWOCR3 was more than three times greater than the highest corresponding values from other off-channel sites, and over four times greater than those recorded from main channel sites. Physical disturbance and suspension of benthic substrates, evapo-concentration, and/or saline groundwater influence are likely contributing factors to elevated dissolved ions at WWOCR3.

Nutrients

Inorganic nitrogen oxides (nitrate + nitrite; $N\text{-}NO_x$) ranged from below the limit of detection (LOD; < 0.01) at WWOCR1 and WWOCR3, to 0.23 mg/L at WWC8 (Figure 5). $N\text{-}NO_x$ was in exceedance of the ANZECC/ARMCANZ (2000) eutrophication TV (0.01 mg/L) at all main channel sites. Values also exceeded the ANZECC/ARMCANZ (2000) 95% toxicity TV for nitrate (NO_3; 0.7 mg/L)[4] at main channel site WWC8 (Figure 5). However, the current ANZECC/ARMCANZ (2000) default 95% TV for nitrate as a toxicant is currently under review, as it is considered too conservative. The new ANZECC/ARMCANZ (2000) 95% TV for NO_3 is likely to be around 11 mg/L (2.5 mg/L $N\text{-}NO_x$), and will incorporate most recent data from acute and chronic toxicity testing in New Zealand (Hickey 2013, R. van Dam, *eriss*, pers. comm.). Recently published guidelines for Canada also recommend a higher NO_3 guideline of 13 mg/L (2.9 mg/L $N\text{-}NO_x$) for protection against toxicity in freshwaters (CCME 2014).

Nitrogen oxides can lower acid-neutralising capacities of waterbodies, impede the growth, survival and reproduction of aquatic fauna, and stimulate eutrophication and algal blooms (Camargo & Alonso 2006). Anthropogenic sources of inorganic nitrogen include agricultural, urban or mine related runoff, livestock waste, deposition of nitrogen-rich atmospheric emissions into surface waters, or the discharge of nitrogen rich groundwaters into receiving surface waters (Carmargo & Alonso 2006). The cause of elevated $N\text{-}NO_x$ concentrations within WWC main channel is currently unknown, however, may in part reflect rain-induced runoff of nutrient rich waters into WWC reflecting catchment pastoral activity, and/or unrestricted cattle access to WWC.

Total nitrogen concentrations ranged between 0.11 mg/L (WWOCR1 & WWOCR2) and 1.2 mg/L (WWOC3). Total nitrogen exceeded the ANZECC/ARMCANZ (2000) TV (0.3 mg/L) at main channel sites WWC6, WWC8 and WWC9, and was four times greater than the ANZECC/ARMCANZ (2000) TV at off-channel site WWOCR3 (Figure 5). Total phosphorous ranged from below the LOD (WWC1, WWC2, WWC3, WWC4, WWC7 & WWC9), to 0.11 mg/L (WWOCR3; Figure 5). Total phosphorous slightly exceeded the ANZECC/ARMCANZ (2000) TV (0.01 mg/L) at WWOCR1, WWOCR2 and WWC8, and total phosphorous was 11 times greater than the ANZECC/ARMCANZ (2000) TV at WWOCR3 (Figure 5). Nutrient enrichment at WWOCR3 can probably be attributed to recent livestock activity in the area, and

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[4] NO_3 (mg/L) = $N\text{-}NO_x$ (mg/L)*4.43.

nutrient concentrations are likely to further increase due to evapo-concentration as the pool recedes in dry season months.

Nutrient enrichment in aquatic systems can lead to eutrophication, and consequent ecological issues such as excessive algal and cyanobacterial growth, particularly towards the end of the dry season as water levels recede and water temperatures increase. Such nuisance blooms can result in adverse impacts to aquatic systems, through toxicity and reduced DO as blooms decay, with consequent losses in biodiversity (ANZECC/ARMCANZ 2000). Highly eutrophic waters tend to support high abundances of pollution-tolerant species, but few rare taxa, and overall, less complexity in community structure (ANZECC/ARMCANZ 2000). Eutrophic waters and consequent reduced dissolved oxygen levels can adversely impact fish, causing loss of equilibrium, increased breathing and heart rate, reduction in hatching success and growth rate, and in extreme cases, death (ANZECC/ARMCANZ 2000). Although nutrient levels often exceeded ANZECC/ARMCANZ (2000) TVs in the current study, these guidelines were developed primarily for water bodies other than those in the arid and semi-arid tropics. The acceptable or 'normal' range of nutrients common to waterbodies of the Pilbara remains poorly understood and consequently, the guidelines should be applied with caution.

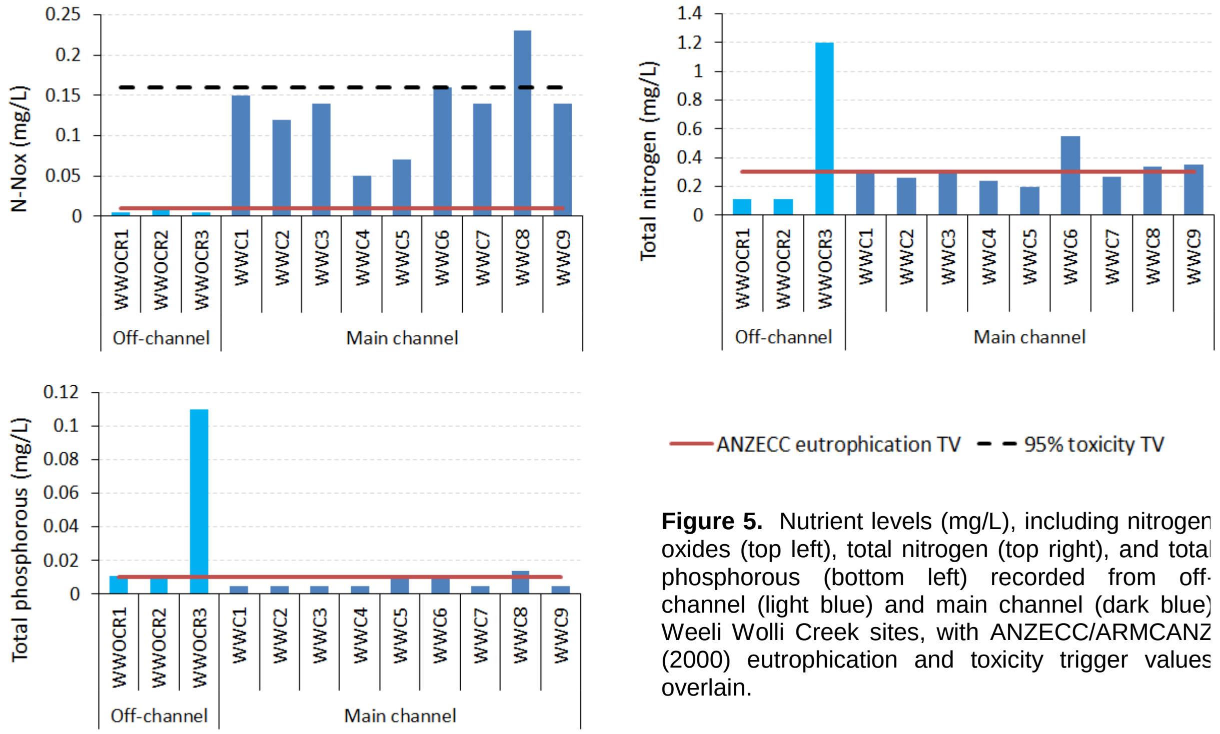

Figure 5. Nutrient levels (mg/L), including nitrogen oxides (top left), total nitrogen (top right), and total phosphorous (bottom left) recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites, with ANZECC/ARMCANZ (2000) eutrophication and toxicity trigger values overlain.

Metals

Dissolved metal concentrations were generally low in the study area, although some metals, e.g. cobalt, iron, manganese, boron and zinc were noticeably elevated at WWOCR3, relative to other off-channel/main channel sites (Appendix 3). Dissolved boron (dB) exceeded the ANZECC/ARMCANZ (2000) TV for the protection of 99% of species at all sites, however, only at WWOCR3 was dB in exceedance of the TV for the protection of 95% of species (Figure 6). This is not likely to be of ecological concern; dB appears to be naturally elevated in Pilbara waterways, and similarly elevated concentrations have been reported previously from other systems (WRM unpub. data). It is likely the aquatic fauna of this region have adapted to high levels of dissolved boron over time. It is important to be aware of naturally elevated potential contaminants prior to operations commencing, so that no blame is attributed to the Project for any perceived impact.

Dissolved zinc (dZn) was above the 99% ANZECC/ARMCANZ (2000) TV at most sites, excluding WWOCR1 and WWC4 (Figure 6). At WWOCR3, dZn also exceeded the 95% ANZECC/ARMCANZ (2000) TV. However, as mentioned previously, water hardness (alkalinity) is known to affect the toxicity of some dissolved metals, including zinc, such that greater hardness may ameliorate toxicity (Markich *et al.* 2001, Charles *et al*. 2002). ANZECC/ARMCANZ (2000) provide algorithms to calculate trigger values for these metals which take hardness into account[5]. Once water hardness was taken into account, dZn concentrations at WWOCR3 did not exceed either 99% or 95% HMTVs.

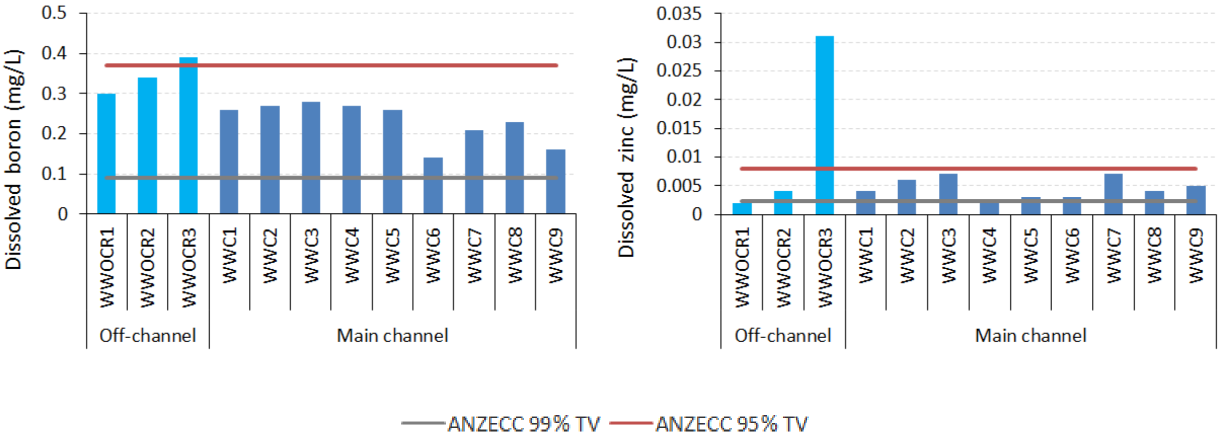

Figure 6. Dissolved boron and dissolved zinc concentrations (mg/L) recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites, with ANZECC/ARMCANZ (2000) trigger values overlain.

4.1.2 Spatial patterns in water quality (multivariate analysis)

PERMANOVA confirmed there was a significant difference in water quality parameters between off-channel ‘reference’ and main channel sites (df = 1, MS = 41.92, Pseudo-F = 4.381, p = 0.014). Cluster analysis and nMDS ordination suggested that WWOCR3 was separate from all other sites (including WWOCR1 & WWOCR2) at a Euclidean distance of 12 (Figure 8A). This reflected between-site comparisons of water quality spot measurements (Section 4.1.1), where numerous analytes (e.g. EC, TSS, dCl, dK, dNa, total N, total P, dZn) were elevated at WWOCR3, in comparison to other off-channel and main channel sites. When considering the nMDS ordination with WWOCR3 removed, off-channel sites WWOCR1 and WWOCR2 were also distinct from all main channel sites (Figure 8B). Separation of WWOCR2 from other sites was influenced by relatively high EC, dCl, dNa, HCO_3 and alkalinity recorded at this site, whereas relatively higher pH and DO were the main causal factors influencing the separation of the majority of main channel sites from off-channel sites (Spearman rank correlations; Figure 8B).

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[5] ANZECC/ARMCANZ HMTV algorithm (zinc) = Default TV*(Hardness/30)^0.85

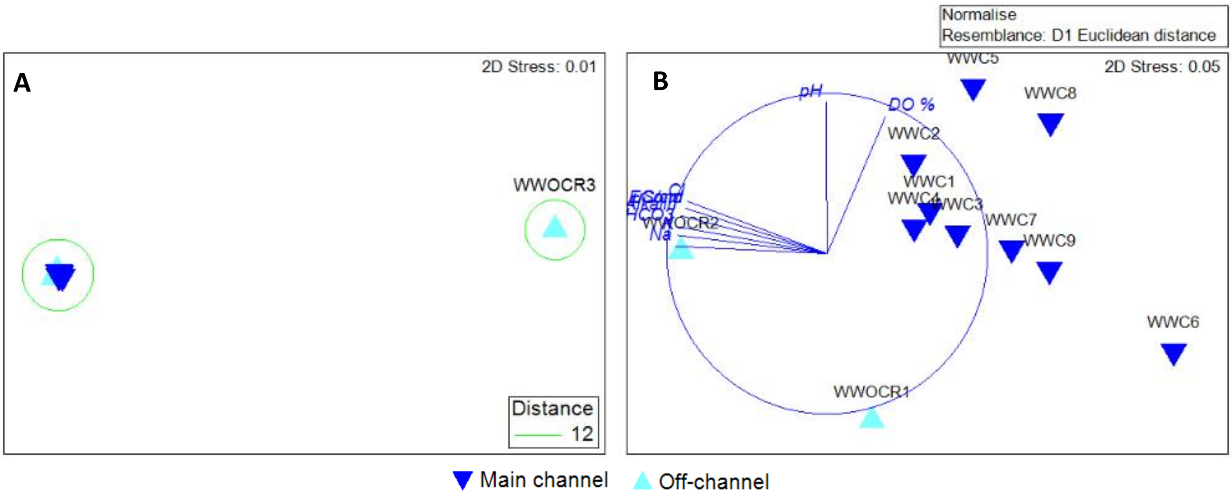

Figure 7. Unconstrained nMDS plots of water quality parameters at off-channel (light blue) and main channel (dar blue) Weeli Wolli Creek sites. Plot A (left) depicts the ordination with all sites included in the analysis, with sample grouped within green circles at a Euclidean distance of 12. Plot B (right) depicts the ordination with WWOCR removed, and with spearman rank correlations (> 0.9) as vectors overlain.

4.2 Substrate and habitat characteristics

Overall, there appeared to be distinct differences in habitat characteristics between off-channel and main channel sites. In particular, off-channel pools were diverse in habitat, with emergent and submerged macrophyte recorded in abundance. Conversely, mineral substrates were dominant within the main channel of WWC, with main channel habitat generally homogeneous between sites.

