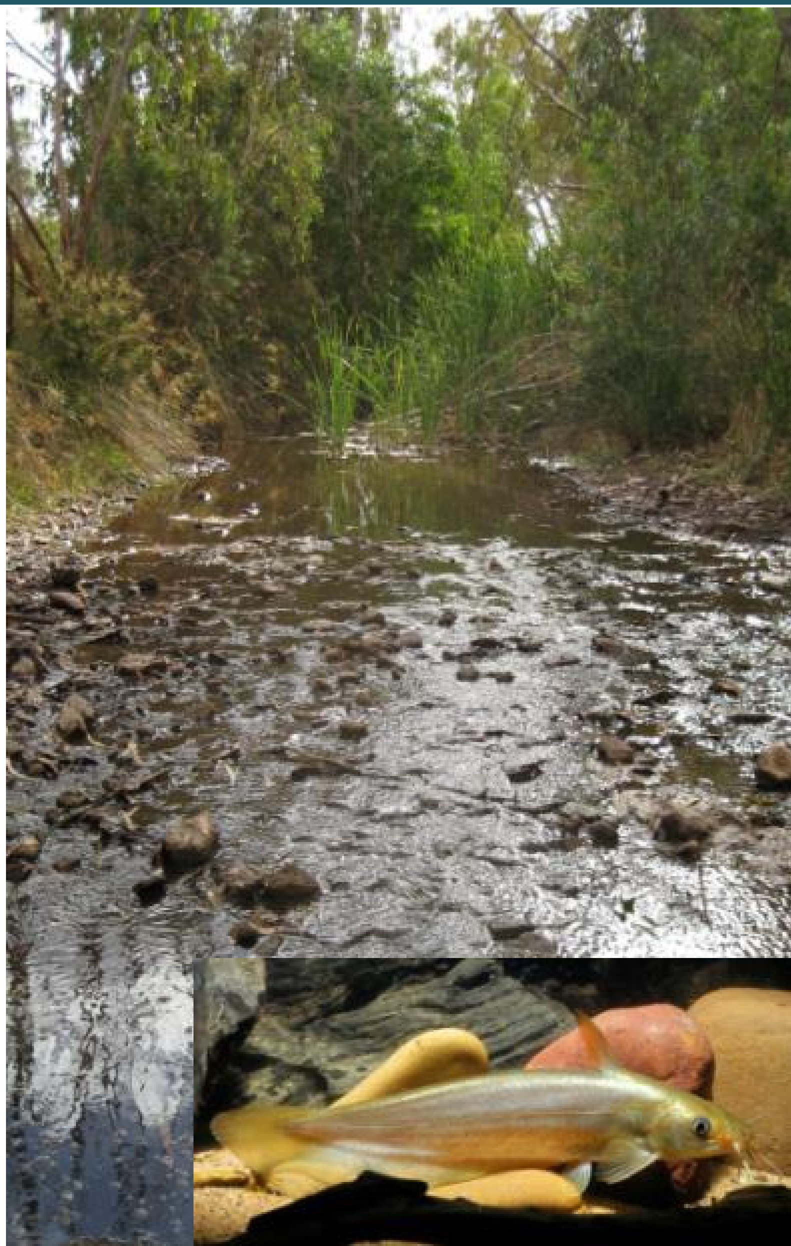
RIO TINTO
IRON ORE

YANDICOOGINA: JSW & OXBOW MINE DEVELOPMENT

AQUATIC MANAGEMENT
FINAL REPORT



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Disclaimer

This document has been printed on 'Reflex Green Recycled Paper'.

Frontispiece (top to bottom): Marillana Creek at WRM's aquatic sampling site 1-5, downstream of BHPBIO's discharge outlet and upstream of RTIO's Yandicoogina (photo by Isaac Cook/WRM October 2009); Marillana Creek at WRM's aquatic sampling site 1-1, immediately downstream of BHPBIO's discharge (photo by Jess Delaney/WRM October 2009); and Hyrtyl's tandan catfish, *Neosilurus hyrtlii* (photo taken and provided by Mark Allen ©).

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1 INTRODUCTION

1.1 Project background

Hamersley Iron Pty. Ltd. proposes to develop new deposits Junction South West (JSW) and Oxbow at Yandicoogina. Mining of the nearby Junction Central (JC) and Junction South East (JSE) deposits at the Yandicoogina minesite has been in operation since 1998 and 2006, respectively. Mining of these deposits is expected to continue until approximately 2014 at JC and 2020 at JSE. As part of these operations, Hamersley Iron de-water pit areas and discharge excess water into Marillana Creek. Additional dewatering and discharge operations will be necessary as part of the JSW and Oxbow developments as around 95% of the ore occurs below the water table (MWH 2010). In addition, realignment of Marillana Creek will likely be necessary as a result of the future development of JSW. There are potential impacts to the aquatic ecosystem of Marillana Creek, as well as downstream Weeli Wolli Creek, as a result of these operations. Therefore, Hamersley Iron Pty. Ltd. commissioned *Wetland Research and Management* to undertake a desktop review of the potential impacts to aquatic ecosystem health associated with each of the possible operations (dewatering, discharge, channel realignment, and mine closure), and provide recommendations for assessment of such impacts and future management and monitoring.

1.2 Study area

The Yandicoogina minesite is located approximately 90 km northwest of Newman in the Pilbara Region of Western Australia (Figure 1). The proposed JSW and Oxbow deposits are situated immediately west of the existing JC mine (Figure 2).

The regional topography of the Newman area 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 number of temporary creeklines traverse the Yandicoogina mine area, including Marillana, Yandicoogina, Phil's and Weeli Wolli creeks. Marillana Creek drains eastward before joining Weeli Wolli Creek (Figure 3). Historically, streamflow was seasonal, with flows usually occurring in response to heavy rainfall events. However, the hydrological regime has been altered due to discharge operations at BHPBIO's Yandi and RTIO's Yandicoogina minesites. On average, Marillana Creek historically flows for 30 to 60 days a year. Annual streamflow in the area around Yandi can range from negligible to tens of millions of cubic metres.

Weeli Wolli Creek is approximately 70 km in length, and has a catchment area of 4100 km^2. A dense network of ephemeral tributary streamlines is associated with the system. Weeli Wolli flows to the north, where it drains into the Fortescue River via the Fortescue Marsh (Figure 3). However, the two systems are only connected during flooding associated with intense cyclonic events (Kendrick 2001a). The Marsh is approximately 40 km downstream, and to the north, of Yandicoogina (Figure 3). The Fortescue Marsh is an extensive, episodically inundated samphire marsh, approximately 100 km long and 10 km wide (Kendrick 2001a, DEC 2009). The site is listed as a wetland system of national importance under the Directory of Important Wetlands in Australia (Environment Australia 2001). It is considered to be a "good example of an extensive, inland floodplain system which is irregularly inundated", and is a "unique wetland landform in Western Australia" (Environment Australia 2001). The Fortescue Marsh comprises lakes, marshes, and pools along the floodplain in the middle reaches of the Fortescue River, and includes Powellinna Pool, Gnalka Gnoona Pool, Gidyea Pool, Chaddelinna Pool, Mungthannannie, Cook Pool and Moorimoordinia Pools (Environment Australia 2001). The marsh is also being considered for nomination as a Wetland of International Importance under the Ramsar convention. If this listing is achieved, the site will be further protected under the EPBC Act. 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).

Weeli Wolli Creek is fed by Weeli Wolli Spring which arises as a result of groundwater flow being "dammed" by the Brockman Formation, which forces groundwater to the surface, appearing as the perennial spring. Prior to dewatering discharge from RTIO's Hope Downs (HD1) mine, the spring resulted in perennial surface flow for approximately 2 km along Weeli Wolli Creek. As a result of discharge of dewatering water, there is now perennial flow in Weeli Wolli Creek for approximately 20 km, with surface flow extending several kilometres downstream of the confluence with Marillana Creek.

Weeli Wolli Spring is considered to be of high ecological, social and cultural value (EPA 2001, Kendrick 2001b, Gardiner 2003, van Leeuwen 2009). It has high environmental significance in the Pilbara region because it is a permanent water body. Due to the aridity of the region, such systems are rare. Halse *et al.* (2002) suggested that such systems provide an important "source of animals for colonisation of newly flooded pools and maintenance of populations of invertebrate species at the regional level". The creek is also of significance to indigenous people as it holds mythological and ceremonial importance (EPA 2001), and has social value in the form of local tourism (van Leeuwen 2009). In 2009 the spring was nominated for listing as a Threatened Ecological Community at the State level, on the basis of floristic communities as well as the diverse aquatic invertebrate and significant stygofauna communities (van Leeuwen 2009).

1.2.1 Climate

The climate of the Pilbara is semi-arid, with relatively dry winters and hot summers. Most rainfall occurs during the summer months and is predominantly associated with cyclonic events; when flooding frequently occurs along creeks and rivers (Gardiner 2003). 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. Average annual pan evaporation in the Pilbara is ten times greater than rainfall (Stoddart 1997).

Long-term average annual rainfall recorded from gauging stations in the vicinity of the Yandicoogina minesite is 395 mm at Flat Rocks (station # 505011) and 415 mm at Munjina (station # 505004). The length of record for complete years extends from 1973 to 2009 for the former station, and the latter from 1969 to 2009.

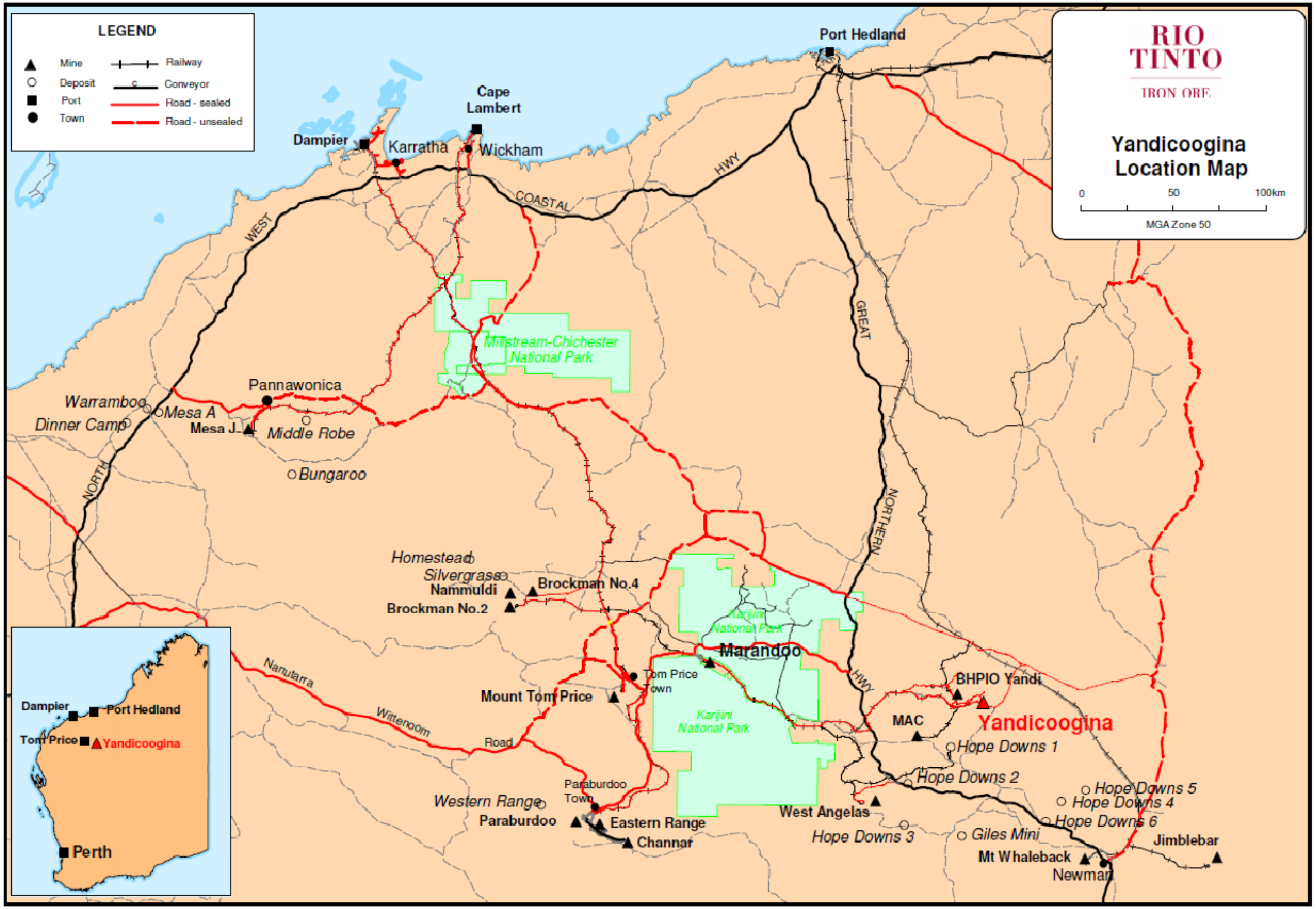

Figure 1. Map showing the location of Yandicoogina in the Pilbara Region of Western Australia.