4.2.1 Substrate characteristics

The inorganic substrate at the majority of sites was dominated by cobbles, pebbles, gravel and sand, with the exception of WWOCR3, where the only two substrate types observed were clay (80%) and silt (20%). Consequently, overall substrate diversity was lower at this site compared to other off-channel and main channel sites (Figure 8). The structure and diversity of substrates are known to influence macroinvertebrate assemblages, with greater substrate complexity generally equating to higher species richness and abundance (Erman & Erman 1984, O'Connor 1991, Jähnig & Lorenz 2008).

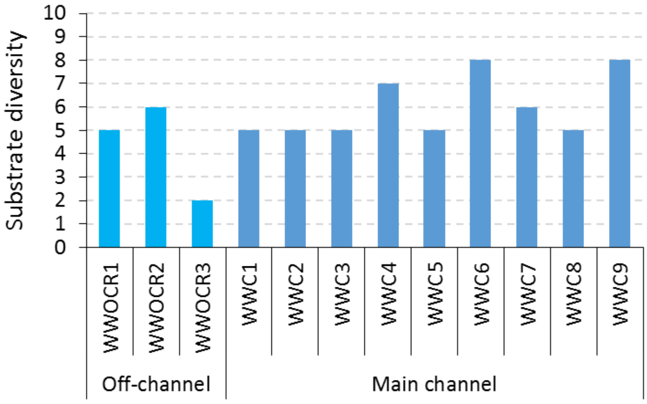

Figure 8. Substrate diversity (no. of substrate types/sizes) recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites.

4.2.2 In-stream habitat

Diversity of in-stream habitat can also play a crucial role in influencing the richness, abundance and assemblage structure of aquatic fauna, with greater habitat complexity (such as aquatic macrophyte, detritus and large woody debris) generally leading to increased species diversity and abundance (Erman & Erman 1984, Heino 2000). Mineral substrate was the dominant habitat type within the main channel of WWC (Figure 9). At off-channel sites, mineral substrates were supplemented by relatively high percentages of emergent macrophyte (e.g. typha and other reeds), submerged macrophyte and algal cover (Figure 9). Overall in-stream habitat diversity was highest at the three off-channel sites, and at main channel site WWC1 (7 habitat types each; Figure 9). Greater habitat diversity at WWOCR sites reflected the greater permanence of water, and reduced flows in comparison to main channel WWC sites, allowing for habitat types such as macrophytes and algae to establish.

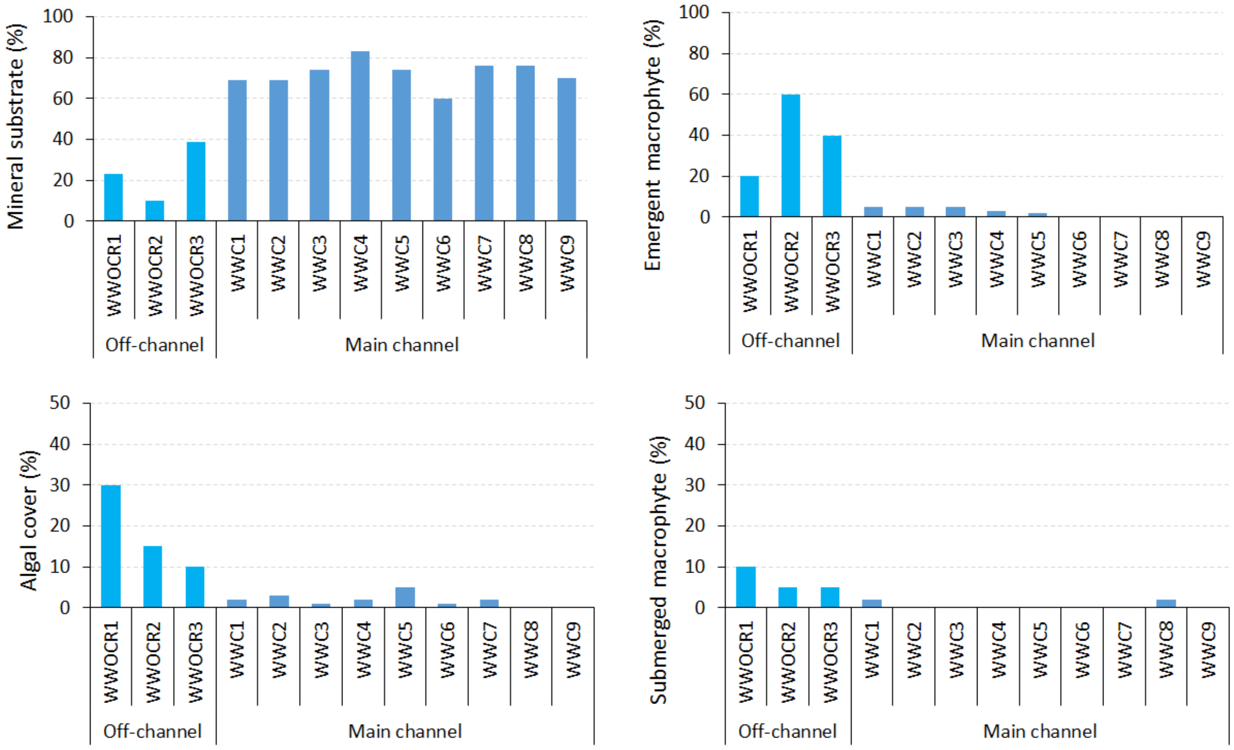

Figure 9. Percent (%) cover of mineral substrate, emergent macrophyte, algae and submerged macrophyte recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites.

There appeared to be a slight negative gradient of habitat diversity within the main channel of WWC, with diversity decreasing with distance downstream of WWC1 (Figure 10). Habitat diversity was lowest at WWC9 (four habitat types), which was a receding remnant pool at the time of sampling. The lack of habitat diversity at main channel sites, particularly downstream of WWC5 (Figure 10), was not unexpected, given that it was likely these sites had only recently flooded following heavy rainfall, and there would not have been enough time for aquatic macrophyte, algae and other vegetation to establish before sampling commenced.

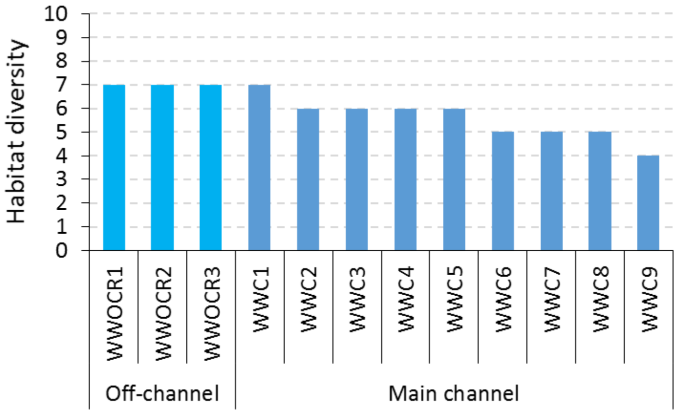

Figure 10. Habitat diversity (no. of habitat types) recorded from off-channel (light blue) and main channel (dark blue Weeli Wolli Creek sites.

4.3 Microinvertebrates (zooplankton)

4.3.1 Taxonomic composition and species richness

A total of 72 microinvertebrate taxa were recorded during the current study, of which, 46 taxa were recorded from off-channel sites, and 42 taxa were recorded from within the main WWC channel (Table 3). These include groups which could not be identified to species level due to unresolved taxonomy and/or immature specimens. Therefore, the total microinvertebrate species richness is likely greater than that reported here. The microinvertebrate fauna comprised Protista (Ciliophora & Rhizopoda), Rotifera (Bdelloidea & Monogononta), Copepoda (Calanoida & Cyclopoida), Cladocera (water fleas), and Ostracoda (seed shrimp; Table 3). The microinvertebrate fauna was typical of tropical systems across the world, with lecanids dominating the Rotifera, and chydorids prominent within Cladocera (e.g. Koste and Shiel 1983, Tait *et al.* 1984, Smirnov and De Meester 1996, Segers *et al*. 2004).

Table 3. Summary of microinvertebrate composition and taxa richness.

	Off-channel	Main channel	Total no. species
Protista	15	8	18
Rotifera	21	14	27
Cladocera	4	10	13
Copepoda	4	7	9
Ostracoda	2	3	5
Total	**46**	**42**	**72**

WWOCR1 supported the highest microinvertebrate taxa ('species') richness (35 taxa), whilst lowest taxa richness was recorded from WWC4 (two taxa; Figure 11). Microinvertebrates were notably abundant at the three off-channel pools, with 187 individuals (in 29% of settled volume counted) at WWOCR1, 201 individuals (in 6.4% of settled volume counted) at WWOCR2, and 205 individuals (in 0.2% of settled volume counted) at WWOCR3 (Figure 11; Appendix 4). Within the main channel, microinvertebrates were relatively depauperate at sites receiving higher surface flows (i.e. WWC1, WWC2, WWC3 & WWC4), while slightly higher taxa richness and abundances were recorded at more ephemeral sites further downstream (Figure 11; Appendix 4). The majority of zooplankton typically prefer low flow or still water habitats, which would explain the high microinvertebrate abundance recorded at off-channel pools, and in ephemeral sites further downstream within the main channel (upstream main channel sites are affected by dewatering discharge from mines located further upstream). It is likely that zooplankton are adapted to a narrow range of water quality, and imposing altered water quality *via* dewatering discharge may have reduced the abundance of more susceptible species in Weeli Wolli Creek (R. Shiel, University of Adelaide, pers. com.).

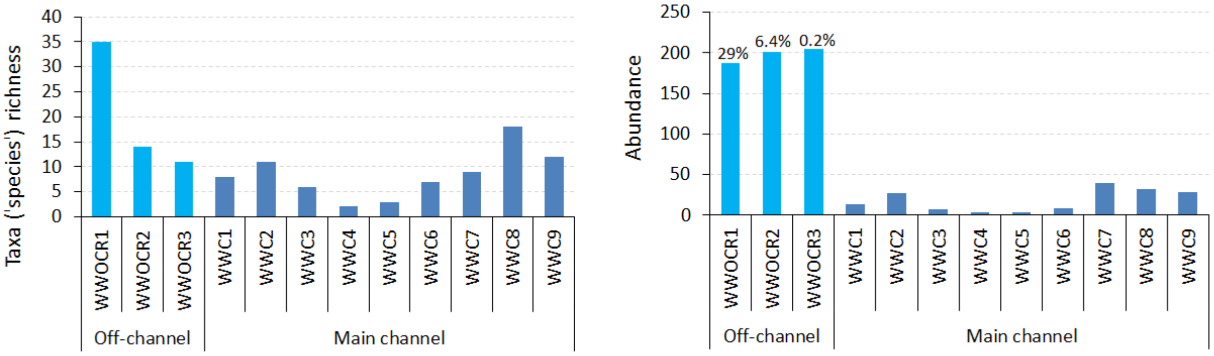

Figure 11. Taxa ('species') richness (left), and total abundance of microinvertebrates (right) recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites. Percentages (%) denote the portion of settled volume counted for abundance values. Where not specified (i.e. at main channel sites), 100% of settled volume was counted.

4.3.2 Microinvertebrate taxa of regional/scientific importance

The majority of microinvertebrate taxa from both off-channel and main channel sites were common, ubiquitous species, usually Australasian or cosmopolitan in distribution. However, a number of regionally significant taxa were recorded, including the Pilbara endemic copepods *Australoeucyclops karaytugi* and *Mesocyclops holynskae*. Two cladocerans of the genus *Simocephalus* were collected, which, although cosmopolitan in distribution, are rarely encountered in the Pilbara. The cladoceran cf. *Anthalona* sp. (family Chydoridae) was of scientific interest, as no species of this recently-erected genus have been described from Australia. Finally, the unexpected collection of the copepod *Boeckella fluvialis*, previously considered restricted to eastern Australia, initiates some interesting discussion. Each of these species are discussed in greater detail below.

The Pilbara endemic copepod *Australoeucyclops karaytugi* was collected from main channel site WWC2. This species is known from a number of other spring and permanent pool systems within the Pilbara, including the Ashburton, DeGrey and Yule River catchments (Pinder *et al.* 2010). WRM (2011) also collected *A. karaytugi* from Marillana Creek, just upstream of the confluence with WWC (4.5 km upstream of the Project). *Mesocyclops holynskae,* also restricted to the Pilbara, was recorded from off-channel pool WWOCR3. Previously, this species has been recorded from surface pools, as well as groundwater environments (bores) across the Pilbara region (Karanovic 2006).

Simocephalus exspinosus and *Simocephalus gibbosus* (Cladocera, family Daphindae) are very rarely collected from the Pilbara (R. Shiel, University of Adelaide, pers. comm.). During the comprehensive Pilbara Biological Survey (PBS), in which 98 sites across the Pilbara were sampled between 2003 and 2006, *S. exspinosus* was only once collected, from a pool on the Ashburton River (Pinder *et al.* 2010). *S. gibbosus* was not recorded during the PBS (Pinder *et al.* 2010).

Anthalona is a recently described (2011) cladoceran genus, which is restricted to tropical and sub-tropical climes due to its stenothermic preference for warm waters (Van Damme *et al.* 2011). A number of species have been described from Central and South America, the Mediterranean, Africa, the Middle East, southern China and South-East Asia, however several species, which are awaiting taxonomic description, also occur in northern Australia (Van Damme *et al.* 2011). In the current study, *Anthalona* specimens (cf. *Anthalona* sp.) were collected from main channel sites WWC2, WWC6 and WWC7, though it is currently unknown whether these represent a new Australian species, or a range extension for a previously described species (R. Shiel, University of Adelaide, pers. comm.).

The collection of calanoid copepod *Boeckella fluvialis* at WWC9 was unexpected, given that this species is considered restricted to the eastern Australian states of Queensland, New South Wales and Victoria (Bayly 1985). The Western Australian Department of Parks and Wildlife (DPaW) have no record of *B. fluvialis* in Western Australia (A. Pinder, DPaW, pers. comm.), however, Bayly (1985) did record this species in ponds outside the Canning Town Council (City of Canning) buildings in the Perth-Metropolitan area between 1978 and 1985. The Canning Town Council ponds were located on a site previously used as a stone fruit nursery, with potted seedlings imported from Victoria and NSW and planted between 1935 and 1960 (Bayly 1985). Therefore, Bayly (1985) suggested that *B. fluvialis* was most likely introduced to these ponds *via* resting cysts, which were stored in the soil of imported potted seedlings.

It is considered unlikely that the presence of *Boeckella fluvialis* in the WWC9 microinvertebrate sample was caused by contamination, as WRM have not recently processed samples from the Eastern States (and have never recorded this species before), and Dr. Russel Shiel, who is sub-contracted by WRM to identify microinvertebrates, has not observed *B. fluvialis* in samples for over four years (R. Shiel, University of Adelaide, pers. comm.). Therefore, the collection of *B. fluvialis* from WWC9 constitutes either a range extension for this species, or more likely, a synanthropic introduction of this species to the study area, *via* imported soil or some other mode of transport, such as waterbird-mediated passive dispersal (R. Shiel, University of Adelaide, pers. comm.). Although uncommon, the introduction of calanoid copepods to foreign waterbodies has been previously recorded; along with the introduction of *B. fluvialis* to the Perth-Metropolitan area from eastern Australia, at least three other calanoid species have been introduced to New Zealand man-made ponds from Australia (Bayly 1985). Another *Boeckella* species, *B. triarticulata*, has been syanthropically introduced to ponds in Northern Italy, either through the stocking of introduced fish species, or through resting cysts associated imported crop seeds (Ferrari & Rossetti 2006).

Although a number of microinvertebrate taxa of scientific value (Pilbara endemic, rarely collected, potential new species) were recorded from main channel and off-channel sites in the current study, all species have known distributions outside the Project area, with the possible exception of the undescribed cf. *Anthalona* sp.

4.3.3 Spatial patterns in microinvertebrate assemblages (multivariate analysis)

PERMANOVA indicated that there was a significant difference in microinvertebrate species assemblages between off-channel and main channel sites (df = 1, MS = 5243.4, Pseudo-F = 1.8316, p = 0.039). SIMPER analysis suggested that there was 83.2% average dissimilarity (Bray-Curtis similarity) between off-channel and main channel sites, with taxa contributing most to these differences including; the cyclopoid copepod *Microcyclops varicans,* the rotifers *Sinantherina procera* and *Tripleuchlanis plicata*, the protists *Arcella discoides* and *Arcella bathystoma,* along with a number of *Difflugia* protists, indeterminate copepods and Bdelloidea rotifers. Each of these taxa was higher in average abundance at off-channel sites.

Non metric multidimensional scaling (nMDS) ordination (Figure 12) displayed clear separation of microinvertebrate assemblages at off-channel sites WWOCR1 and WWOCR2 from all other sites, as identified by PERMANOVA and SIMPER. BIOENV analyses (BEST procedure) suggested that five habitat variables (boulders, submerged macrophyte, algal cover, trailing vegetation & roots) influenced the variation of these assemblages, though the strength of the correlation was moderate (rho: 0.629, p = 0.05). Spearman rank correlations (correlation > 0.5) indicated that submerged macrophyte most influenced the separation of WWOCR1 and WWOCR2 from other sites, while high percentages of roots, pebbles and large woody debris appeared to influence the separation of the majority of main channel sites (Figure 12).

As mentioned previously, microinvertebrates are known to prefer natural, sluggish or still waterbodies in preference to areas of high flow and altered hydrological regime. Microinvertebrate assemblage composition in the study area broadly reflected these preferences, where there was a distinct separation of off-channel sites WWOCR1 and WWOCR2 from main channel assemblages, with higher abundances of numerous taxa recorded at these standing off-channel pools (Figure 12). The separation of microinvertebrate assemblages at WWOCR1 and WWOCR2 from WWORC3 appeared to be influenced mainly by the presence of submerged macrophytes and other vegetation. Periphytic taxa (i.e. obligate inhabitants of aquatic plant surfaces), such as Lecanid rotifers and testate protists, were notably diverse and abundant at WWOCR1 (and to a lesser extent WWOCR2), in comparison to other off-channel and main channel sites (R. Shiel, University of Adelaide, pers. comm.), highlighting the influence of submerged habitat (particularly aquatic macrophytes) on microinvertebrate assemblage structure in the study area.

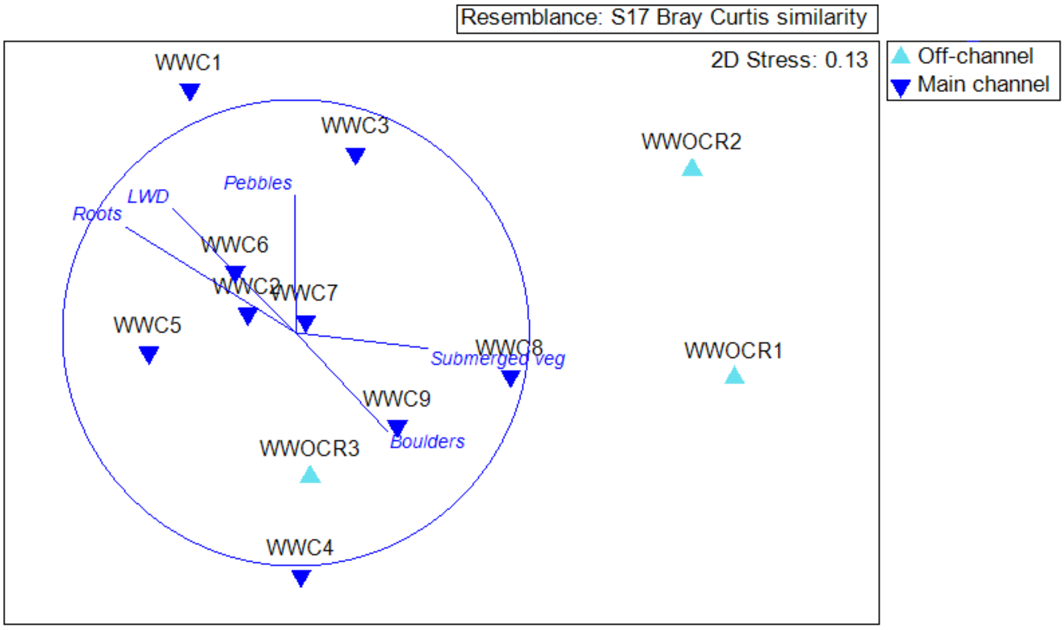

Figure 12. Unconstrained nMDS plot of microinvertebrate species assemblages at off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites, with spearman rank correlations of habitat variables (> 0.5) as vectors overlain.

4.4 Hyporheic fauna

4.4.1 Taxanomic composition

A total of 74 taxa were recorded from hyporheic samples taken in the Project area. A hyporheic sample could not be taken at WWOCR3 due to unsuitable substrate composition, i.e., predominantly clay and silt, with limited interstitial habitat for the movement of hyporheic fauna.

The majority of taxa recorded from both off-channel and main channel sites were considered “stygoxene”, i.e. they do not show specialised adaptations to groundwater or interstitial habitats (Appendix 4). Only four taxa were considered to be restricted to the hyporheic zone (stygobite[6]). These included the ostracod *Candonopsis tenuis*, and three Paramelitidae amphipod species, which were also considered short range endemics (SREs). Taxa which were not true hyporheic fauna, but do show some morphological adaption to groundwater environments (occasional hyporheos stygophile[7]), included the cyclopoid copepod *Microcyclops varicans*, and a number of aquatic segmented worm (Oligochaeta) and aquatic beetle (Coleoptera) taxa. These classifications followed those by Boulton (2001), however, this

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[6] Taxa that show specialised adaptations to groundwater environments, e.g. lack eyes, pigmentation.

[7] Species that are occasionally recorded in groundwater/hyporheic zones, and show some mophological adaptation to groundwater environments.

type of analysis must be considered with caution, as results are likely to be affected by availability of information on life-history, taxonomic resolution and interpretation of classification categories.

4.4.2 Hyporheic fauna

The stygobitic ostracod *Candonopsis tenuis* was recorded from main channel site WWC2. *C. tenuis* was originally described from eastern Australia (Brady 1886, Sars 1896) and is commonly recorded from groundwater environments across the Pilbara (Halse *et al.* 2002) and Australia (DeDeckker 1982, Karanovic & Marmonier 2002).

The occasional hyporheos stygophile *Microcyclops varicans* was collected from off-channel site WWOCR1, and from WWC2, WWC4, WW7, WWC8 and WWC9 within the main channel. *M. varicans* occurs widely in Pilbara surface waters and groundwater environments, including deep bores and hyporheic zones (Martens & Rossetti 2002, Pesce *et al*. 1996, Halse *et al.* 2002, DEC 2009).

A number of aquatic oligochaete (segmented worm) taxa were recorded at both off-channel and main channel sites. Although not specifically adapted to subterranean habitats, a majority of freshwater oligochaete groups appear to be morphologically pre-adapted to hyporheic environments, with their small size allowing them to move easily in interstitial spaces (Des Châtelliers *et al.* 2009). Further, oligochaetes of the family Naidinae, including *Pristina* and *Dero* species*,* are known to be active exchangers between surface and groundwaters (Lafont *et al.* 1992).

The coleopteran families of Hydraenidae and Scirtidae, larvae of which were collected from a number of main channel sites during the current study, have commonly been reported from hyporheic habitats throughout the world (Boulton *et al.* 1997, del Rosario & Resh 2000, Matthaei & Townsend 2000, Olsen & Townsend 2003, Langhans 2006), and therefore, are classified as occasional hyporheos stygophiles. The Dytiscid beetle *Limbodessus occidentalis* is also considered an occasional hyporheos stygophile, as it has been collected in calcrete aquifers, surface waters and hyporheic environments across the Pilbara region (Watts & Humphreys 2004, Pinder *et al.* 2010). Many calcrete aquifers across inland Western Australia have recently been discovered to support unique diving beetle (Dytiscid) assemblages (commonly including *L. occidentalis*), which also frequent surface waters and hyporheic zones connected to aquifers (Leys *et al.* 2003, Watts & Humphreys 2006). In the current study, *L. occidentalis* was recorded from WWOCR1.

4.4.3 Short range endemics (SREs)

Three short range endemic (SRE) species, as defined by Harvey (2002)[8], were recorded in the study area. These were the stygobitic amphipods Paramelitidae sp. B, Paramelitidae sp. D, and *Chydaekata* sp. These taxa comprised only 50% of SRE species likely to occur in the hyporheic zone of WWC adjacent to the Project, as identified by WRM (2015) (Table 4). However, it should be noted that these results only present a snapshot of hyporheic assemblages present in the study area, and it is likely that other species would be identified if sampling were to be conducted at more sites and at differing times of the year.

Paramelitidae sp. D was recorded in the hyporheic zone of WWC2, and Paramelitidae sp. B was recorded at off-channel sites WWOCR1 and WWOCR2. Both species have been previously collected from the hyporheic zones of WWC and Marillana Creek, upstream of the Project (WRM 2011, DPaW 2015). These species have also been collected in bores within the Project tenement (Bennelongia 2010). Of particular interest is Paramelitidae sp. D, whose WWC and Marillana Creek populations, despite their close geographical proximity, have been found to be genetically distinct, based on over four million years of reproductive isolation (WRM 2011).

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[8] Short range endemic as defined by Harvey (2002): a species occupying an area of less than 10, 000 km^2.

Table 4. SRE taxa recorded in the hyporheic zones of off-channel and main channel sites, versus SRE taxa expected to occur in the study area as identified by WRM (2015). * indicates species was also collected in surface water (macroinvertebrate) samples.

Taxa		Observed		Likely to occur
		Off-channel	Main channel	
Amphipoda	Paramelitidae sp. B	✓	*	✓
	Paramelitidae sp. D		✓	✓
	Chydaekata sp.	✓		✓
	Maarrka weeliwolli			✓
Isopoda	*Pygolabis weeliwolli*			✓
Syncarida	Bathynellidae/Parabathynelllidae			✓

Chydaekata sp. (family Paramelitidae) is known previously from bores within the Project tenement (Bennelongia 2010), as well as the hyporheic zone of a small number of nearby creeks; WWC, Marillana Creek, Coondiner Creek and Mindy Mindy Creek (DPaW 2015). In the current study, this species was recorded at off-channel site WWOCR1.

Along with Paramelitidae sp. B, Paramelitidae sp. D and *Chydaekata* sp., a number of immature stygal amphipods of the family Paramelitidae were also collected at WWOCR1, WWOCR2 and WWC2. These may have represented any of the aforementioned amphipod species, or possibly *Maarrka weeliwolli*, another stygal Paramelitidae amphipod known from the Project area, which was not recorded in the current study. Because of the immature condition of the specimens, it was not possible to definitively identify them to species level.

Although a number of stygobitic and SRE hyporheic taxa were recorded at WWC main channel and off-channel sites in the current study, all taxa have known local and/or regional distributions outside the Project area.

4.5 Macroinvertebrates

4.5.1 Taxanomic composition and species richness

A total of 172 macroinvertebrate taxa (‘species’) were recorded from WWC during the current study; 78 were collected from off-channel sites, and 151 were collected from the main channel (Table 5). As for microinvertebrates, these include groups which could not be identified to species level due to unresolved taxonomy and/or immature specimens, and total macroinvertebrate species richness is likely greater than that reported here. Taxa comprised predominately of fugitive, opportunistic and/or predatory groups, i.e. Coleoptera (27%) and Diptera (27%) and Hemiptera (12%). Other taxa included Acarina (aquatic mites), Collembola (spring tails), Gastropoda (aquatic snails), Ephemeroptera (mayflies), Lepidoptera (aquatic caterpillars), Odonata (dragonflies & damselflies), Trichoptera (caddisflies), Amphipods (side swimmers) and Oligochaeta (segmented worms) (Table 5).

Highest macroinvertebrate taxa (‘species’) richness was recorded from WWC1 (70 taxa), whereas lowest richness was recorded from WWC6 (38 taxa; Figure 13). Within the main channel, there was a general decline in macroinvertebrate taxa richness downstream of WWC1, and particularly between WWC1 and WWC6 (Figure 13). This appeared to follow a similar trend to in-stream habitat diversity within the main channel, which also declined with distance downstream of WWC1 (see Section 4.2.1).

Table 5. Summary of macroinvertebrate composition and abundance at off-channel and main channel Weeli Wolli Creek sites.

Taxa	Off-channel	Main channel	Total no. species
Acarina (aquatic mites)	2	2	3
Collembola (spring tails)	2	2	3
Gastropoda (aquatic snails)	2	2	2
Coleoptera (aquatic beetles)	15	39	46
Diptera (true flies)	22	41	46
Ephemeroptera (mayflies)	6	9	9
Hemiptera (true bugs)	8	19	21
Lepidoptera (aquatic caterpillars)	1	3	4
Odonata (dragonflies & damselflies)	10	14	16
Trichoptera (caddisflies)	4	10	12
Amphipods (side swimmers)	0	1	1
Oligochaeta (segmented worms)	6	9	9
Total	**78**	**151**	**172**

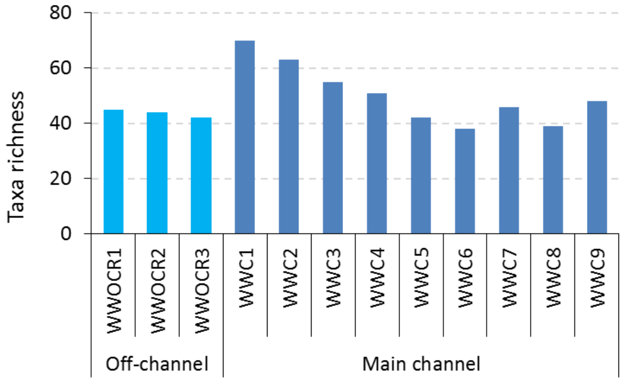

Figure 13. Taxa ('species') richness of macroinvertebrates recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites.