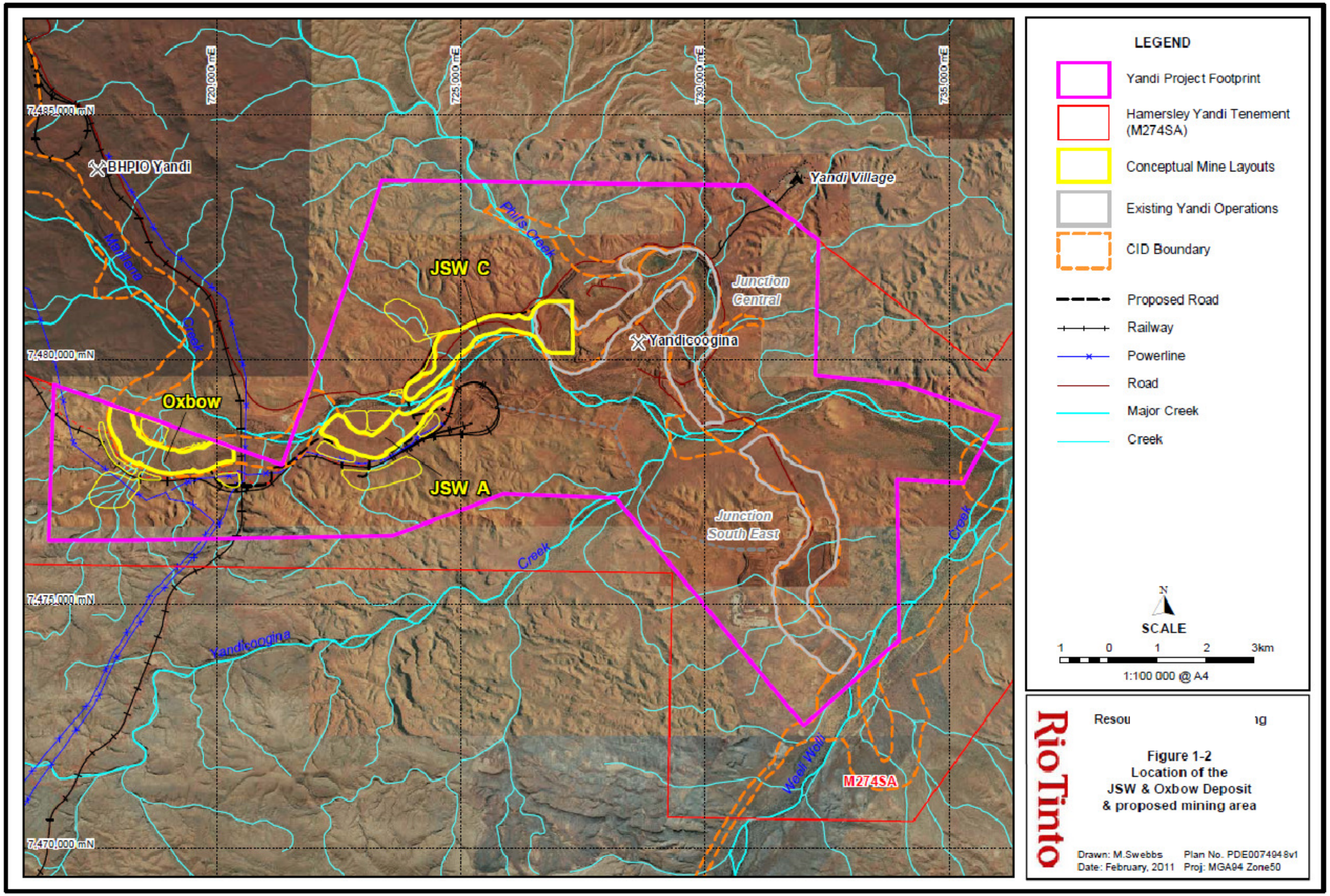

Figure 2. Location of the iron ore deposits at the Yandicoogina mine, including the current JC and JSE mines and the proposed JSW and Oxbow developments. The upstream BHPBIO's Yandi is also shown, as are the Marillana and Weeli Wolli creeks.

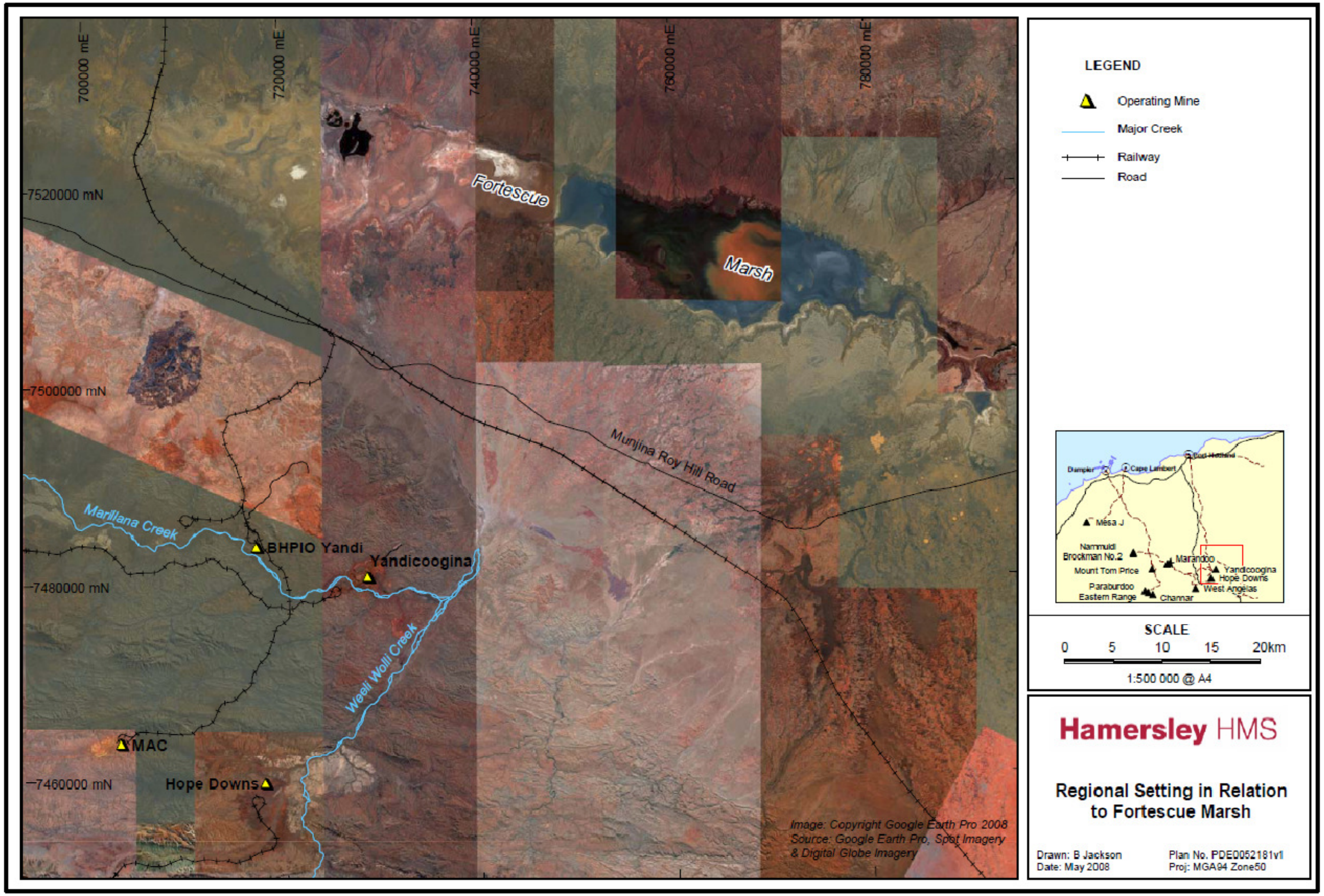

Figure 3. Map showing the location of Marillana Creek and Weeli Wolli Creek with respect to the Fortescue Marshes in the Pilbara Region of Western Australia.

1.2.2 Geology

The Yandi CID has formed within a channel eroded into bedrock of shale, dolerite and banded iron formation (BIF) of the Weeli Wolli Formation overlying the Brockman Iron Formation (MWH 2010). The broad easterly-trending Yandicoogina syncline is bounded by the Lower Proterozoic Brockman Formation, which forms the scarp of the Hamersley range to the north.

The Yandi CID is found in palaeochannels of ancestral equivalents of the Marillana and Yandicoogina creek systems (MWH 2010), is incised within the Weeli Wolli Formation, and comprises early Tertiary, chemically enriched talus and fluvial deposits (Hall and Kneeshaw 1990). Within the Marillana catchment area the CID is up to 70 m in thickness and consists of iron oxide spheroids. The CID is mostly below the water table and lies beneath unconsolidated alluvium/colluvium comprising BIF, chert, shale, minor dolerite and some CID clasts in a red-brown sandy to clay rich matrix (MWH 2010).

1.2.3 Hydrogeology

The Yandicoogina Iron Ore deposits infill the dissected palaeochannel of the Marillana-Yandicoogina system, also known as the channel iron deposit (CID). The main CID is located adjacent to the current Marillana Creek and extends for some 80 km (MWH 2010). It is bounded at depth by relatively less permeable basement rocks of the Weeli Wolli Formation, and is characterised by a relatively high water yield (MWH 2010). Relatively transmissive alluvium and unconsolidated materials border the CID. The overall aquifer system is bounded by less transmissive parent rock materials (MWH 2010). Recent hydrogeological modelling by RTIO highlighted the hydraulic connection between the superficial alluvium and the CID (RTIO 2010).

The Yandi CID is recharged by rainfall, as well as seepage from surrounding alluvium and basement materials (MWH 2010, RTIO 2010). Marillana Creek is also considered a major source of recharge to the aquifer. Discharge from the CID occurs via evapotranspiration by phreatophytic vegetation in the creek alluvium and through flow to the southeast (Strategen 2005). The natural flow direction of groundwater was to the east within the Marillana Creek catchment, and to the northeast along Weeli Wolli Creek (RTIO 2010). However, dewatering operations associated with the various mines (BHPBIO's Yandi, RTIO's Yandicoogina, and HD1), have led to changes to groundwater flow gradients and localised fluctuations in water levels (RTIO 2010). Dewatering discharge from BHPBIO's Yandi mine has saturated the creek alluvium between BHPBIO and Yandicoogina, approximately 12 km downstream (Strategen 2005).