Regression analysis indicated there was a significant correlation between habitat diversity and macroinvertebrate taxa richness within the main WWC channel ($R^2 = 0.46$, $F = 5.93$, $p = 0.045$), with taxa richness increasing with greater habitat diversity (Figure 14). This was in accordance with other studies (e.g. Erman & Erman 1984, Heino 2000), which suggest that complexity and heterogeneity of in-stream habitat can play a crucial role in influencing macroinvertebrate richness and abundance.

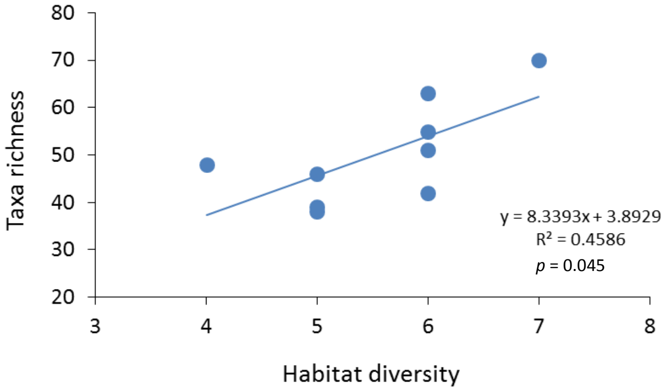

Figure 14. Linear regression plot of macroinvertebrate taxa richness against habitat diversity within the main channel o Weeli Wolli Creek. Regression equation, with R^2 and *p* value is displayed.

Reduced richness at main channel sites adjacent and downstream of the Project area (WWC5 - WWC9), relative to sites further upstream, likely reflects the ephemeral nature of the downstream reach of WWC. The current wetting front from dewatering discharge operations upstream of the Project likely affects upstream sites (WWC1 – WWC3), providing permanent or semi-permanent flows/inundation, however, sites further downstream still maintain ephemerality. As the survey took place immediately following a high rainfall event (and following above average rainfall for the month), downstream reaches would have recently filled, allowing limited time for macroinvertebrate fauna to colonise these pools prior to the survey commencing. This may in part provide reason for the lower richness observed at these sites, in comparison to upstream sites, which have greater permanency of surface water and connectivity between pools.

Taxa richness was relatively low at the three off-channel sites, with 45, 44 and 42 taxa recorded at WWOCR1, WWOCR2 and WWOCR3, respectively (Figure 13). Richness was lower than expected, given the high diversity of in-stream habitat, particularly aquatic macrophytes, present at these sites. Raw taxa lists indicated a number of species adapted to flowing conditions (lotic species) were either absent or present in reduced abundance at off-channel sites, compared to main channel sites (Figure 15). It is possible that comparatively poor water quality, such as low dissolved oxygen, and elevated EC and nutrients (See section 4.1), may have influenced taxa richness at these sites. However, it is more likely, lack of surface flow / riffles / rapids at off channel sites (isolated pools), provides reason for the observed absence of a number lotic species, compared to main channel sites.

Furthermore, isolated habitats, such as the off-channel pools, tend to support lower macroinvertebrate species richness than stream channels, due to the aerial dispersal patterns of macroinvertebrates (Bogan & Boersma 2012). Winged-adult forms allow many groups (e.g. Odonata, Coleoptera, Hemiptera, Ephemeroptera etc.) to avoid inbreeding and predation in isolated habitats, and migrate from waterbodies when environmental conditions become unfavourable (Palmer et al. 1996, Leibold et al. 2004, Bogan & Boersma 2012). Heavy rainfall also serves as a cue for many aquatic invertebrate taxa to disperse from perennial waterbodies to nearby ephemeral channels, which provide important migratory corridors for macroinvertebrates (Lytle & Poff 2004, Bogan & Boersma 2012). Therefore, differences in hydrology, dispersal patterns and heavy rainfall prior to the survey provide plausible causation for lower diversity recorded at off-channel pools during the current study.

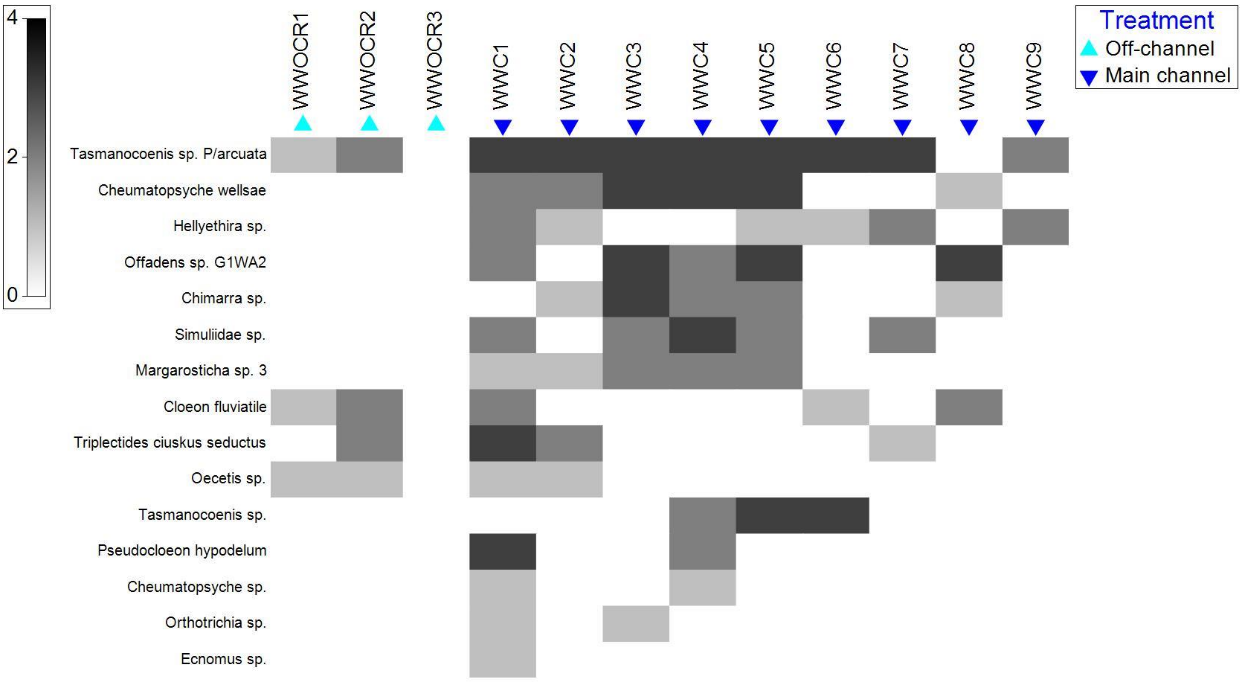

Figure 15. Shade plot of flow-adapted (lotic) taxa at off-channel and main channel Weeli Wolli Creek sites, with shaded box showing $\log_{10}$ abundance of taxa at each site.

4.5.2 Macroinvertebrate taxa of regional/scientific importance

No conservation listed (IUCN Red List or DPaW priority) macroinvertebrate species were recorded in the study area. However, one SRE amphipod (Paramelitidae sp. B), and four Pilbara endemic Coleoptera (aquatic beetle) species were recorded, including *Limbodessus occidentalis* (discussed in Section 4.4.2) and the recently described *Haliplus fortescueensis*.

The stygal SRE amphipod Paramelitidae sp. B was collected from the surface waters of WWC2. This species was also collected in the hyporheic zone of off-channel sites WWOCR1 and WWOCR2. The conservation significance of Paramelitidae sp. B is discussed in detail in Section 4.4.2.

The Haliplid beetle *Haliplus fortescueensis* is a Pilbara endemic relatively new to science. It was first described from a specimen collected from the Fortescue Marsh during the PBS (Pinder *et al.* 2010, Watts & McRae 2010). It appears to be mainly restricted to the Fortescue River, and most abundant in the Fortescue Marsh (Watts & McRae 2010). However, this species has also been collected once from a claypan near Port Hedland (Watts & McRae 2010), and also from a Claypan on Coondiner Creek (DPaW 2015, WRM unpub. data). During the current study, *H. fortescueensis* was recorded from the furthest-downstream (i.e. closest to Fortescue Marsh) main channel site, WWC9. This species appears largely restricted to ephemeral waterbodies.

The Pilbara endemic beetles *Tiporus tambreyi* (Dytiscidae) and *Laccobius billi* (Hydrophilidae) were recorded from a number of main channel sites. *Tiporus tambreyi* appears to be common and ubiquitous across the Pilbara region (Pinder *et al.* 2010, DPaW 2015, WRM unpub. data). However, *Laccobius billi* is a Pilbara endemic rarely collected. It was only recorded once during the PBS, from Cangan Pool on the Yule River, approximately 100 km north-west of the Project (Pinder *et al.* 2010). It has also been recorded previously by the authors from Weeli Wolli Creek, Coondiner Creek and Mindy Mindy Creek (DPaW 2015, WRM unpub. data).

Limbodessus occidentalis, Tiporus tambreyi, Laccobius billi and Paramelitidae sp. B have known local and/or regional distributions outside the Project area. As such, any potential impact to local populations of these species as a result of dewatering discharge is unlikely to impact their regional populations. However, the collection of *Haliplis fortescueensis* from main channel site WWC9 is of some interest. This species appears largely restricted to ephemeral waterbodies. As such, if dewatering discharge creates permanent surface flows along WWC downstream of the Project, it is possible that the local population of *H. fortescueensis* could be adversely affected.

4.5.3 Spatial patterns in macroinvertebrate assemblages (multivariate analysis)

As there appeared to be distinct differences in taxa richness between and within main channel and off-channel pools, multivariate analysis was used to investigate the variation in macroinvertebrate species assemblages within and between these ecosystem types. PERMANOVA indicated there was a significant difference in macroinvertebrate species assemblages between off-channel and main channel sites (df = 1, MS = 4133.7, Pseudo-F = 2.95, $p = 0.005$). SIMPER analysis suggested there was 62.7% average dissimilarity (Bray-Curtis similarity) between off-channel and main channel groups. Taxa contributing mostly to these differences were a large number of chironomid (non-biting midge) species, which were generally higher in average abundance at WWOCR3 compared to other sites. As indicated by shade plotting (Figure 15), taxa which are known to prefer high flows and lotic conditions (e.g. the mayflies *Tasmanocoenis* sp. P/*arcuata, Cloeon* sp. Red Stripe & *Offadens* sp. G1WA2, and the caddisfly *Cheumatopsyche wellsae*), were all higher in average abundance at main channel sites, compared to off-channel sites (SIMPER). This was expected, given the presence of flowing riffle habitats within the main channel, which were absent at off-channel sites. However, each of the aforementioned taxa contributed less than 3% to the overall variation between groups.

The nMDS ordination (Figure 16) displayed the differences in macroinvertebrate species assemblages between and within main channel and off-channel sites, where WWOCR3 was distinct from all other sites. This may have reflected a response of macroinvertebrate fauna to relatively poor water quality at this site (i.e. brackish water, low dissolved oxygen, elevated nutrients and/or elevated suspended sediment loads). BIOENV analysis indicated that five water quality variables (boron, iron, magnesium, N-NOx & turbidity) best influenced the variation in macroinvertebrate species assemblages (rho = 0.732, $p = 0.01$). Spearman rank correlations (correlation > 0.5) showed that emergent vegetation, algae, submerged vegetation and silt influenced the separation of WWOCR1 and WWOCR2 from main channel sites, whereas a variety of substrates (pebbles, sand, clay) and max. depth (m) influenced the separation of main channel sites from off-channel pools (Figure 16).

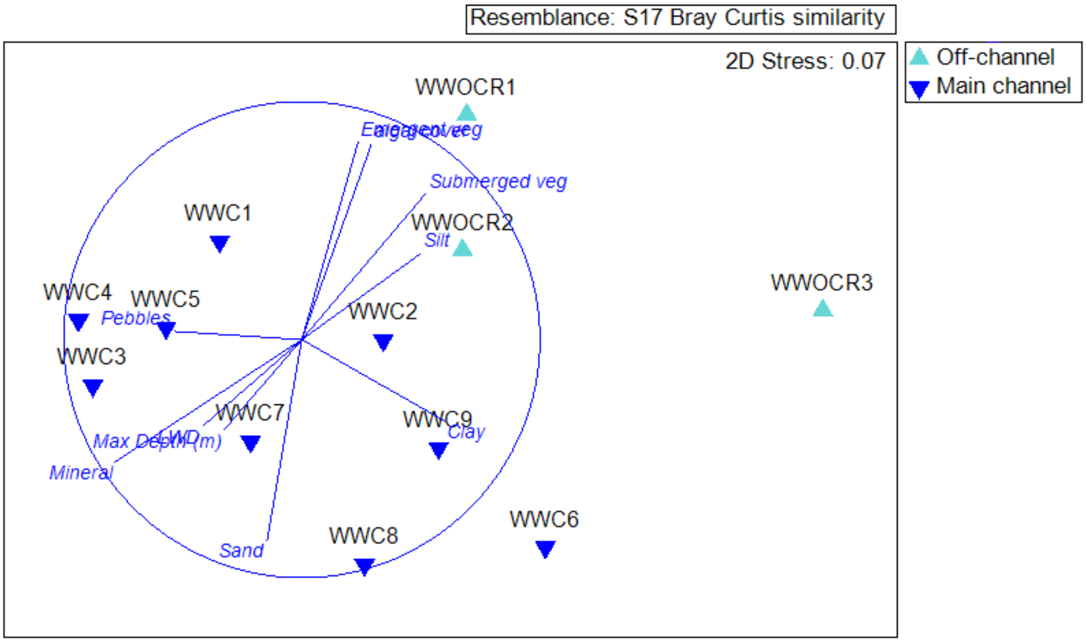

Figure 16. Unconstrained nMDS plot of macroinvertebrate species assemblages at off-channel (light blue) and mai channel (dark blue) Weeli Wolli Creek sites, with spearman rank correlations of habitat variables (> 0.5) as vector overlain.

4.6 Fish

4.6.1 Species composition

A total of 411 fish were caught, measured and released during the current study, of which 68 individuals were from off-channel sites, and 343 individuals were from main channel sites. Three of the 12 freshwater fish species known from the Pilbara were recorded; the western rainbowfish *Melanotaenia australis,* the spangled perch *Leiopotherapon unicolor,* and the Hyrtl's tandan (eel-tailed catfish) *Neosilurus hyrtlii.* Each of these species are common, ubiquitous and widespread across the Pilbara region.

Results reflected those of previous studies of freshwater fish in the vicinity of the Project. For example, WRM (2011), during bi-annual sampling of Marillana Creek between 2008 and 2011, recorded the same three species as recorded in the current study. Low diversity of fish fauna is common in the upper reaches of the Fortescue River and its tributaries (including WWC), in comparison to the lower Fortescue River and other catchments across the Pilbara (Morgan *et al.* 2009).

4.6.2 Species abundance

The western rainbowfish was the most common fish species of the study area, comprising 67% of all fish caught. This was mainly due to the high abundances of rainbowfish recorded at WWC1 and WWC2, where 105 and 85 individuals were caught, respectively (Figure 17). Rainbowfish abundance was relatively low at all other sites (i.e. < 28). No rainbowfish were caught or observed at WWC5 or WWC6 (Figure 17). Rainbowfish of the genus *Melanotaenia* are the most common freshwater fish of tropical Australian waterways (Allen *et al.* 2002). Rainbowfish are generally shoaling, omnivorous species, which utilise the entire water column to forage, and can occupy a range of hydrological habitats, from high velocity streams to stagnant pools (Allen *et al.* 2002, McGuigan *et al.* 2003).

A total of 78 spangled perch were recorded in the current study. The highest abundance of spangled perch was recorded at WWC1 (19 individuals), however, spangled perch were also relatively abundant at off-channel sites WWOCR1 (12 individuals) and WWOCR2 (15 individuals; Figure 17). Lowest spangled perch abundance was at WWC6 (one individual), and no spangled perch were recorded at either WWOCR3, WWC7 or WWC9 (Figure 17). Spangled perch are widespread throughout Australian inland waters, owing to their tolerance of extremes in water quality (Gehrke & Fielder 1988). For example, they are known to survive in waterbodies with dissolved oxygen concentrations of 1mg/L, temperatures from 5 - 44° Celsius, and salinities over 50,000 µS/cm (Gehrke & Fielder 1988). Further, this species is thought to aestivate in wet mud or under moist leaf litter in order to avoid desiccation during the dry season, when remnant pools recede or dry out (Allen *et al.* 2002).

Hyrtl's tandan was the least common species recorded in the study, comprising only 14% of fish caught. As with western rainbowfish and spangled perch, highest Hyrtl's tandan abundance was recorded at WWC1 (23 individuals), with the species also relatively abundant at WWC2 (18 individuals; Figure 17). Abundance of Hyrtl's tandan was relatively low (< 8 individuals) at all other sites, with no individuals recorded at WWC6, WWC7 or WWC9 (Figure 17). The Hyrtl's tandan is known to occupy a diverse range of habitats across northern Australia, including still or flowing water of streams, billabongs and pools (Allen *et al*. 2002).

In the current study, the upstream main channel sites WWC1 and WWC2, which experience permanent/semi-permanent flows due to dewatering discharge operations upstream, supported relatively high abundances of each fish species. The hydrological and habitat characteristics of WWC1 and WWC2 were considered favourable for fish populations, i.e., they were wide (20 – 40 m), relatively shallow (~0.8 m) and fast-flowing (~25 litres/sec), with good in-stream habitat complexity. As the downstream reaches are ephemeral and lack surface-water connectivity between pools, these likely support naturally small fish populations. Further, given the survey followed a high rainfall event, it is probable that fish did not have enough time to successfully colonise newly inundated sites prior to sampling, with consequent lack of in-stream habitat and prey animals at these sites (i.e. micro and macroinvertebrates) influencing low fish abundance (Figure 17).

Spangled perch were relatively abundant at WWOCR1 and WWOCR2 (Figure 17). In comparison, western rainbowfish and Hyrtl's tandan numbers were low at off-channel these sites. Predatory pressure from spangled perch, with lack of connectivity between pools preventing recolonisation, were likely the main causal factors influencing low rainbowfish and Hyrtl's tandan abundance at these sites. Further, dense emergent and submerged macrophytes made these sites more difficult to fish, which may have affected catch data (Figure 17). All fish species were low in abundance (or absent in the case of the spangled perch) at WWOCR3 (Figure 17). This was also likely due to the high density of aquatic macrophytes at this site hampering catch rates, rather than the influence of environmental variables or stochastic factors.

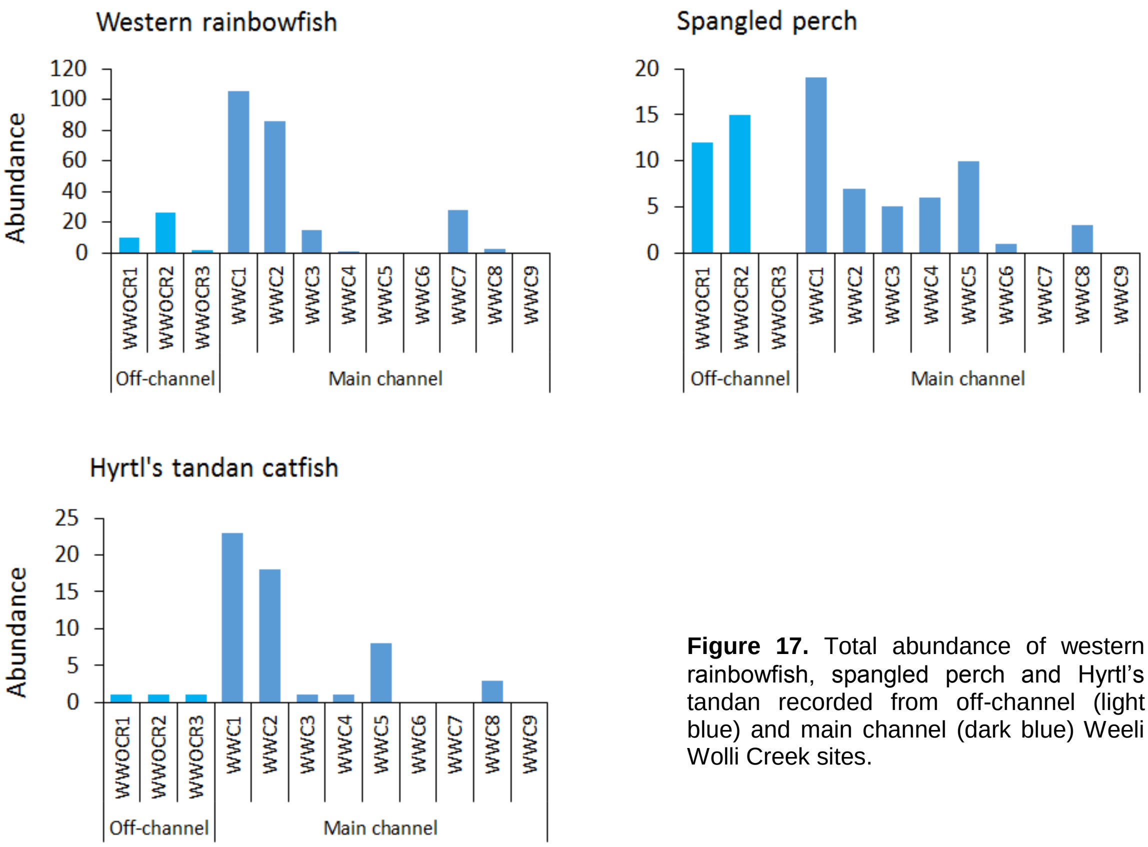

Figure 17. Total abundance of western rainbowfish, spangled perch and Hyrtl's tandan recorded from off-channel (light blue) and main channel (dark blue) Weeli Wolli Creek sites.

4.6.3 Age-class structures

The reproductive strategies of Pilbara fish species are ‘opportunistic’ and ‘periodic’, reflecting the seasonal yet unpredictable nature of rainfall and streamflow in the region (Beesley 2006). Breeding of many species occurs during the wet season, when there is increased connectivity between and within systems. During flood events, adults of most species travel upstream, where multiple spawning events are known to occur (Beesley 2006). In order to further examine population structures of fish in the study area, length-frequency data for each species were split into age-classes estimated from published literature (i.e. Lake 1971, Bishop *et al.* 2001, Morgan *et al.* 2002, Beesley 2006; Table 6).

Table 6. Age-class classifications for each fish species.

Species	Age-class	Size mm (SL)
Western rainbowfish	New recruit	< 30
	Juvenile	31-40
	Sub-adult	41-50
	Adult	>51
Spangled perch	New recruit	< 30
	Juvenile	31-50
	Sub-adult	51-70
	Adult	>71
Hyrtl's tandan	New recruit	< 30
	Juvenile	31-70
	Sub-adult	71-90
	Adult	>91

The population structure of western rainbowfish and Hyrtl's tandan at off-channel sites, and sites downstream of WWC2, were difficult to assess due to the low abundance of each species recorded. However, the populations of western rainbowfish at the two most upstream main channel sites (WWC1 & WWC2) appeared to be healthy, with individuals from all age classes represented, including new recruits (Figure 20). This indicates western rainbowfish are breeding in upstream reaches of main channel, where there is favourable streamflow and habitat characteristics for preproduction and predator avoidance.

Comparatively, no Hyrtl's tandan new recruits were recorded in the study area, and only four juvenile Hyrtl's tandan were recorded in total (all at WWC1; Figure 20). However, a variety of other age classes were present, particularly at WWC1 and WWC2 (Figure 20). Similarly, no spangled perch new recruits were recorded, either within the main channel or at off-channel sites (Figure 19). Sites which supported the most spangled perch juveniles were WWOCR1 and WWC1, with sub-adults and adults also represented at these sites (Figure 19). Adult spangled perch were the most common age-class captured across all other sites, although four sub-adults were recorded from off-channel site WWOCR2 (Figure 19).

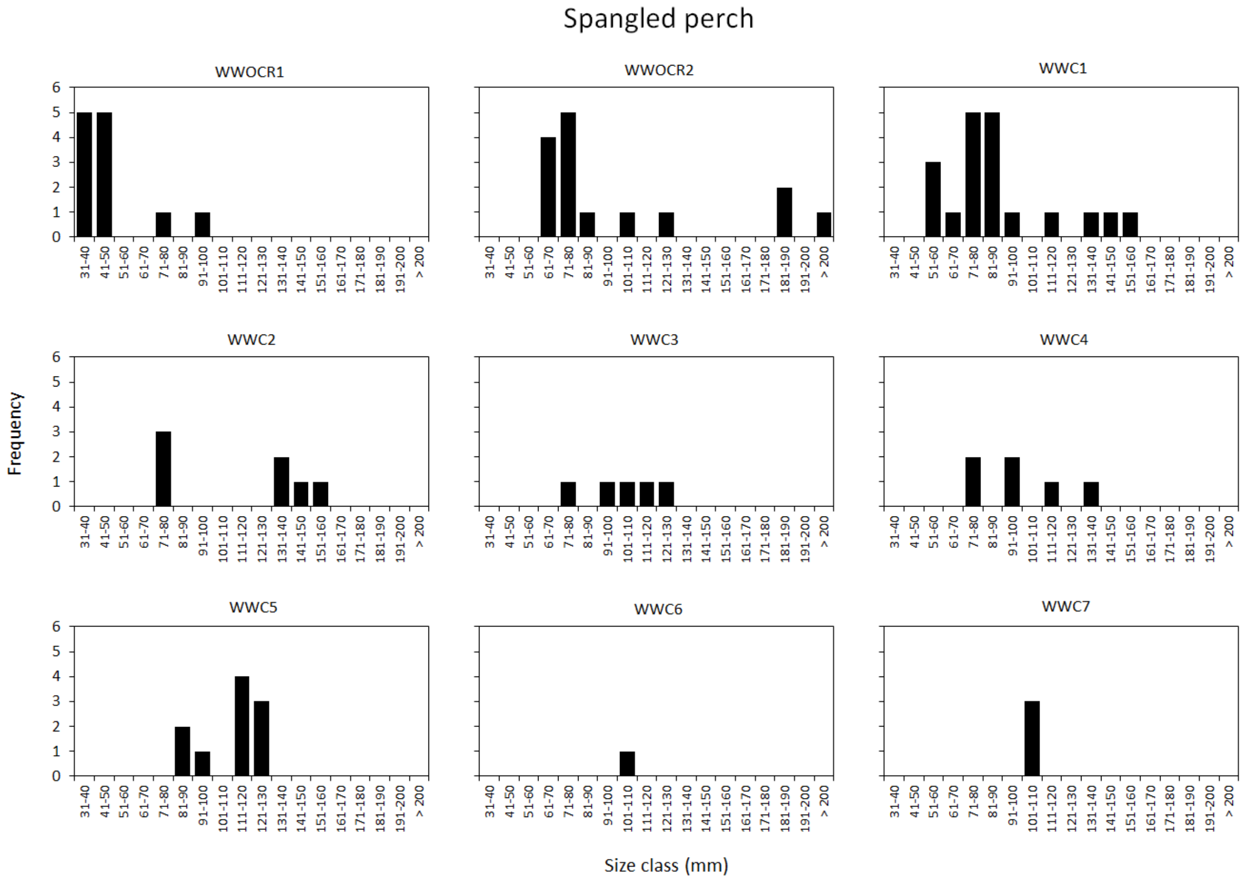

Figure 18. Age-class population structure of spangled perch at off-channel and main channel Weeli Wolli Creek sites.