Groundwater in the Yandi CID aquifer is fresh, with salinities ranging from 150 to 600 mgL^{-1} (MWH 2010).

1.2.4 Hydrology

Rainfall is highly variable (Halse *et al*. 2001) and dependent on cyclonic events. There are two rainfall gauging stations in the vicinity of the project area, including Munjina (station #

505004) Flat Rocks (station # 505011). Rainfall data for these gauging stations show that most rainfall occurs during the summer months (Figure 4).

Consequently, 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 rainfall event and continuing for several days. Figure 5 shows this relationship between rainfall and streamflow for the Flat Rocks gauging station on Marillana Creek (station # 708001), with streamflow volumes generally being highest following large rainfall events. However, the response in stream flows is influenced by intensity and duration of rainfall events, and the relationship between monthly rainfall and flows is variable. Streamtec (2004) also reported an exponential relationship between rainfall and discharge for the nearby Weeli Wolli Creek, whereby “linear increases in rainfall tended to result in exponential increases in stream discharge”.

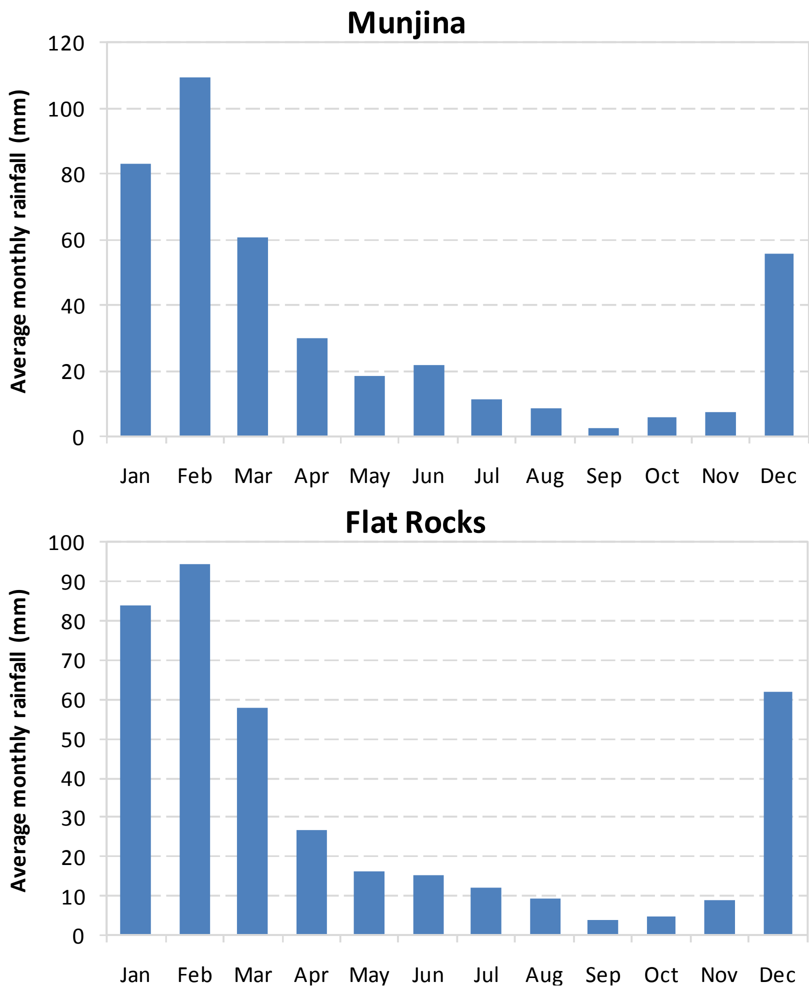

Figure 4. Average total rainfall data for two gauging stations on Marillana Creek, Munjina (left), and Flat Rocks (right).

Downstream of the Flat Rocks gauging station, Marillana Creek has been influenced by the discharge from BHPBIO Yandi and RTIO Yandicoogina since 1998. Discharge of surplus water has resulted in continuous stream flow and saturated bank storage. The increased discharge rates and continuous creek flow have resulted in significant leakage into the CID aquifer (MWH 2010).

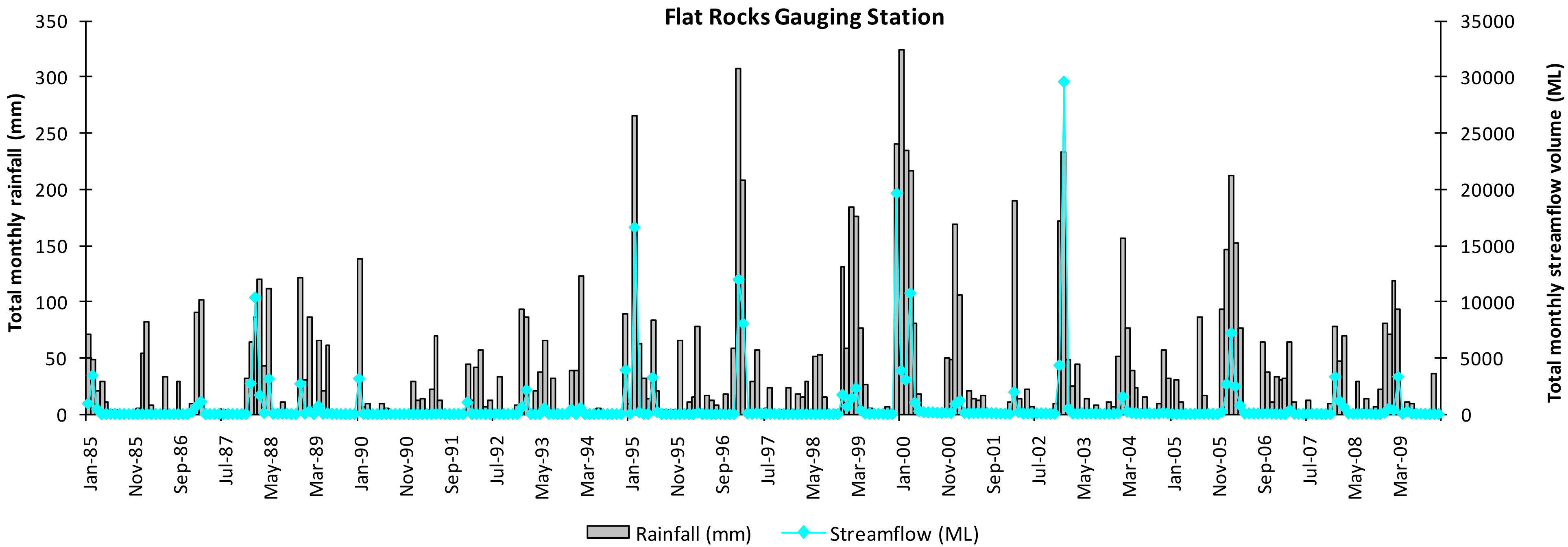

Figure 5. Total monthly rainfall (mm) and total monthly streamflow (ML) data for Flat Rocks gauging station on Marillana Creek.

1.2.5 Vegetation

The flora and vegetation associations of the broader area have been documented by Beard (1975). According to Beard (1975), Yandicoogina occurs within the Fortescue Botanical District of the Eremaean Botanical Province. Vegetation of this Province is typically open, and dominated by spinifex, wattles and some eucalypts. Both diversity of vegetation and floristic richness is known to be high (EPA 2001).

The vegetation in the project area is dominated by a number of families, including Poaceae (grasses), Malvaceae (hibiscus), Mimosaceae (wattles), Papillonaceae (peas), Asteraceae (daisy's) and Amaranthaceae (mulla mulla) (MWH 2010). Along Marillana Creek, the vegetation associations can be classified as woodlands and open forests of *Eucalyptus camaldulensis*, *Eucalyptus victrix* and other tree species over mixed understorey of shrubs and grasslands (MWH 2010). Mattiske Consulting (1995) and Biota (2004) both reported degradation of the understorey due to cattle grazing.

Discharge into Marillana Creek from the current Yandicoogina mine operations, as well as from upstream BHPBIO operations, have maintained artificially high water levels in the alluvials. This has resulted in changes to composition of creek vegetation, with an increase in phreatophytic vegetation in areas of increased water availability, i.e. around discharge points (MWH 2010).

Two species associated with creeklines in the area are listed as priority flora under the Wildlife Act 1950. *Olearia fluvialis* (a daisy) is a Priority 2 species that is restricted to sporadic populations in creek habitats. *Sida sp. Barlee Range* (a spreading shrub; Plate 1) is a Priority 3 species that has been recorded from a single site on the bank of Yandicoogina Creek (MWH 2010).

Plate 1. The Priority 3 Sida sp. Barlee Range recorded from one site along Yandicoogina Creek (photo taken from florabase).

2 CURRENT MINE WATER PROCEDURES

The Yandicoogina mine has been operating since 1996, and as part of mine operations de-watering of the Yandi JSE and JC pits has been necessary since 1998, with excess water discharged directly into Marillana Creek. Since late 2007, excess water has also been discharged into Weeli Wolli Creek (from discharge outlet D06; Figure 6). For the period 1998-2009, average annual discharge into Marillana Creek from all outlets combined was 0.61 GL/year (Figure 7). Peak average discharge into Marillana Creek was 1.29 GL/year in 2009. Average annual discharge into Weeli Wolli Creek between 2008 and 2009 was 0.15 GL/year (Figure 7). Projected average discharge into Marillana Creek and Weeli Wolli Creek is anticipated to be 1.06 GL/year and 0.92 GL/year, respectively (Figure 7). Upstream of RTIO Yandi on Marillana Creek, the BHP-BIO Yandi mine (operating since 1994) also dewaters their developing pit, with discharge occurring into the upstream section of Marillana Creek. It is likely that discharge from BHP-BIO will increase over the next few years as an increase in their abstraction rate to a peak of 15GL/year has been approved, with excess water likely being discharged into Marillana Creek. Downstream of these mining operations, Marillana Creek flows into Weeli Wolli Creek, into which RTIO's Hope Downs 1 (HD1) operation also discharges their dewatering water (see Figure 3). Discharge from HD1 is predominantly via a single gabion structure adjacent to the main creek, however a system of spur lines deliver water as seepage flows to important trees and pools upstream of the gabion, in the area of the historic spring and permanent pools. Approximately 10% of dewatering discharge is released via the system of spur lines, with the remainder released from the gabion. The total volume discharged from HD1 into Weeli Wolli Creek varies between years, but was approx. 25.55 GL/year during 2008/09. HD1 has a licence to discharge up to 40 GL/yr.