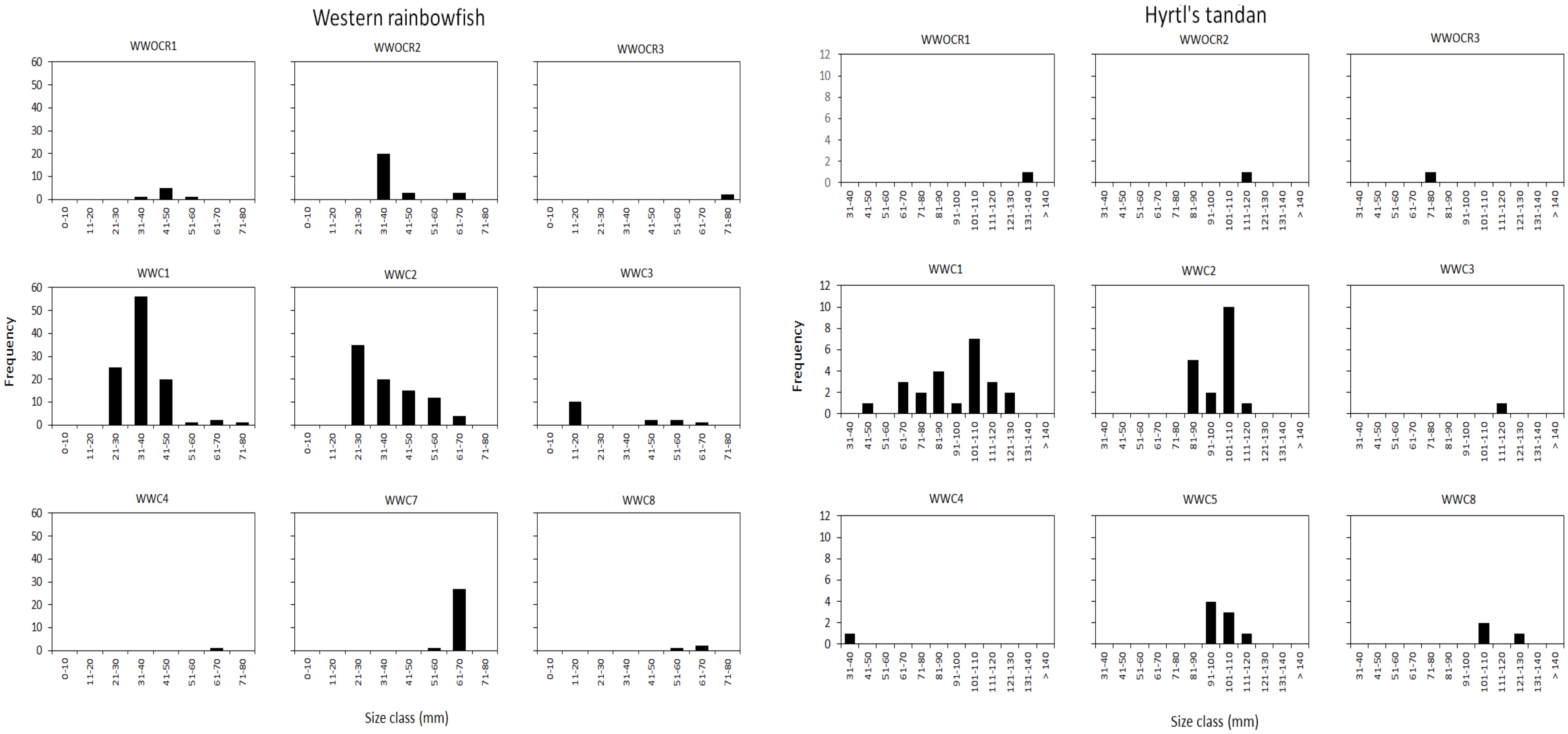

Figure 19. Age-class population structure of western rainbowfish (right) and Hyrtl’s tandan (left) at off-channel and main channel Weeli Wolli Creek sites

5 SYNOPSIS AND CONCLUSIONS

5.1 General

- Established dewatering discharge operations upstream of the Project (i.e. RTIO HD1, RTIO Yandicoogina, and BHBPIO Yandi) have resulted in semi-permanent / permanent surface water flows along Weeli Wolli Creek (main channel) immediately upstream, and adjacent to the tenement. Currently, surface flows as a result of dewatering discharge do not extend to sites further downstream along Weeli Wolli Creek (i.e WWC5 – WWC9). Flows at these downstream sites remains ephemeral in nature, with surface flow currently still rainfall dependent, generally lasting for a period of days to weeks.
- Rainfall in the weeks prior to sampling likely resulted in increased surface flows adjacent to, and downstream of the Project, with newly inundated pools observed at the time of sampling (evidenced by a lack of in-stream habitat, A.Harman pers. comm). Short residence time of surface waters (either flowing or pools) at downstream sites along WWC likely provided insufficient time for a number of aquatic invertebrates and fish to establish populations prior to sampling, resulting in lower taxa richness at these sites in comparison to permanently inundated sites upstream.

5.2 Water quality

- *In situ* spot measurements indicated surface waters were generally circum-neutral to slightly alkaline, relatively fresh (however, WWOCR3 was considered brackish), with dissolved oxygen concentrations ranging from low to supersaturated.
- Low dissolved oxygen concentrations recorded at off-channel ‘reference’ sites have the potential to adversely affect many aquatic fauna (invertebrates and fish). Low DO reflects the standing nature of these pools, with limited aeration due to lack of surface flows, along with the use of DO by aerobic heterotrophic bacteria oxygen as they decompose the organic matter (dead plant material).
- Nitrogen oxide (N_NO_x) concentrations at all main channel WWC sites, and total nitrogen (TN) and total phosphorus (TP) levels at WWOCR3, were in exceedance of respective default ANZECC/ARMCANZ (2000) TV for stressors for slightly disturbed ecosystems (equivalent to 95% protection of species). Additionally, nitrate (NO_3) levels at main channel site WWC8 exceeded the TV for toxicants for 95% protection of species. Elevated nutrient concentrations could reflect inherent natural variation in background levels, however, groundwater in the Pilbara is naturally elevated in nutrients, and levels recorded in the current study might be influenced by dewatering discharge activities upstream, and unrestricted livestock access to the creekline from pastoral stations nearby.
- Dissolved metal concentrations were generally low, however, dissolved boron (dB) and dissolved zinc (dZn) concentrations at a number of sites were above respective ANZECC/ARMCANZ (2000) TVs for toxicants for 95% protection of species. Exceedances were considered to be of little ecological concern, with naturally elevated dB levels widely reported in Pilbara creeklines, and dZn levels were below hardness-modified trigger values (HMTVs) when water hardness was taken into consideration.
- Multivariate analysis indicated overall water quality at off-channel site WWOCR3 was distinct in comparison to other off-channel and all main channel WWC sites. Water quality data indicated dB, dZn, TN, TP and EC concentrations were elevated, and exceeded respective default ANZECC/ARMCANZ (2000) TVs. Additionally, ionic composition, dCo, dFe, dMn, TSS and turbidity were elevated, relative to all other sites sampled.

5.3 Microinvertebrates

- Microinvertebrate fauna was abundant at off-channel sites, and particularly diverse at WWOCR1. In comparison, microinvertebrates were relatively depauperate at main channel WWC sites, particularly upstream sites which receive permanent surface flows from dewatering discharge operations. Multivariate analysis indicated microinvertebrate assemblage composition was significantly different between off-channel and main channel WWC sites, with periphytic taxa in particular dominant at off-channel site WWOCR1. Results broadly reflect the hydrological preferences of microinvertebrates, which generally favour standing or slow-flowing waters (lentic conditions).
- The majority of microinvertebrate taxa recorded at off-channel and main channel WWC sites were common, ubiquitous species, mostly Australasian or cosmopolitan in distribution. However, a number of regionally significant taxa were recorded, including;
    - the Pilbara endemic copepods *Australoeucyclops karaytugi* and *Mesocyclops holynskae*.
    - two cladocerans of the genus *Simocephalus*, which although cosmopolitan in distribution, are rarely collected from the Pilbara.
    - the cladoceran cf. *Anthalona* sp. (family Chydoridae). Specimens could not be identified to species level. It is unknown whether individuals represent a new Australian species, or a range extension for a previously described species (R. Shiel, University of Adelaide, pers. comm.). No species of this recently-erected genus have been described from Australia to date.
    - the copepod *Boeckella fluvialis.* This record was unexpected, as *B. fluvialis* is considered restricted to eastern Australia. Causation could not be determined for presence of this species in the current study.
- Although a number of microinvertebrate taxa of scientific value (Pilbara endemic, rarely collected, potential new species) were recorded in the current study, all species, except the unidentified cladoceran cf. *Anthalona* sp. have known local and/or regional distributions outside the Project area.

5.4 Hyporheic fauna

- The majority of taxa recorded from hyporheic samples were classified as stygoxene, and do not have specialised adaptations to groundwater or interstitial habitats. Only four taxa were considered to be restricted to the hyporheic zone (stygobitic fauna). These included the ostracod *Candonopsis tenuis*, and three amphipod species; Paramelitidae sp. B, Paramelitidae sp. D, and *Chydaekata* sp., which are considered to be short range endemics (SREs) and therefore of conservation significance. Taxa which were not true hyporheic fauna, but show some morphological adaption to groundwater environments (occasional hyporheos stygophiles), included the cyclopoid copepod *Microcyclops varicans*, and a number of aquatic segmented worms (Oligochaeta) and aquatic beetles (Coleoptera).
- Although a number of stygobitic and SRE hyporheic taxa were recorded in the current study, all taxa have known local and/or regional distributions outside the Project area.

5.5 Macroinvertebrates

- There was evidence of a longitudinal gradient in macroinvertebrate taxa richness along the main channel of WWC upstream of, and adjacent to, the Project. Taxa richness was greatest upstream at WWC1, declining with increasing distance downstream to WWC6. Regression analysis indicated a significant linear relationship between habitat diversity and macroinvertebrate richness within the main channel, with richness decreasing with lower in-stream habitat diversity.
- Macroinvertebrate diversity was relatively low at off-channel sites, compared to main channel sites. This was somewhat unexpected, given the documented habitat-richness patterns along the main channel, particularly considering habitat at off-channel sites was more diverse (macrophytes, algae, etc.) compared to that of main channel sites. Low taxa diversity at off-channel pools likely reflected hydrology and water quality (i.e. low dissolved oxygen, lack of surface flows, elevated ions & metals, etc.), with lack of surface flow in particular depriving flow-adapted taxa (e.g. caddisflies and mayflies) of specific habitat requirements (e.g. riffle zones).
- Multivariate analysis indicated macroinvertebrate assemblage composition was significantly different between off-channel and main channel WWC sites, with a number of flow-adapted taxa (e.g. mayflies and caddisflies) either absent, or recorded in reduced abundance at off-channel sites. This further reflected the influence of the standing nature of these off-channel pools, with lack of specific habitat (e.g. riffle zones) for these flow-adapted taxa.
- No conservation listed (IUCN Red List or DPaW priority) macroinvertebrate species were recorded in the study area. However, one SRE amphipod (Paramelitidae sp. B), and four Pilbara endemic Coleoptera (aquatic beetle) species were recorded, including *Limbodessus occidentalis* and the recently described *Haliplus fortescueensis.*
- Although a number of endemic/SRE macroinvertebrate fauna were recorded in the current study, no State, nationally or internationally listed species of conservation significance were recorded. However, *Haliplis fortescueensis*, collected at WWC9, appears largely restricted to ephemeral waterbodies within the Pilbara region. Should dewatering discharge result in permanent surface flows along WWC downstream of the Project, it is possible local populations of *H. fortescueensis* will be adversely affected.

5.6 Fish

- Three of the 12 freshwater fish species known from the Pilbara were recorded from the study area. These were the western rainbowfish *Melanotaenia australis,* the spangled perch *Leiopotherapon unicolor*, and the Hyrtl's tandan (eel-tailed catfish) *Neosilurus hyrtlii.* Low diversity of fish fauna is common in the upper reaches of the Fortescue River and its tributaries (including WWC), in comparison to the lower Fortescue River and other catchments across the Pilbara.
- Along the main channel of WWC, fish diversity was highest upstream (WWC1 & WWC2), reflecting the greater permanence of water, and higher diversity of in-stream habitat at this reach. Fish diversity and abundance were lower further downstream (e.g. WWC5 – WWC9), with short residence time of surface water following recent inundation, and consequent lack of in-stream habitat and food source, not allowing for successful fish colonisation prior to sampling.
- Additionally, low diversity and abundance of fish recorded at off-channel sites, compared to main channel sites, may in part reflect challenges whilst sampling due to dense macrophyte growth reducing the efficiency of fishing methods. However, it cannot be discounted that reduced diversity and abundance of fish reflects predation effects by larger spangled perch in the confined off-channel sites, and the lack of connectivity to main channel sites preventing recolonisation of these pools.

5.7 Conclusions

Data reported herein provide insight into water quality and aquatic fauna present at WWC main channel sites and off-channel pools during the late wet season, 2015. It should be noted that the current dataset does not account for any temporal and/or seasonal (wet and dry season) variation in water quality parameters and aquatic faunal assemblages, and hence, provides only a snapshot of ecosystem values at one point in time. Therefore, it is likely ecosystem values, both within the main channel of WWC and at off-channel pools within vicinity of the Project, are greater than reported in the current study.

Baseline water quality data indicated a number of parameters measured at off channel sites (and to a lesser degree main channel sites) were in exceedance of, and in some instances outside (i.e. below recommended range), default ANZECC/ARMCANZ (2000) TVs for toxicants/stressors, including; EC, daytime DO, pH, total N, total P, N-NO$_x$, dB and dZn. These differences could be related in part to the standing (lentic) nature of isolated off-channel pools, which showed evidence of impacts from unrestricted livestock access. Elevated nutrient and dissolved metal concentrations could reflect inherent natural variation in background levels. However, groundwater in the Pilbara is naturally elevated in nutrients and some dissolved metals (dB), and therefore, levels recorded in the current study might be influenced by unknown dewatering discharge activities upstream.

Aquatic invertebrate data indicated off-channel and main channel WWC sites support different (i.e. distinct) microinvertebrate and macroinvertebrate species assemblages, which likely reflect variation in habitat, water quality and hydrology between these ecosystem types. Although no conservation listed fauna were recorded in the current study, several regionally and/or scientifically important taxa were present, and stygobitic SRE taxa of conservation significance were collected at both off-channel and main channel WWC sites.

Along the main channel of WWC, macroinvertebrates and fish were generally more diverse and abundant at upstream sites, which possessed greater in-stream habitat, and permanence of surface flows due to the influence of dewatering discharge operations upstream. Comparatively, sites further downstream, which are more ephemeral in nature, and therefore only recently inundated prior to sampling, were relatively depauperate in macroinvertebrate and fish fauna.

Generally, microinvertebrate diversity and abundance was higher at off-channel sites, compared to main channel WWC sites, reflecting the preference of these fauna for still (lentic) conditions. Conversely, macroinvertebrate diversity was lower at off-channel pools, compared to main channel sites. These differences were influenced by the reduced abundance and/or absence of a number of fauna at off-channel sites, including mayflies and caddisflies, which are adapted to flowing (lotic) conditions, and which were common in the main channel. Lentic conditions are unsuitable for filter feeding species such as mayflies and caddisflies, with these taxa being replaced by a number of non-biting midge species at off-channel sites, which are adapted to living in benthic sediments and thrive in non-flowing conditions.

Although a number of stygobitic and SRE hyporheic, microinvertebrate, and macroinvertebrate taxa were recorded in the current study, the majority of these taxa have known local and/or regional distributions outside the Project area.

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APPENDICES

Appendix 1. Photographs of WWC sites sampled during March 2015

WWC1

WWC2

WWC3

WWC4

WWC5

WWC6

WWC7

WWC8

WWC9

WWOCR1

WWOCR2

WWOCR3

Appendix 2. ANZECC/ARMCANZ (2000) trigger values for the protection of aquatic systems in northern Australia

Table A2-1. Default trigger values for some physical and chemical stressors for tropical Australia for slightly disturbed ecosystems (TP = total phosphorus; FRP = filterable reactive phosphorus; TN = total nitrogen; NOx = total nitrates/nitrites; NH4+ = ammonium). Data derived from trigger values supplied by Australian states and territories, for the Northern Territory and regions north of Carnarvon in the west and Rockhampton in the east (ANZECC/ARMCANZ 2000).

	TP	*FRP*	*TN*	*NOx*	*NH_4^+*	*DO*	*pH*
	(μg L^{-1})	*(μg L^{-1})*	*(μg L^{-1})*	*(μg L^{-1})*	*(μg L^{-1})*	*% saturation^f*	
Aquatic Ecosystem							
Upland River^e	10	5	150	30	6	90-120	6.0-7.5
Lowland River^e	10	4	200-300^h	10^b	10	85-120	6.0-8.0
Lakes & Reservoirs	10	5	350^c	10^b	10	90-120	6.0-8.0
Wetlands^3	10-50^g	5-25^g	350-1200^g	10	10	90^b-120^b	6.0-8.0

b = Northern Territory values are 5µgL$_{-1}$ for NO$_x$, and <80 (lower limit) and >110% saturation (upper limit) for DO;
c = this value represents turbid lakes only. Clear lakes have much lower values;
e = no data available for tropical WA estuaries or rivers. A precautionary approach should be adopted when applying default trigger values to these systems;
f = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability;
g = higher values are indicative of tropical WA river pools;
h = lower values from rivers draining rainforest catchments.

Table A2-2. Default trigger values for salinity and turbidity for the protection of aquatic ecosystems, applicable to tropical systems in Australia (ANZECC/ARMCANZ 2000).

Salinity	*(µs/cm)*	*Comments*
Aquatic Ecosystem		
Upland & lowland rivers	20-250	Conductivity in upland streams will vary depending on catchment geology. The first flush may result in temporarily high values
Lakes, reservoirs & wetlands	90-900	Higher conductivities will occur during summer when water levels are reduced due to evaporation

Table A2-3. Trigger values for toxicants at alternative levels of protection. Values are in ug/L.

	Trigger values for freshwater Level of protection (% species)			
Compound	**99%**	**95%**	**90%**	**80%**
METALS & METALLOIDS				
Aluminium pH > 6.5	27	55	80	150
Aluminium pH < 6.5	ID	ID	ID	ID
Arsenic (As III)	1	24	94	360
Arsenic (As IV)	0.9	13	42	140
Boron	90	370	680	1300
Cadmium	0.06	0.2	0.4	0.8
Cobalt	ID	ID	ID	ID
Chromium (Cr III)	ID	ID	ID	ID
Chromium (Cr VI)	0.01	1	6	40
Copper	1	1.4	1.8	2.5
Iron	ID	ID	ID	ID
Manganese	1200	1900	2500	3600
Molybdenum	ID	ID	ID	ID
Nickel	8	11	13	17
Lead	1	3.4	5.6	9.4
Selenium (Se total)	5	11	18	34
Selenium (Se IV)	ID	ID	ID	ID
Uranium	ID	ID	ID	ID
Vanadium	ID	ID	ID	ID
Zinc	2.4	8	15	31
NON-METALLIC INORGANICS				
Ammonia	320	900	1430	2300
Chlorine	0.4	3	6	13
Nitrate	17	700	3400	17000

Appendix 3. Water quality parameters and habitat characteristics

Table A3 - 1. *In situ* water quality parameters recorded during March 2015 sampling. Highlighting indicates values were outside of ANZECC/ARMCANZ (2000) TVs.

	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Temp ^{0}C	28.1	28.4	27.4	28.7	31.6	27.6	27.8	30.8	31.3	26.6	29.5	27.5
pH	7.48	7.53	7.79	8.00	8.18	8.04	8.10	8.36	7.37	7.93	8.17	7.88
Redox	-46.1	-49.3	-63.5	-78.9	-88.3	-79.1	-83.2	-98.0	-40.8	-77.1	-87.7	-68.4
DO (%)	27.2	31.2	41.3	79.1	102.8	71.5	93.4	122.8	76.6	89.9	147.1	77.1
DO (mg/L)	2.21	2.31	3.22	6.19	7.58	5.58	7.43	9.17	5.69	7.11	11.20	6.06
EC (µS/cm)	718	967	1930	760	753	691	720	706	449	585	611	546

Table A3 - 2. Dissolved ions, metals and other water quality parameters recorded during March 2015 sampling. Highlighting indicates values were in exceedance of ANZECC/ARMCANZ (2000) TVs.

	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Al	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Alkalinity	243	297	386	254	261	231	238	234	148	189	202	171
As	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B	0.3	0.34	0.39	0.26	0.27	0.28	0.27	0.26	0.14	0.21	0.23	0.16
Ba	0.041	0.051	0.098	0.031	0.03	0.03	0.032	0.03	0.031	0.028	0.023	0.031
CO3	<1	<1	<1	<1	<1	<1	<1	8	<1	<1	8	<1
Ca	43.4	56.5	72.9	46.4	45.4	42.4	45.9	42	35.1	39.8	39	37.9
Cd	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cl	70	108	374	74	74	65	72	70	41	55	58	55
Co	0.0001	<0.0001	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Cr	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Cu	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Fe	0.11	0.036	0.2	0.009	0.01	0.011	0.016	0.008	0.013	<0.005	0.006	0.006
HCO3	296	362	470	309	318	282	290	269	180	230	230	208
Hardness	260	340	470	290	280	260	260	250	150	210	220	200

	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
K	7.8	9.3	34.2	7.4	7.4	7.1	7.2	7.2	5.3	6.3	6.5	6
Mg	36.4	47.8	68.8	41.1	40.1	36.6	36.5	34.1	15.4	25.7	30.2	24.7
Mn	0.054	0.023	0.23	0.003	0.002	<0.001	0.005	0.001	0.004	<0.001	<0.001	0.006
Mo	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N_NH3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	<0.01	<0.01
N_NOx	<0.01	0.01	<0.01	0.15	0.12	0.14	0.05	0.07	0.16	0.14	0.23	0.14
Total N	0.11	0.11	1.2	0.29	0.26	0.29	0.24	0.2	0.55	0.27	0.34	0.35
Na	51.2	68	218	50.9	49.3	47.1	48.2	46.1	33.9	40	42.7	36.2
Ni	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
OH	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total P	0.011	0.011	0.11	<0.010	<0.010	<0.010	<0.010	0.01	0.01	<0.010	0.014	<0.010
Pb	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
S	11	19	21	14	14	13	14	13	8.7	11	11	11
SO4_S	33.8	56.3	64.4	43.3	42.3	39.3	41.3	38.3	26.2	32.9	34.4	31.8
Se	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
TSS	2	2	13	<1	2	2	2	<1	2	2	<1	2
Turbidity (NTU)	1.3	0.6	2.6	1.1	1.4	<0.5	<0.5	<0.5	0.6	<0.5	0.5	0.7
U	0.0005	0.0015	0.001	0.0007	0.0007	0.0008	0.001	0.0009	0.0002	0.0007	0.0007	0.0007
V	0.0005	0.0011	0.0014	0.0028	0.0031	0.003	0.0035	0.0038	0.0018	0.0033	0.0041	0.0029
Zn	0.002	0.004	0.031	0.004	0.006	0.007	0.002	0.003	0.003	0.007	0.004	0.005

* all values are in mg/L, unless specified otherwise

Table A3 - 3. Habitat and substrate data recorded *in situ*.

	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Bedrock %	0	0	0	0	0	0	2	0	5	0	0	10
Boulders %	1	2	0	0	0	0	5	0	2	0	2	5
Cobbles %	5	20	0	5	5	23	15	5	11	5	18	5
Pebbles %	25	60	0	50	30	45	35	28	25	63	40	10

	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Gravel %	57	11	0	40	58	20	36	60	20	15	30	15
Sand %	2	5	0	3	5	10	5	5	15	5	10	20
Silt %	10	2	20	2	2	2	2	2	2	2	0	20
Clay %	0	0	80	0	0	0	0	0	20	10	0	15
Mineral %	23	10	39	69	69	74	83	74	60	76	76	70
Emergent veg %	20	60	40	5	5	5	3	2	0	0	0	0
Submerged veg %	10	5	5	2	0	0	0	0	0	0	2	0
Floating Veg %	0	0	0	0	0	0	0	0	0	0	0	0
Algal cover %	30	15	10	2	3	1	2	5	1	2	0	0
Detritus %	10	2	2	3	1	3	5	1	20	5	5	25
Trailing veg %	2	5	2	2	2	2	2	2	2	2	2	2
LWD %	5	3	2	15	20	15	5	15	15	15	15	3
Other (roots) %	0	0	0	2	0	0	0	1	2	0	0	0
Approx. velocity (litres/second)	< 3	No flow	No flow	25	25	25	25	25	No flow	< 3	25*	No flow
Max. Depth	0.5	2	0.7	0.8	0.8	1.2	1.7	1	1	1.6	1.2	1.8
Length (m)	40.00	90.00	40.00	20.00	30.00	100.00	20.00	20.00	70.00	70.00	200.00	200.00
Width (m)	15.00	20.00	15.00	20.00	40.00	20.00	35.00	25.00	10.00	15.00	30.00	7.50
Habitat diversity	7	7	7	7	6	6	6	6	5	5	5	4
Substrate diversity	5	6	2	5	5	5	7	5	8	6	5	8

* Site was sampled on a day following substantial rainfall, and was flowing for less than 24 hrs.

Appendix 4. Microinvertebrate fauna data (total abundance) collected during March 2015 sampling.

Higher taxon	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Protista													
Ciliophora													
	Euplotes sp.		1										
Rhizopoda													
Arcellidae													
	Arcella bathystoma	1	3										
	Arcella discoides	3	5			1	1			1		1	
	Arcella hemisphaerica		4										
	Arcella megastoma	1											
	Arcella sp. a [tiny, blue]											1	
	Arcella sp. b [sm, disc, br.]	1											
	Arcella sp. c [med., domed, br.]	1											
	Centropyxidae												
	Centropyxis aculeata												1
	Centropyxis ecornis	6								1			
	Centropyxis sp. [sm, br]						2				1		
	Difflugiidae												
	Difflugia cf. globulosa	5											
	Difflugia sp. a [sm. spher.]		2								2	1	
	Difflugia sp. b [sm. pyrif.]	16											
	Difflugia sp. c [lg. glob.]	19											
	Difflugia sp. d [med. ov.]	1				1							
Lesquereusiidae													
	Lesquereusia spiralis	21										3	1
	Trigonopyxidae												

Higher taxon	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
	Cyclopyxis kahlii	2											
Rotifera													
Bdelloidea													
	indet. bdell a [sm.]	1											
	indet. bdell b [lg.]	14	8										
Monogononta													
Asplanchnidae													
	Asplanchnopus hyalinus		*										
Brachionidae													
	Platyias quadricornis												1
Dicranophoridae													
	Dicranophorus epicharis	1											
Euchlanidae													
	Tripleuchlanis plicata	10	2										2
	Euchlanis cf. meneta									2	20		8
Flosculariidae													
	Sinantherina procera	3	171		1								
Lecanidae													
	Lecane aculeata	2										1	
	Lecane cf. braumi											1	
	Lecane bulla	20		*	1							7	
	Lecane curvicornis		3									2	
	Lecane ludwigii	3											
	Lecane luna	1											
	Lecane lunaris	2										2	
	Lecane noobijupi	2											1
	Lecane cf. obtusa	2											
	Lecane papuana	1										1	
	Lecane rhenana	1											
	Lecane rhytida	3											
	Lecane thalera	1											

Higher taxon	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
	Lecane unguitata											2	
	Lecane (M.) a												
	Lecane (M.) b					1							
	Lecane (s. str.)												
Lepadellidae													
	Colurella sp.	1											
	Lepadella sp.										1		
	Testudinellidae												
	Testudinella patina	2											
Cladocera													
Chydoridae													
	Alona sp.						1					1	
	cf. Anthalona sp.					2				1	4		
	Armatalona macrocopa					1							
	Chydorus sp.											1	
	Karualona karua												1
Daphnidae													
	Simocephalus exspinosus				1								
	Simocephalus gibbosus				1								
	Simocephalus sp. [juv]			*									
	Ilyocryptidae												
	Ilyocryptus sp. [juv]				1								
	Macrotrichidae												
	Macrothrix sp. [juv]										1	1	2
Moinidae													
	Moina micrura			*									
Copepoda													
	copepodite	4	2	13	3	7	2		1	2	3	1	3
	nauplii	7		191		5		2	1	1	7	3	6
	indet. adult a [med]												2

Higher taxon	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Calanoida													
	Boeckella fluvialis												1
Cyclopoida													
	Australoeucyclops karaytugi					*							
	Microcyclops varicans	1	*	1			1	2				2	
	Mesocyclops holynskae			*									
Ostracoda													
	indet. juv.				6	8			1	1			
Cyprididae													
	Cypretta sp. [juv.]						1						
	cf. cypridopsid	25											
Darwinulidae													
	Vestalenula sp.	3											
Limnocytheridae													
	Limnocythere sp.					1					1	1	
	Richness	**35**	**14**	**11**	**8**	**11**	**6**	**2**	**3**	**7**	**9**	**18**	**12**
	Total abundance	**187**	**201**	**205**	**14**	**27**	**8**	**4**	**3**	**9**	**40**	**32**	**29**
	Portion sample counted:	29%	6.4%	0.2%	100%	100%	100%	100%	100%	100%	100%	100%	100%

* = in scan of tray after initial count

Appendix 5. Hyporheic fauna data recorded during March 2015 sampling. Values are LOG_{10} abundance categories, where 1 = 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000. Hyporheic Classifications: Stygobitic (S), Occasional hyporheous stygophile (O), Possible hyporheic (P), Stygoxene (X), and Unknown (U).