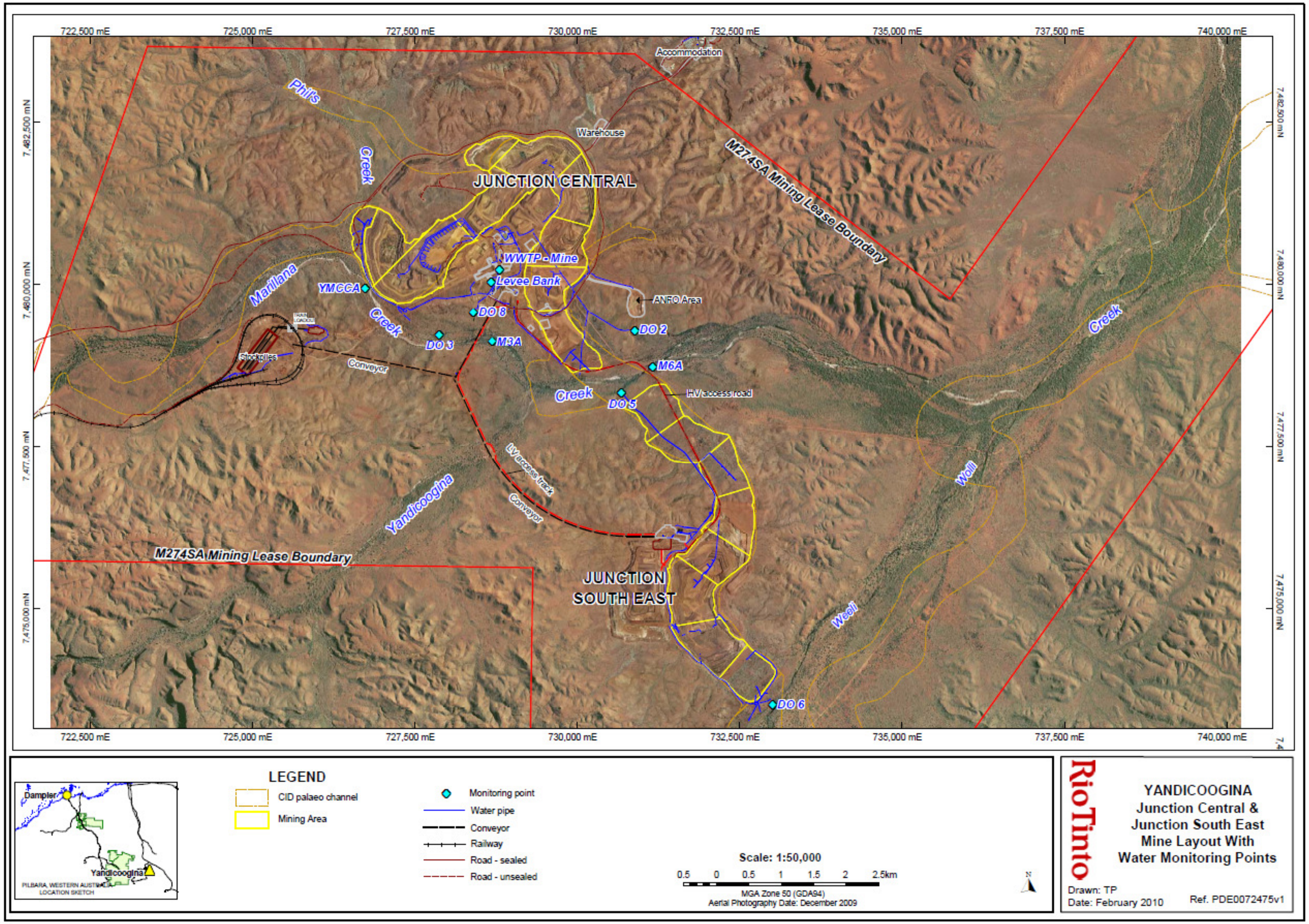

Figure 6. Map showing the location of all discharge outlets (D01-D09) across the Yandi mine lease.

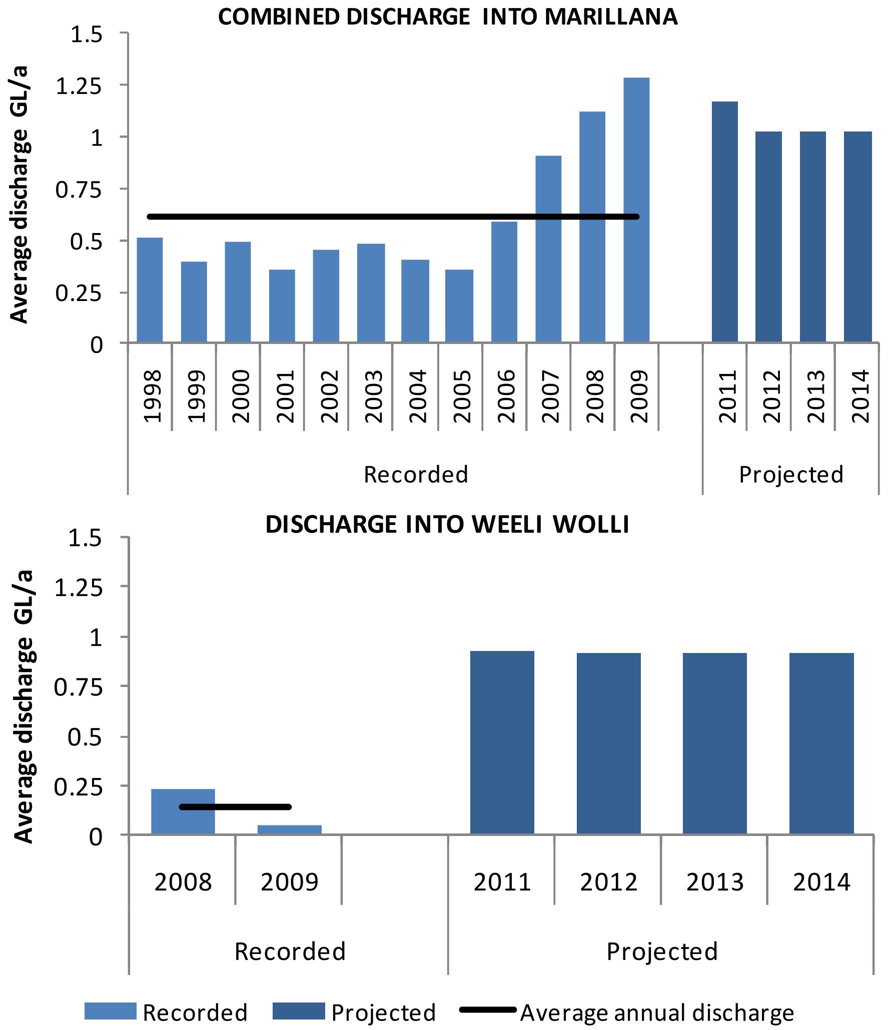

Figure 7. Current and projected average discharge (GL/year) from RTIO Yandi into Marillana Creek for all outlets combined (top), and into Weeli Wolli Creek (bottom). Information provided by RTIO.

3 KNOWN ECOLOGICAL VALUES OF MARILLANA CREEK

The aquatic fauna of Marillana Creek is becoming reasonably well known due to recent sampling by the authors (WRM 2010a). As part of a broader study on Marillana and Weeli Wolli creeks, twelve sites were sampled along Marillana Creek in October 2008 (dry season), May 2009 (wet), October 2009 (dry) and May (2010). Six sites were located downstream of BHPBIO's Yandi discharge, but upstream of Yandicoogina, and six sites were located downstream of RTIO's Yandicoogina discharge (Figure 8). This work is ongoing as part of site monitoring, as well as a cumulative impacts study of mining operations on the Weeli Wolli/Marillana system. Prior to the WRM sampling programme, few studies included sample sites along Marillana Creek (Halse *et al.* 2001, Streamtec 2004).

As part of a wider program throughout Western Australia called the First National Assessment of River Health (FNARH), aquatic macroinvertebrates of the upper Fortescue River were sampled, including one site along Marillana Creek (Halse *et al.* 2001). This site was located downstream of both BHPBIO and RTIO's discharge and was sampled in March 1998 and November 1998 (site named Marillana Creek; Figure 9). A number of habitats were sampled, including channel, riffle, macrophytes, and pool rocks. FNARH was the second phase in the Australia-wide program, known as the Monitoring River Health Initiative (MRHI), to develop a biomonitoring system for assessing river condition based on aquatic macroinvertebrates (Halse *et al.* 2001). The biomonitoring system (AusRivAS) used predictive models to compare the occurrence of families of aquatic macroinvertebrate from a particular river, with those expected to occur if the site was in good biological condition (Halse *et al.* 2001). More than 550 sites in all of the major river systems of Western Australia were assessed in this manner.

The site sampled under FNARH was also sampled by the authors as part of the Pilbara Regional Aquatic Survey for RTIO (WRM 2009a). It was sampled in October 2008, May 2009, October 2009 and May 2010. Data currently exist for the October 2008 sampling round. This project is also ongoing.

In addition, Streamtec (2004) conducted an aquatic survey of a number of freshwater systems within the upper Fortescue River catchment, including Marillana Creek. This survey was commissioned by BHPBIO to "assess the potential impacts, if any, of nearby iron-ore mining operations" (Streamtec 2004). The study was undertaken over two years, with field sampling being carried out during two seasons; the "wet" (March 2002 and 2003) and the "dry" (November 2001 and 2003). Surveys incorporated water quality, riparian vegetation, aquatic macroinvertebrates, fish, and other vertebrates.

Marillana Creek was sampled by Streamtec (2004) at Flat Rocks, a permanent pool located approximately 20 km upstream of all mining operations (Figure 9). Sampling involved *in situ* water quality measurements (temperature, dissolved oxygen and pH) and laboratory analyses (salinity, electrical conductivity, turbidity and nutrients). Aquatic macroinvertebrates were collected using both standard qualitative (composite sweep samples) and quantitative (Surber sampling) methods (Streamtec 2004). In addition, stable carbon and nitrogen isotope analysis was undertaken to "examine the structure of stream food webs" (Streamtec 2004).

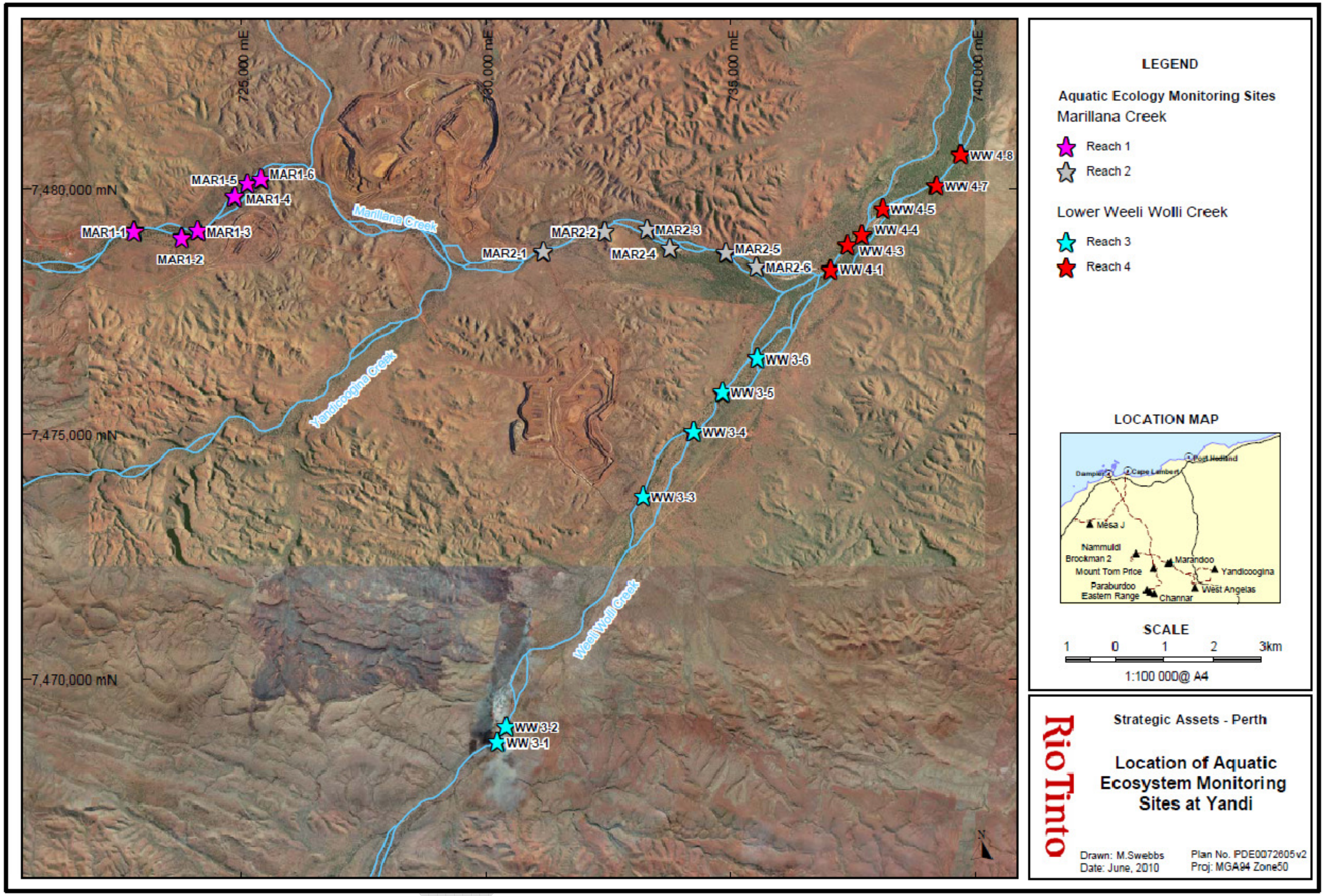

Figure 8. Location of the WRM sampling sites along Marillana Creek and lower Weeli Wolli Creek (NB. there are additional sampling sites further upstream on Weeli Wolli Creek, not visible on this map).