Higher taxon	Lowest taxon ID	Classification	WWOCR1	WWOCR2	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Arachnida													
Astigmata													
	Astigmata sp.	X			1								
Mesostigmata													
	Mesostigmata sp.	X					1	1					
Trombidiformes													
	Hydracarina sp.	P					2	1	1				
	Acarina sp.	X	1	1				1	2			1	
Entognatha													
Entomobryomorpha													
	Entomobryoidea sp.	O							1	2		1	
Poduromorpha													
	Poduroidea sp.	O	2				2	1	3		1		
Symphypleona													
	Symphypleona sp.	O					2	1	3				
Insecta													
Coleoptera													
Dytiscidae													
	Allodessus bistrigatus	X									1		
	Bidessini sp.	X				1							
	Dytiscidae sp. (L)	X						1					
	Hydrovatus sp. (L)	X							1				
	Limbodessus compactus	X									1		
	Limbodessus occidentalis	O	1										

Higher taxon	Lowest taxon ID	Classification	WWOCR1	WWOCR2	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
	Tiporus sp. (L)	X									2		
Hydraenidae													
	Hydraenidae sp.	O						2					
Hydrophilidae													
	Paracymus sp. (L)	X						1					
Scirtidae													
	Scirtidae sp. (L)	O				3							
Staphylinidae													
	Staphylinidae sp.	X					2						
Diptera													
Cecidomyiidae													
	Cecidomyiidae sp.	X					1	1					
Ceratopogonidae													
	Ceratopogonidae sp. (P)	X	1									1	1
	Ceratopogoninae sp.	X	2	2	2	3	2	3	2	2	2		2
	Dasyheleinae sp.	X							2				
Chironomidae													
	Ablabesmyia hilli	X				2					2		
	Chironomidae sp. (P)	X								1			1
	Chironomini sp. (WWC34)	X				1		2					
	Cladopelma curtivalva	X				2			1		1		
	Cladotanytarsus sp. (WWTS4)	X				2			1		2		1
	Cricotopus albitarsis	X									1		1
	Cryptochironomus griseidorsum	X				2			1				
	Dicrotendipes sp. 1	X				2					2	1	1
	Dicrotendipes sp. 2	X				2		2			3	2	3
	Larsia albiceps	X				3					3		2
	Paramerina sp. (WWT1)	X		1		1			2		1		1
	Paramerina sp. 2	X						1	2		3		
	Paratanytarsus sp. (WWTS2)	X											2

Higher taxon	Lowest taxon ID	Classification	WWOCR1	WWOCR2	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
	Polypedilum sp. 1	X										1	
	Polypedilum sp. 2	X				2			1		1		
	Polypedilum watsoni	X											1
	Procladius sp. (WWT5)	X				2							
	Rheotanytarsus sp. 1	X				1							1
	Skusella subvittata	X				2							
	Tanytarsus sp. (WWTS1)	X		2		3		2	2		2	2	2
	Thienemanniella sp. (WWO4)	X									1		
Dolichopodidae													
	Dolichopodidae sp.	X						1					
Tipulidae													
	Tipulidae sp.	X								2			
Ephemeroptera													
Baetidae													
	Baetidae sp.	X							2		3		
	Cloeon sp. Red Stripe	X									2		
Caenidae													
	Caenidae sp.	X							2		3		
	Tasmanocoenis sp. M	X									2		
	Tasmanocoenis sp. P/arcuata	X									3		
Odonata													
Libellulidae													
	Diplacodes haematodes	X									1		
Trichoptera													
Leptoceridae													
	Leptoceridae sp.	X				2							
Malacostraca													
Amphipoda													
Paramelitidae													
	Chydaekata sp.	S	1										

Higher taxon	Lowest taxon ID	Classification	WWOCR1	WWOCR2	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
	Paramelitidae sp.	S	3	3		3							
	Paramelitidae sp. B	S	3	2									
	Paramelitidae sp. D	S				1							
Oligochaeta													
	Oligochaeta sp.	U				1			1				
Tubificida													
Naididae													
	Allonais paraguayensis	P				1		1					
	Allonais pectinata	P						2					
	Allonais ranauana	P										1	
	Dero sp.	P									1		
	Naididae sp.	P						1			3		
	Naidinae sp.	P					2		2				2
	Pristina leidyi	P					1	2	2			2	1
	Pristina sp.	P									2		
Phreodrilidae													
	Phreodrilidae sp.	P		2									
Nematoda													
	Nematoda sp.	X	1										
Cladocera													
Macrotrichidae													
	Macrothrix sp.	X									2	1	
Copepoda													
Cyclopoida													
Cyclopidae													
	?Diacyclops sp. [3 -seg P1-4]	X		1									
	Metacyclops sp.	X							3			1	
	Microcyclops varicans	O	2			3		3			3	3	3
	immature copepodites/nauplii	U					2			1			

Higher taxon	Lowest taxon ID	Classification	WWOCR1	WWOCR2	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Ostracoda													
Candonidae													
	Candonopsis tenuis	S				2							
Darwinulidae													
	Vestalenula sp.	U					1						
		Richness	**10**	**8**	**2**	**24**	**11**	**20**	**21**	**5**	**28**	**12**	**16**

Appendix 6. Macroinvertebrate fauna data recorded during March 2015 sampling. Values are LOG_{10} abundance categories, where 1 = 1 individual, 2 = 2-10 individuals, 3 = 11-100, 4 = 101-1000.

Higher taxon	Family	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
Arachnida														
Trombidiformes		Hydracarina sp.	3	2		3	1	2	1	2		3		2
		Trombidioidea sp.			1									
		Acarina sp.										1		
Entognatha														
Entomobryomorpha		Entomobryoidea sp.		2	2						2			
Poduromorpha		Poduroidea sp.		1										
Symphypleona		Symphypleona sp.				2				1				
Gastropoda														
Hygrophila	Lymnaeidae	Bullastra vinosa		1		2	2		1			1	1	
	Planorbidae	Gyraulus sp.	2	3	1	3	3	2	2	2	1	2		
Insecta														
Coleoptera	Curculionidae	Curculionidae sp.							2					
	Dytiscidae	Batrachomatus sp. (L)						1						
		Bidessini sp. (L)	2		1									
		Cybister sp. (L)			2								1	
		Hydroglyphus grammopterus			2			1						
		Hydroglyphus leai	2											
		Hydroglyphus orthogrammus						2				1		1
		Hydrovatus sp. (L)	2		1									
		Hyphydrus lyratus												1
		Hyphydrus sp. (L)			1									
		Laccophilus clarki					1							
		Laccophilus sharpi									1			1
		Laccophilus sp. (L)			3									
		Limbodessus compactus									1			2

Higher taxon	Family	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
		Limbodessus occidentalis	1						1					
		Onychohydrus sp. (L)	1			2								
		Platynectes decempunctatus var. decempunctatus						2	2					
		Platynectes sp. (L)				1								
		Tiporus sp. (L)						1		1		2	1	1
		Tiporus tambreyi				1			2			1		
	Elmidae	Austrolimnius sp.						1		1				
		Elmidae sp. (L)					1							
	Gyrinidae	Dineutus australis					1							
		Dineutus australis (L)									2			
		Dineutus sp.												1
		Dineutus sp. (L)						1						
		Macrogyrus paradoxus				2								
	Haliplidae	Haliplus fortescueensis												2
	Hydraenidae	Hydraena sp.				3	2		2					
		Hydraena sp. (L)											1	
		Limnebius sp.							1			1		
	Hydrochidae	Hydrochus sp.				2	2	2		1	1	2		
		Hydrochus sp. (L)						1						
	Hydrophilidae	Berosus dallasae	1					2	1					
		Berosus sp. (L)			1					1		1	2	1
		Enochrus sp. (L)						1	1					
		Helochares sp.						2				2		
		Helochares sp. (L)	2	2	1	2			1		1			
		Helochares tatei												1
		Laccobius billi							1					
		Paracymus sp. (L)					1		2	1				
		Regimbartia attenuata (L)				1								
		Regimbartia sp. (L)			2						1			
	Noteridae	Neohydrocoptus subfasciatus										2		
	Scirtidae	Scirtidae sp. (L)		1	1	2	3	3	2	1				

Higher taxon	Family	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
	Spercheidae	Spercheus sp. (L)			2									
Diptera	Cecidomyiidae	Cecidomyiidae sp.											1	
	Ceratopogonidae	Ceratopogonidae sp. (P)	2		3						2		1	
		Ceratopogoninae sp.	2	2			2	1	2			2	2	2
		Dasyheleinae sp.	3	2	3	1	1							1
	Chironomidae	Ablabesmyia hilli				2	2			2	3	2	3	2
		Ablabesmyia notabilis									2			
		Chironomidae sp. (P)	2	2	3	2	2	2	2	3	3	3	3	2
		Chironomini sp. (WWC34)					2							
		Chironomus sp. (WWC3)	3	3	4		2				3		3	2
		Cladopelma curtivalva	2			2	2	1	2			2		2
		Cladotanytarsus sp. (WWTS4)	3	2		3	3	1	2	2	2	2		
		Coelopymia pruinosa					2							
		Corynoneura sp. (WWO5)				3								
		Cricotopus albitarsis				3		3	3			3	3	
		Cryptochironomus griseidorsum					2		2			3	2	2
		Dicrotendipes sp. 1				3		3	3	2	3	3	2	2
		Dicrotendipes sp. 2				3		2	3	3		3	3	2
		Harnischia sp. (WWC22)					2							2
		Kiefferulus intertinctus			2									
		Larsia albiceps	3	4	2	3	3	3	3	3	3	3	3	3
		Orthocladiinae sp. (WWO7)												2
		Parachironomus sp. K2		2										
		Paracladopelma sp. K2						2						
		Paramerina sp. (WWT1)		2		3	2	2	3	3		2	1	2
		Paramerina sp. 2	2	2	3	2	2	1			3	2	1	3
		Paratanytarsus sp. (WWTS2)	3	3	3		2							2
		Paratendipes sp. K1		2										
		Polypedilum sp. 1	2	2	3	2	2			2				2
		Polypedilum sp. 2					2				2			2
		Polypedilum watsoni	2					2						
		Procladius sp. (WWT5)					3				3	2	3	3

Higher taxon	Family	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
		Rheocricotopus sp. (WWO1)				2		2	3	3				
		Rheotanytarsus sp. 1	2	2		3	2	3	4	3		3	3	2
		Skusella subvittata					3				3		3	2
		Tanytarsus sp. (WWTS1)	4	3	3	3	3	2	3	3	4	3	3	3
		Thienemanniella sp. (WWO4)				4		3	3	3		2		
		Thienemannimyia sp. (WWT2)				2		1						
	Culicidae	Anopheles sp.			2				1		2			
		Culex sp.		3	3									
		Culicidae sp. (P)			3									
	Dolichopodidae	Dolichopodidae sp.						2						
	Simuliidae	Simuliidae sp.				2		2	3	2		2		
		Simuliidae sp. (P)							1					
	Stratiomyidae	Stratiomyidae sp.	2			1								
	Tabanidae	Tabanidae sp.						1						
	Tipulidae	Tipulidae sp.						1						
Ephemeroptera	Baetidae	Baetidae sp.	2	3	2	3	3	2	3	3	2	2	3	3
		Cloeon fluviatile	1	2		2					1		2	
		Cloeon sp.			2		3				2			
		Cloeon sp. Red Stripe		3	2		2	3	1		3	3	3	3
		Offadens sp. G1WA2				2		3	2	3			3	
		Pseudocloeon hypodelum				3			2					
	Caenidae	Caenidae sp.	2	2		3	3	3		1		3	2	2
		Tasmanocoenis sp.							2	3	3			
		Tasmanocoenis sp. P/arcuata	1	2		3	3	3	3	3	3	3		2
Hemiptera	Belostomatidae	Diplonychus sp.	2	1	3	3	2	2	1	1	2	2	3	1
	Corixidae/Micronectidae	Corixidae/Micronectidae sp.				2			1					1
	Gerridae	Gerridae sp.		2		2			2	1				
		Limnogonus fossarum gilguy	2	2		3		2	2	2				1
		Limnogonus sp.	1		2									
	Hebridae	Hebridae sp.	2											
		Merragata hackeri	1			2	1					2		
	Mesoveliidae	Mesovelia hungerfordi				2								

Higher taxon	Family	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
		Mesovelia vittigera				2		1					1	
	Micronectidae	Micronecta gracilis				1								
		Micronecta paragoga				1								
		Micronecta robusta							2					
		Micronecta sp.	1		2								1	
	Nepidae	Ranatra sp.					1							
	Notonectidae	Anisops hackeri					1							
		Anisops sp.												1
		Notonectidae sp.			2		1						1	
	Pleidae	Paraplea sp.				3					2	2		
		Pleidae sp.											2	
	Veliidae	Microvelia peramoena				1						1		
		Veliidae sp.				1						2		
Lepidoptera	Crambidae	Acentropinae sp.				1	1	3					1	
		Margarosticha sp. 3				1	1	2	2	2				
		Margarosticha sp. WRM01							1					
		Parapoynx sp.	1											
Odonata		Anisoptera sp.	2	2		3	3	2	2	2	3	3	3	3
		Zygoptera sp.		2	2	3	1				2	2		2
	Aeshnidae	Aeshnidae sp.			2									
		Hemianax papuensis			2						1			
	Coenagrionidae	Agriocnemis sp.					2							
		Argiocnemis rubescens	2	1		2	2	1		1				
		Ischnura aurora		1	2	2	1					1	1	1
		Pseudagrion aureofrons		1		2								1
		Pseudagrion microcephalum									1			
	Gomphidae	Austrogomphus gordoni										1		
	Libellulidae	Diplacodes bipunctata			2					2				
		Diplacodes haematodes	2	1	1	2	2	1	2	2				1
		Diplacodes sp.									1			
		Orthetrum caledonicum				1	2				2		2	1
		Pantala flavescens										1		

Higher taxon	Family	Lowest taxon ID	WWOCR1	WWOCR2	WWOCR3	WWC1	WWC2	WWC3	WWC4	WWC5	WWC6	WWC7	WWC8	WWC9
		Tramea sp.			1									
Trichoptera	Ecnomidae	Ecnomus sp.				1								
	Hydropsychidae	Cheumatopsyche sp.				1			1					
		Cheumatopsyche wellsae				2	2	3	3	3			1	
	Hydroptilidae	Hellyethira sp.				2	1			1	1	2		2
		Orthotrichia sp.				1		1						
	Leptoceridae	Leptoceridae sp.					2							
		Leptocerus sp.					1							
		Oecetis sp.	1	1		1	1							
		Setodes sp.		1										
		Triplectides ciuskus seductus		2		3	2					1		
	Philopotamidae	Chimarra sp.					1	3	2	2			1	
	Polycentropodidae	Paranyctiophylax sp. AV5		1										
Malacostraca														
Amphipoda	Paramelitidae	Paramelitidae sp. B					1							
Oligochaeta		Oligochaeta sp.	2	1			2	1	2					
Tubificida	Naididae	Allonais paraguayensis	2											
		Allonais pectinata	3	1	2	2		1		2	2		1	1
		Allonais ranauana					1							
		Naidinae sp.	3	2		2	1			2		1		1
		Nais variabilis	2			1	1			2				
		Pristina leidyi	2	1						1				
		Pristina sp.					3							
	Phreodrilidae	Phreodrilidae sp.						2						
		Richness	**45**	**44**	**42**	**70**	**63**	**55**	**51**	**42**	**38**	**46**	**39**	**48**