Figure 9. Location of the Marillana Creek site sampled as part of the DEC AusRivAS FNARH study (MC), and the site sampled by Streamtec (2004) (FR).

Again, Flat Rocks was sampled by the authors as part of the Pilbara Regional Aquatic Survey for RTIO in October 2008, May 2009, October 2009 and May 2010. Data currently exist for the dry season sampling in October 2008 (WRM 2009a).

3.1 Microinvertebrates

Neither the AusRivAS FNARH study nor the Streamtec (2004) work included aquatic microinvertebrates[1]. However, WRM sample the microinvertebrate fauna on each occasion (i.e. WRM 2010a). Aquatic microinvertebrates constitute an important component of aquatic biodiversity, containing rare and restricted species, they also comprise an important part of the food web, which, if affected, would flow on to affect macroinvertrates and higher consumers (i.e. fish). Data from the WRM sampling programme is available for the October 2008 and May 2009 sampling rounds (WRM 2010a). A total of 59 taxa of microinvertebrates were recorded from twelve sites along Marillana Creek (reaches one and two), with 45 being recorded in October 2008, and 41 taxa in May 2009 (Appendix 1a; WRM 2010a). Micro-invertebrate taxa richness ranged from zero (MAR1-6 in the wet) to 20 (MAR1-3 also in the wet; Figure 10; WRM 2010a).

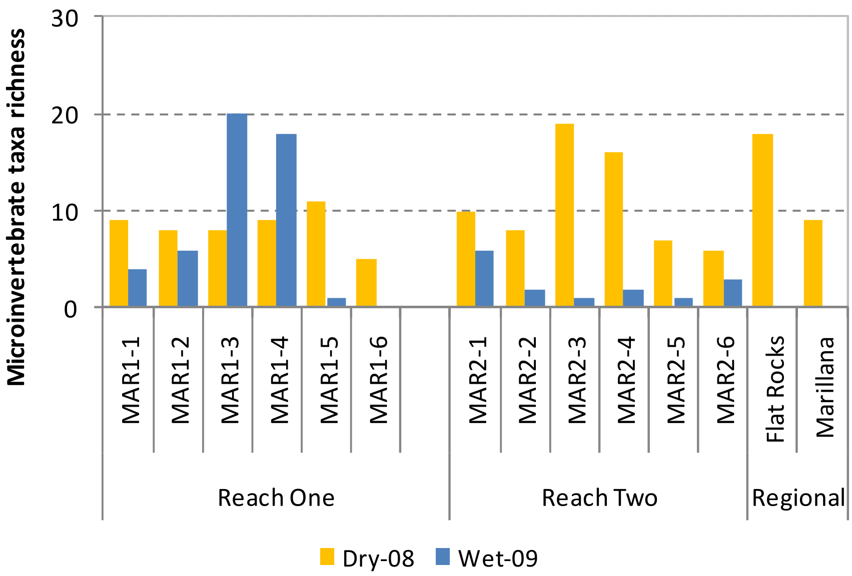

Figure 10. Microinvertebrate taxa richness recorded by WRM

At the regional sampling sites, a total of 18 micro-invertebrate taxa were collected from Flat Rocks and 9 taxa from Marillana, in the dry season of 2008[2] (WRM 2009a).

The microinvertebrate fauna comprised Protista (Ciliophora & Rhizopoda), Rotifera (Bdelloidea & Monogonata), Cladocera (water fleas), Copepoda (Cyclopoida) and Ostracoda (seed shrimp). The microinvertebrate fauna were typical of tropical systems reported elsewhere (e.g. Koste and Shiel 1983, Tait *et al.* 1984, Koste and Shiel 1990, Smirnov and De Meester 1996, Segers *et al*. 2004). For example, Brachionidae within the Rotifera were poorly represented. This family tends to dominate temperate rotifer plankton, but is overshadowed by Lecanidae in tropical waters, as was the case here. Within the Cladocera fauna, daphniids tend to predominate in temperate waters, with low representation in the tropics. Only one species of daphniid has been recorded from Marillana Creek. This was

[1] A microinvertebrate is an animal without a backbone which can only be seen under magnification such as a rotifer, and is retained by small mesh nets (< 50 µm).

[2] Data for the wet season 2009 are not yet available for WRM's Pilbara Regional Aquatic sampling sites such as Flat Rocks and Marillana.

recorded from Flat Rocks during the Regional Survey (WRM 2009a). In tropical systems throughout the world, daphniids tend to be replaced by sidids, moinids, and in the case of heavily vegetated or shallow waters, by chydorids, as seen here (see Appendix 1a).

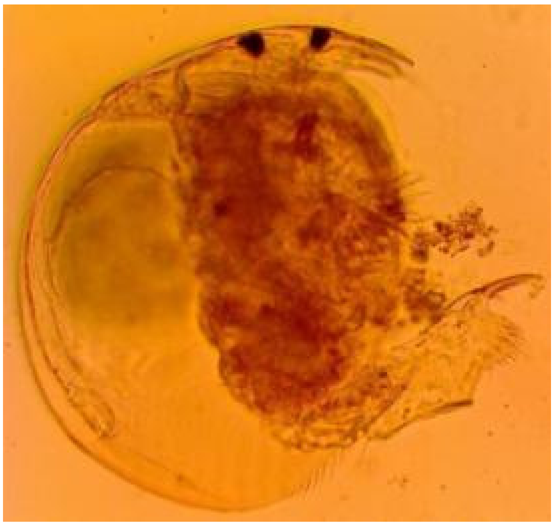

Plate 2. The Australian endemic Cladocera *Alona rigicaudis* collected from Marillana Creek (photo by Dr Russ Shiel/University of Adelaide).

The majority of microinvertebrate taxa known from Marillana Creek are common, ubiquitous species. Of interest however, is the presence of a species known only from the Gondwanan continents; the Protist *Difflugia australis*. This species previously has been recorded from Kakadu in the Northern Territory, north-west W.A., and was collected from the regional Marillana Creek site (Appendix 1b). In addition, one species endemic to Australia, the Cladocera *Alona rigicaudis* is also known from Marillana Creek (Plate 2). This species was collected by the authors from MAR1-5, MAR2-3 and MAR2-6 (WRM 2010a). *Alona rigicaudis* has been collected widely across Australia, with a greater number of records from the eastern states (Dr Russ Shiel, University of Adelaide, pers. comm.).

3.2 Hyporheic fauna

Neither the AusRivAS FNARH study nor the Streamtec (2004) work included hyporheic fauna[3] sampling. Yet the hyporheic zone[4] is becomingly increasingly recognised as a critical component of many streams and rivers (Edwards 1998). This zone is known to function in a number of important ways. For example, hyporheic biogeochemical processes can influence surface water quality (Bencala 1984), and streams with an extensive hyporheic zone can retain and process solutes more efficiently than those without (Valett *et al.* 1996). Other physico-chemical services include moderating river water temperature and providing a natural attenuation zone for certain pollutants by biodegradation, sorption and mixing (Buss *et al.* 2009). The hyporheic zone is also thought to provide a rearing habitat (Brunke and Gonser 1999) and important refuge for aquatic invertebrates, buffering them from floods (Palmer *et al.* 1992, Dole-Oliver and Marmonier 1992, Edwards 1998), disturbance in food supply (Edwards 1998), and drought (Cooling and Boulton 1993, Edwards 1998, Coe 2001, Hose *et al*. 2005). Some animals can actively burrow into the sediments when a disturbance occurs, and then re-colonise benthic habitats once the disturbance has passed (Fenoglio *et al.* 2006). In this way, the hyporheic zone serves to enhance the resilience of the benthic community to disturbance and influence river recovery following perturbations. The often diverse and abundant fauna of hyporheic zones has been found to dominate the biological productivity of rivers (Stanford and Ward 1988, Smock *et al.* 1992). In studies undertaken in

[3] Aquatic invertebrate fauna which reside in the area below the streambed where water percolates through spaces between the rocks and cobbles.
[4] Hyporheic zone = the mixing zone of streamwater and groundwater; an ecotone largely, or totally, dependent on groundwater.

the Northern Hemisphere, the largest numbers of groundwater animals have been found in shallow groundwater of the hyporheos rather than the deeper phreatic zone (Marmonier *et al.* 1993, Rouch and Danielopol 1997).

Interstitial fauna exhibit unique traits and adaptations to survive life in sediment pores. They have long, slender and flexible bodies which facilitate movement through interstitial spaces, and their small, hard, blunt bodies allow them to force their way through (Williams 1984). Some organisms are simply very small. Stygobites are blind and lack pigmentation.

The hyporheic fauna of Marillana Creek was sampled by the authors at twelve sites in October 2008 and May 2009 (see Figure 8 for site locations; WRM 2010a). Sampling was undertaken using the Karaman-Chappuis pit method (Karaman 1935, Chappuis 1942, Delamare Deboutteville 1953) also used in similar studies by Danielopol (1980), Mary and Marmonier 2001, Boulton *et al.* (2004), and Sak *et al.* (2008). This involved digging a hole in alluvial gravels in the dry streambed adjacent to the waters edge, allowing the hole to infiltrate with water, and then sweeping through with a modified 53 µm mesh plankton net (WRM 2010a). All taxa recorded were classified using Boulton's (2001) categories;

- stygobite – obligate inhabitants of hypogean habitats, including the hyporheic zone and deeper groundwater habitats (such as aquifers), with special adaptations to survive such conditions
- permanent hyporheos stygophiles - epigean[5] species which may be present in the hyporheic zone during all life stages, but may also be able to complete their life-cycle in benthic habitats
- occasional hyporheos stygophiles – typically early instars of organisms that usually predominate in benthic habitats at later stages of development. May use the hyporheic zone seasonally (seeking refuge during spates or drought) or during early life history stages
- stygoxene - species that have no affinity with groundwater habitats, but occur there accidentally due to passive infiltration.

Of the invertebrate taxa recorded from hyporheic habitats along Marillana Creek in the dry season of October 2008, the vast majority were classified as stygoxene (72%) and do not have specialised adaptations for groundwater habitats. However, 5% of the taxa were classified as occasional hyporheos stygophiles, 5% were stygobites, and 9% were possible hyporheic taxa. There were no taxa classified as permanent hyporheic stygophiles, and 9% were unknown due to insufficient taxonomy and/or information. Of the taxa recorded during the wet season, most were stygoxene taxa (81%), with 9% being considered hyporheos fauna (5% occasional hyporheos stygophiles, 2% stygobites, and 2% possible hyporheic taxa). These results are similar to those reported previously in the Pilbara (Halse *et al.* 2002, WRM 2009a, b, WRM 2010a, b), in that <20% of taxa collected in hyporheic habitats were entirely dependent on groundwater for their persistence as a species. Halse *et al*. (2002) suggested that it is not surprising that the hyporheos is dominated by species with some affinity for surface water, because the hyporheos is an "ecotone between productive, species-rich surface water systems and nutrient-poor groundwater systems with lower number of species per sampling unit".

5 Epigean – living or occurring on or near the surface of the ground.

Hyporheos fauna were recorded from both reaches of Marillana Creek during both seasons (Figure 11). The greatest number of occurrences of hyporheos taxa was recorded from Reach Two in the wet season of May 2009, and the least from Reach One during the dry of October 2008 (Figure 11).

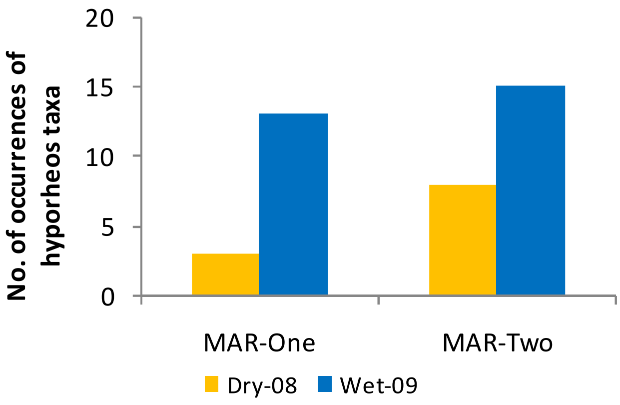

Figure 11. Number of occurrences of taxa considered hyporheos recorded from each reach along Marillana Creek during the dry 2008 and May 2009.

Species considered to be restricted to the hyporheos included a number of species of stygobitic amphipod, possible hyporheos species Oligochaeta spp. and *Diacyclops* sp. (copepodites), and the occasional stygophiles Baetidae Genus 1 WA sp.1 (mayfly larvae), *Limbodessus occidentalis* and Dytiscidae spp. beetle larvae (Appendix 2).

Up to four species of stygal amphipod are known from Marillana Creek, all of which are restricted to the Marillana/Weeli Wolli Creek system (Helix 2010) including *Chydakaeta* sp., *Marrka weeliwolli*, Species D-WW and Species D-Mar (WRM 2010b; Helix 2010). *Chydakaeta* sp. belongs to a genus which also includes formally described species from Ethel Gorge and Ebathacalby Well west of the Fortescue Marsh, but the species from Marillana and Weeli Wolli creeks is different from these. *Chydaekata* sp. is currently undescribed. *Marrka weeliwolli* is a previously recognised formally described species that is only known from Weeli Wolli and Marillana Creeks. The other two species known from Marilllana Creek are undescribed. Species D is found in both Marillana and Weeli Wolli Creek, but Helix (2010) found some genetic differentiation between the Marillana and Weeli Wolli populations, such that they were named as separate species, D-Mar and D-WW. Helix (2010) suggested that the high divergence over such a short geographical distance suggested that D-Mar and D-WW were reproductively isolated (in fact, the differentiation between populations of the two corresponds to approx. 4 million years of isolation from each other). None of the aforementioned stygobitic amphipod species have been recorded outside the Marillana/Weeli Wolli system, suggesting they are short-range endemics. This infers high conservation value and implications for management. Stygal amphipods were recorded from both reaches along Marillana Creek and are also known to be abundant along Weeli Wolli Creek (WRM 2010a, b).

The occasional hyporheos stygophile *Limbodessus occidentalis*[6] (dytiscid beetle) was recorded from MAR1-3 during the wet season (WRM 2010a). This species is endemic to the Pilbara region of Western Australia where it is known from both epigean and stygal habitats. It appears to be relatively commonly recorded across its range, but is not generally recorded in high abundance. *Limbodessus occidentalis* has been recorded from calcrete aquifers while sampling bores at Moorarie and Killara North, but is most commonly recorded from the edge of pools in sandy riverbeds and interstitially to at least two meters from the

[6] Previously known as *Boongurrus occidentalis* sp. nov. (Watts and Humphreys 2004). The genus *Boongurrus* has since been synomised with *Limbodessus* (Balke and Ribera 2004).

water's edge in an upstream direction (Watts and Humphreys 2004). This species has been previously recorded from interstitial samples taken from Weeli Wolli in September 2003 during surveys conducted by the DEC (Adrian Pinder, DEC, unpub. data) and more recently during the Living Water Study undertaken by the authors (WRM 2009b).

3.3 Macroinvertebrate fauna

As part of the AusRivas FNARH study, a total of 23 macroinvertebrate[7] families from nine orders were recorded (see Appendix 3a). Using the AusRivas approach, Halse *et al.* (2001) found the Fortescue to be a relatively undisturbed system. The other major rivers of the Pilbara, the Ashburton and the De Grey, were also considered undisturbed. In a comparison with rivers of the Kimberley, Halse *et al.* (2001) suggested that these systems were in better biological "condition than the Ord and parts of the Fitzroy, but not as undisturbed as parts of the Kimberley".

Streamtec (2004) recorded a total of 63 macroinvertebrate taxa from Flat Rocks on Marillana Creek (see Appendix 3b). The composition of taxa was typical of lotic (flowing) freshwater systems throughout the world (Hynes 1970), and was dominated by Insecta (over 93% of taxa). The most common insects were Coleoptera (over 35% of the insects). However, chironomids (non-biting midge larvae) were not identified to species level in this study (Streamtec 2004). Chironomidae typically comprise the most abundant insects in lotic systems. Taxa richness varied between seasons, with the majority of taxa being collected during the dry season of 2003 (Figure 12).

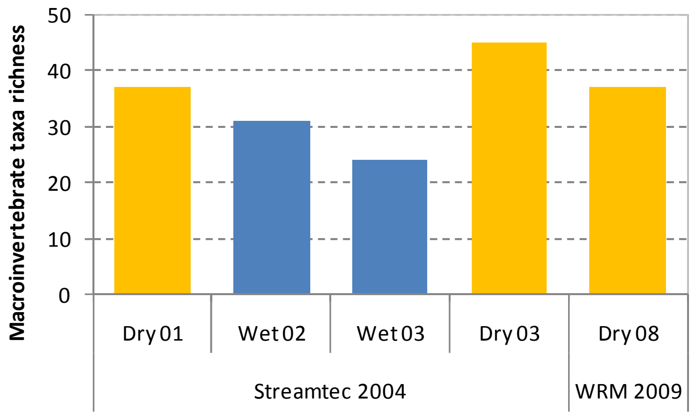

Figure 12. Macroinvertebrate taxa richness recorded from Flat Rocks by Streamtec (2004) on each sampling occasion between 2001 and 2003, and by WRM (2009) in October 2008.

More recently, the authors sampled twelve sites along Marillana Creek in October 2008 and May 2009 and collected 115 taxa of macroinvertebrates (WRM 2010a). During the dry season of October 2008, the greatest number of macroinvertebrate taxa was recorded from MAR2-5 and MAR2-6 (55 taxa), and the least from MAR2-2 (32 taxa; Figure 13). During the wet, the greatest number of taxa was again collected from MAR2-6 (33 taxa), and the least from MAR1-1 (23 taxa) (Figure 13; WRM 2010a). The macroinvertebrate fauna included Cnidaria (freshwater hydra), Mollusca (freshwater snails), Oligochaeta (aquatic segmented worms), Crustacea (side swimmers), Acarina (water mites), Ephemeroptera (mayfly larvae),

[7] A macroinvertebrate is an animal without a backbone which is visible to the naked eye, and is retained by a net with mesh aperture of 250 µm, such as insect larvae or amphipoda.

Odonata (dragonfly and damselfly larvae), Hemiptera (true aquatic bugs), Coleoptera (aquatic beetles), Diptera (two-winged fly larvae), Trichoptera (caddisfly larvae), and Lepidoptera (aquatic moth larvae) (Appendix 3c).

A total of 37 taxa of macroinvertebrates was recorded from Flat Rocks and 48 taxa from the Marillana Regional site by WRM (2009a) in October 2008 (see Figure 12; Appendix 3d).

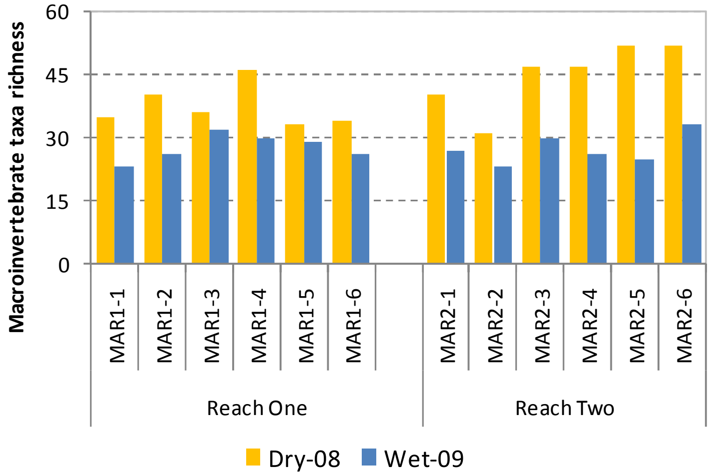

Figure 13. Macroinvertebrate taxa richness recorded by WRM (2010a) from each site along Marillana Creek during both seasons.

Taxa known from Marillana Creek which are endemic to Western Australia include the mayfly Baetidae Genus 1 WA sp1 (*Offadens* WA sp1), dragonfly *Austrogomphus gordoni*, dytiscid beetle *Hydroglyphus orthogrammus*, and caddisfly *Chimarra* sp. AV17. Macroinvertebrates known from Marillana Creek with distributions restricted to the Pilbara region of Western Australia include the dragonflies *Ictinogomphus dobsoni* and *Nannophlebia injibandi*, dytiscid beetles *Limbodessus occidentalis* and *Tiporus tambreyi*, and the hydrophilid beetle *Laccobius billi*.

The caddisfly *Chimarra* sp AV17 (Philopotamidae) is endemic to Western Australia. It is a northern species, and is only known from the Kimberley and the Pilbara (Cartwright 1997). Within the Pilbara, *C.* sp AV17 appears to be quite common and is known from Fortescue Falls, Hamersley Gorge (Fortescue River), Bamboo Springs (DeGrey River), Skull Springs (DeGrey River), Nyeetbury Springs (Robe River), and Weeli Wolli Creek (DEC 2009, WRM 2009a, b, WRM 2010b, Adrian Pinder DEC pers. comm.). Like other Philopotamids, *Chimarra* occur in faster flowing streams on the underside of rocks. They construct silken tubes or sack-like nets which they hold in the water's flow and collect algae, and fine plant and animal detritus as it flows past.

Plate 3. The Pilbara Tiger, *Ictinogomphus dobsoni* (photo taken and provided by Dr Jan Taylor/WA Insect Study Society).

The Pilbara Tiger dragonfly, *Ictinogomphus dobsoni* (Plate 3), occurs in permanent still or sluggish waters (Watson 1991). This species is known only from a few localities in the Pilbara region of north-west Western Australia (Watson 1991). It has been collected previously from Gregory Gorge (ANIC Database), Fortescue River on Millstream

Station (ANIC Database), Bobswim Pool, Dales Gorge (DEC 2009), Fortescue Falls in Karijini National Park (Adrian Pinder, DEC, pers. comm.), and Weeli Wolli Creek (WRM 2010b).

Although endemic to the Pilbara, *Tiporus tambreyi* appears to be commonly recorded and widespread throughout its range. It is previously known from the Millstream area (ANIC Database), Palm Pool in Millstream National Park (DEC 2009), Dales Gorge in Karijini National Park (DEC 2009), the Upper Fortescue River, Weeli Wolli Creek, Coondiner Creek, Kalgan Creek, and Bobswim Pool in Karijini NP (WRM 2009a). This beetle is most abundant in the littoral zone at the edge of ponds, lakes, billabongs and pools in intermittent streams. This wide range of habitats includes numerous types of substrata, such as rock, pebbles, gravel, sand, mud, silt, peat and other organic debris.

3.4 Fish

A number of studies have examined the freshwater fish fauna of river systems in the Pilbara region of Western Australia (Dames and Moore 1975, Masini 1988, Allen *et al*. 2002, Morgan *et al.* 2002, 2003, Morgan and Gill 2004, Streamtec 2004). However, other than work undertaken by the authors, only one study included a sample site on Marillana Creek (at Flat Rocks; Streamtec 2004). The fish fauna of the Pilbara is characterised by low species diversity yet high levels of endemicity; over 42% of species recorded are restricted to the region (Unmack 2001, Allen *et al.* 2002). Masini (1988) found the relatively clear waters of permanent and semi-permanent waterbodies supported the best developed fish assemblages in the region. In a study of the biogeography of Australian fish fauna, Unmack (2001) recognised ten distinct freshwater fish biogeographic provinces, of which the Pilbara Province was one. This region was considered distinct because its fauna did not cluster with other drainages in multivariate (parsimony and UPGMA) analysis of fish distribution patterns (Unmack 2001).

Allen *et al.* (2002) suggested the sparse freshwater fish fauna of the Pilbara was due to its aridity. The fish which inhabit the region are adapted to the extreme conditions and many have strategies for surviving drought (Unmack 2001). For example, Australia's most widespread native fish, the spangled perch (*Leiopotherapon unicolor*), is thought to survive drought by aestivating in wet mud or under moist litter in ephemeral waterbodies (Allen *et al.* 2002). However, conclusive evidence is required to validate this hypothesis. Spangled perch can migrate in very shallow waters, and can be found in any temporary water of the Pilbara following rainfall, including wheel ruts of vehicle tracks (Allen *et al.* 2002). They are known to tolerate extremes in the aquatic environment (Llewellyn 1973, Beumer 1979, Glover 1982) and occupy a wide range of habitats (Bishop *et al*. 2001, Allen *et al.* 2002). Spangled perch and western rainbowfish are the only species known from an area in the Pilbara with little or no surface run-off in the Great Sandy Desert (Morgan and Gill 2004).

Beesley (2006) found life history strategies of fish species in the Fortescue River lay between 'opportunistic' and 'periodic', reflecting the seasonal yet unpredictable nature of rainfall in the region. Breeding in spangled perch of the Pilbara occurs during the summer wet season, between late November and March (Beesley 2006). During this time, multiple spawning events are known to occur (Beesley 2006). Breeding in the western rainbowfish occurs throughout the year, with multiple spawning bouts which take full advantage of the regions intermittent rainfall and streamflow (Beesley 2006).

According to Allen *et al.* (2002), 12 native freshwater fish species (including catadromous[8] species) are known from the Pilbara. However, Morgan and Gill (2004) proposed an additional undescribed species of eel-tailed catfish, *Neosilurus* sp., may exist in the Robe and Fortescue rivers, but this is yet to be formally recognised. This species was considered different to *N. hyrtlii* based on its proportionally larger head and longer snout. Other known species from the Pilbara include spangled perch (*Leiopotherapon unicolor*), Fortescue grunter (*Leiopotherapon aheneus*), barred grunter (*Amniataba percoides*), western rainbowfish (*Melanotaenia australis*), bony herring (*Nematalosa erebi*), flat head goby (*Glossogobius giuris*), empire gudgeon (*Hypseleotris compressa*), golden gudgeon (*Hypseleotris aurea*), Hyrtl's tandan (eel-tailed catfish; *Neosiluris hyrtlii*), blue catfish or lesser salmon catfish (*Neoarius graeffei*), Murchison River hardyhead (*Craterocephalus cuneiceps*), and Indian short-finned eel (*Anguilla bicolor*) (Masini 1988, Allen *et al.* 2002, Morgan and Gill 2004, Beesley 2006). In addition, two endemic cave fishes have also been recorded from the North West Cape in the Pilbara Drainage Division; the blind cave eel (*Ophisternon candidum*) and the blind gudgeon (*Milyeringa veritas*) (Humphrey and Adams 1991, Allen *et al.* 2002). Four introduced fish species are known from the Pilbara; mosquitofish (*Gambusia holbrooki*), guppy (*Poecilia reticulata*), swordtail (*Xiphophorus helleri*), and tilapia (*Oreochromis mossambicus*) (Morgan and Gill 2004).

At least two studies have examined the fish fauna of the Fortescue River (Morgan and Gill 2004, Beesley 2006). Morgan and Gill (2004) sampled 16 sites along the Fortescue River as part of a broader study describing the distribution of fishes in inland waters of the Pilbara. A total of 171 sites were sampled across the region between December 2000 and November 2002 using a combination of methods, including seine nets, gills nets, cast nets, mask and snorkel, and rods and lines (Morgan and Gill 2004). Exact locations of study sites were not provided by Morgan and Gill (2004). Therefore, it is not known whether any sites along Marillana Creek or Weeli Wolli Creek were sampled. The authors have attempted to find out this information from David Morgan, but have been unsuccessful.

Beesley (2006) examined the role of environmental stability in structuring fish communities of the Fortescue River. Sampling was restricted to pools within the western catchment of the Fortescue. Between December 2000 and December 2002, pools were sampled on nine occasions over both 'wet' and 'dry' seasons. Fish recorded by Beesley (2006) included the Indian short-finned eel, bony herring, lesser salmon catfish, Hyrtl's tandan, western rainbowfish, barred grunter, Fortescue grunter, spangled perch, empire gudgeon, and the flathead goby. Morgan and Gill (2004) also reported the new catfish species *Neosilurus* sp., which may have been collected by Beesley (2006) but not recognised. No introduced species have been recorded from the Fortescue River. All known introduced fishes of the Pilbara are currently restricted to the region south of the Lyndon River (Morgan and Gill 2004).

[8] catadromous fishes live in freshwaters as juveniles or sub-adults, but migrate to estuaries or the sea to spawn

The fish fauna of Marillana Creek were surveyed by Streamtec (2004) as part of the larger BHPBIO aquatic fauna study previously described. A combination of sampling methods was used, including sweep netting, seine nets and direct observation (Streamtec 2004). Fish surveys were undertaken in conjunction with macroinvertebrate sampling at the same location (Flat Rocks). Only two of the eleven species known from the Fortescue River were recorded from Flat Rocks by Streamtec (2004). These were the spangled perch (Plate 4) and western rainbowfish (Plate 4).

Plate 4. Western rainbowfish *Melanotaenia australis* (left) and spangled perch *Leiopotherapon unicolor* (right) (photos taken and provided by Mark Allen ©).

During more recent surveys of twelve sites along Marillana Creek, three species of fish were recorded, including spangled perch, western rainbowfish and Hyrtl's tandan (eel-tailed catfish; Plate 5; WRM 2010a). Western rainbowfish were the most abundant species and were collected from both reaches during both season (WRM yandi). Hyrtl's tandan catfish were more abundant from the downstream reach of Marillana Creek, and included juveniles (WRM 2010a).

Plate 5. Hyrtl's tandan, *Neosiluris hyrtlii* (photo taken and provided by Mark Allen ©).

These three fish were also the only species known from Weeli Wolli Creek (WRM 2009a, WRM 2010b, Streamtec 2004), and were the only species collected from the entire upper Fortescue during the Streamtec (2004) surveys. Streamtec (2004) attributed the low species diversity to physical barriers, such as waterfalls, impeding dispersal.

All three species are common and widespread. The spangled perch is the most widespread fish species in Australia, with a distribution in coastal drainages from the Greenough River in WA north across the Top End and southwards to the Hunter River and Murray-Darling system in NSW. It also occurs inland in the Lake Eyre/Bulloo-Bancannia Drainage System (Allen *et al*. 2002). Spangled perch occur in a variety of habitats across this range including, flowing streams, small billabongs, lakes, dams and bores (Allen *et al.* 2002). The western rainbowfish has a distribution from the Ashburton River in Western Australia to the Adelaide River near Darwin in the Northern Territory. It is common and abundant throughout the Pilbara and Kimberley regions of WA (Allen *et al*. 2002). Hyrtl's tandan catfish has a broad distribution across Australia, from the Pilbara and Kimberley in WA, across tropical northern Australia, to eastern Queensland and as far south as the Mary River (Allen *et al.* 2002). However, further research is required on the many geographic populations as Hyrtl's tandan may actually represent more than one species (Allen *et al.* 2002).

4 MINE OPERATIONS WHICH HAVE THE POTENTIAL TO IMPACT AQUATIC SYSTEMS

4.1 De-watering

As part of the development of the JSW and Oxbow deposits dewatering will be required to access ore below the water table. Proposed peak dewatering rates up to 14 GL/year and 8 GL/year have been estimated for JSW and Oxbow, respectively (MWH 2010).

Dewatering of the alluvium beneath the channel bed may result in impacts to the environment of the hyporheic zone of Marillana Creek. Given the importance of the hyporheic zone to stream ecosystem and biogeochemical functioning and integrity, as well as its importance in maintaining biodiversity, the need to maintain and protect vertical linkages within riverine systems is widely accepted within Australia (Hancock *et al.* 2009) and internationally (Buss *et al.* 2009). The exchange of water and nutrients between surface water systems and their underlying aquifers is occasionally bidirectional and may change throughout the year (Hancock *et al.* 2009). Pressure gradients caused by differences in head potential drive the direction of hydrological exchange. This means that in areas where the water table of an alluvial aquifer is higher than the bed of the adjacent stream, groundwater will often flow towards the stream, and *vice versa* (Packman and Bencala 2000, Gordon *et al.* 2004). For hyporheic ecotones, both downwelling (where surface water enters the stream bed) and upwelling (where water exits the bed) areas are required proper ecological functioning, such as the maintenance of bed filtration and fish nurseries (Hancock 2002). However, pumping from bores located near rivers can create unidirectional flow of river water into the stream bed (Hancock *et al.* 2009, Buss *et al.* 2009). This would alter exchange patterns to downwelling only, resulting in reduced filtration effect of water passing through the hyporheic zone (Mauclaire and Gibert 1998).

Dewatering may impact hyporheic fauna through a reduction in habitat and limiting connectivity with the creek. Generally, reductions in groundwater discharge to creeklines can affect biodiversity by affecting stream metabolism and failing to support dry season refugia (Boulton and Hancock 2006). Pumping from groundwater aquifers is considered excessive if it results in deterioration to groundwater quality, irrespective of whether or not there is excessive drawdown of the aquifer (Margat 1994). Dewatering may also impact stygofauna communities, although this component of fauna is not considered in this report.

In general, dewatering drawdown has the potential to affect permanent pools which act as refuges for aquatic fauna during the dry season in the arid Pilbara. Excessive dewatering may drawdown the aquifer, resulting in permanent pools drying, with concomitant loss of ecological values. However, there don't appear to be any permanent pools within the dewatering footprint of Oxbow or JSW. Flat Rocks is the only permanent pool known by the authors in the vicinity, but this is around 20 km upstream of RTIOs proposed developments and thus would not be impacted by dewatering drawdown.

4.2 Discharge into creeklines

Discharge from Yandi (RTIO & BHPBIO) operations pose potential impacts to the aquatic ecosystem of Marillana Creek, and also to the lower Weeli Wolli Creek system downstream of the confluence with Marillana; this section of Weeli Wolli Creek is also impacted by discharge water from HD1, adding to the cumulative impact on this section of the creekline. With additional discharge from BHP-BIO's Yandi, RTIO's Yandicoogina and RTIO's HD1 operations, surface flows along Weeli Wolli will continue to increase, and the concern from the regulators is ensuring that permanent flows do not reach Fortescue Marsh. Prior to dewatering discharge at HD1, the spring resulted in perennial surface flow for approximately 2 km along the upper section of Weeli Wolli Creek. Since the commencement of discharge from HD1, surface flows in Weeli Wolli Creek now extend approximately 20 km downstream of historic perennial flow, and currently extend past Yandicoogina operations, beyond the confluence with Marillana Creek, downstream of Gray's Crossing.

Increased discharge by RTIO as a result of JSW and Oxbow developments has the potential to increase the extent of surface flows in Weeli Wolli Creek. Hydrological modelling indicated a discharge footprint of 17 km downstream of the Marillana/Weeli Wolli Creek confluence under the scenario of maximum modelled regional surplus discharge of 110 GL/year (Figure 14; RTIO 2010), including an option of relocating the discharge location in Marillana Creek downstream of mine operations (and closer to Weeli Wolli Creek). This would extend the footprint further into the Fortescue Valley and closer to the Fortescue Marsh (RTIO 2010).

Discharge of dewatering water into a seasonally/episodically flowing creekline will affect the fauna and flora of the creek.

4.2.1 Water quality

It is envisaged that water quality within Marillana Creek will not be adversely affected by the discharge operations given the high quality and similarity between surface- and ground-water qualities. This assumes no adverse effects of mining operations on water quality, such as ARD or nitrate contamination from explosives.

The potential for water quality issues will arise if dewatering water is used on-site and then discharged to the creekline. Monitoring should be undertaken at discharge points to ensure any discharge water does not exhibit any adverse water quality, i.e. high dissolved metal levels, high nutrient levels. Significantly higher total nitrogen levels have been recorded by the authors downstream of RTIOs Yandi discharge, compared with upstream on Marillana Creek (WRM 2010a). The cause of the elevated total nitrogen levels from the downstream Marillana reach is unknown, but may be coming from any number of potential sources, including current pastoral activities and cattle stocking, past cattle use and leaching from soils, and/or some influence from Yandi operations such as elevated total nitrogen in groundwater discharge water, contamination of groundwater from ammonium nitrate storage or septic systems associated with offices and accommodation, and/or elevated total nitrogen in mine process water discharged into the creek (WRM 2010a). Elevated total nitrogen and total phosphorus levels have been recorded from mine process water which is discharged from the levee bank discharge point upstream of Marillana Reach Two (Table 1). The authors are unaware of whether any baseline data exist for total nitrogen levels in the groundwater, but it could be that groundwater is naturally elevated in nutrients. Naturally high levels of nitrate have been reported from arid zone groundwaters in Australia (Barnes *et al.* 1992). If baseline data do exist for water quality of the groundwater in the vicinity of the discharge point on the levee bank it would assist in discriminating between natural conditions and possible mine effects. This highlights the importance of obtaining adequate baseline data prior to development.

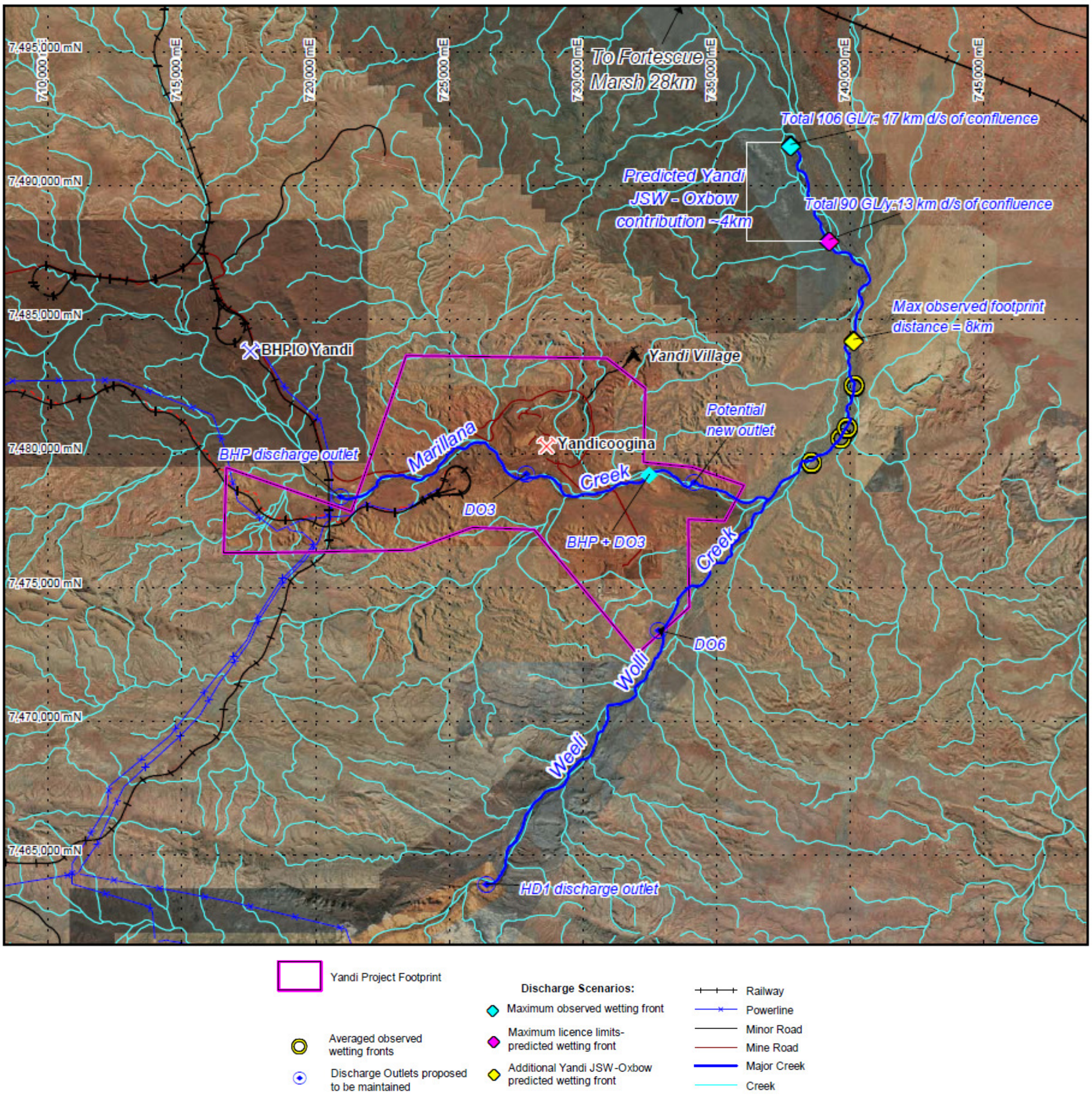

Figure 14. Estimated discharge footprints for Marillana and Weeli Wolli Creeks for different discharge rates.

Currently, the hydrology of Marillana Creek is influenced by aseasonal, intermittent, low flow discharge from BHPBIO and RTIOs Yandi operations. This has led to almost continual low flows in some sections of the creek which has allowed the excessive algal growth characteristic of the creek. The permanent water attracts cattle, increasing nutrient loads, and the low flows, low turbidity, and high light intensity create ideal conditions for the proliferation of algae. Due to the consistently high algal growth along the creek, the authors collected samples in October 2009 sampling and sent them to Gosia Przybylska (Algaltest, Melbourne) for identification. Species recorded from these samples included the filamentous greens *Spirogyra* sp., *Mougeotia* sp. and *Zygnema* sp. (Chlorophyta), diatoms *Encyonema silesiacum, Mastogloya sp.* and *Nitzschia sp.*, and Cyanobacteria *Gloeotrichia raciborskii*, *Trichodesmium* sp., and *Phormidium* sp. The filamentous greens *Spirogyra*, *Mougeotia* and *Zygnema* are common in waters of ponds, ditches and lagoons with reasonably clean, not polluted but rather eutrophic waters. They can also occur at the edge of running water. However with the right conditions they will create slimy, unpleasant masses under the surface. The cyanobacteria *Gloeotrichia raciborskii* is a non-toxic algae, but can be abundant in the right conditions, growing periphytically on aquatic plants and submerged stones and wood. The colonies of filaments enveloped in slime can detach from the substrate and float on the surface (Gosia Przybylska, Algaltest, pers comm.).

Table 1. Total nitrogen (mg/L) and total phosphorus (mg/L) concentrations in mine process water recorded from the levee bank discharge point at RTIOs Yandi. Data provided by RTIO Yandi. Shading indicates the value exceeds ANZECC/ARMCANZ (2000) guidelines.

Year	Sample date	Total N (mg/L)	Total P (mg/L)
2009	27/01/2009	1.7	1.7
	25/02/2009	2.9	1.6
	24/03/2009	15	9.2
	15/04/2009	20	5
	26/05/2009	17	20
	17/06/2009	26	13
	28/07/2009	19	23
	27/08/2009	57	0.83
	16/09/2009	6.9	10
	28/10/2009	12	8.9
	30/11/2009	3.1	7.3
2010	19/01/2010	2.5	5.9
	15/02/2010	3.1	7.4

The lack of wet season flushing flows leads to the accumulation of black, anoxic decomposing algae. Therefore, future discharge could perhaps be advantageous to the water quality of Marillana Creek if the regime allowed for some higher magnitude wet season flows to flush the system of excess nutrients and decomposing algae. Monitoring of the nearby Weeli Wolli Creek, which initially had elevated nutrient levels, has shown a significant decline in mean nutrient concentrations over time, which may, in part, be attributed to flushing by dewatering discharge.

Another potential water quality impact is the possibility for change to surface water temperatures from groundwater discharge. Water temperature in groundwater is generally more stable than surface water because the high specific heat capacity of water and the insulating effect of soil and rock can mitigate the effects of climate on groundwater temperatures. However, discharge water from deep aquifers is likely to be considerably hotter than surface water at different times of the year. Discharging water of a higher temperature than the receiving environment is called thermal pollution, and the change in temperature in the surface water can impact the ecosystem through decreased oxygen

supply (Chang *et al.* 1992, Meyer *et al.* 1999); increased metabolic rate of aquatic fauna (Rouse *et al*. 1997, Gillooly *et al*. 2001); affects to the timing of breeding, spawning and other life-history cycles; increased primary production leading to algal blooms (Robarts and Zohary 1987, Ochumba and Kibaara 1989); and, can ultimately reduce aquatic biodiversity (Parker *et al.* 1973, Ward 1976).
Increases in dissolved oxygen and water temperatures associated with discharge of groundwater high in ions such as calcium and carbonate can also lead to changes in water chemistry and the dissolution of calcrete. This may also lead to the formation of precipitate which armours the creek bed and 'cements' the gravel together. This armouring of the streambed effectively reduces the available habitat diversity and heterogeneity for aquatic invertebrates. Habitat heterogeneity is known to play a crucial role in the structure and trophic organisation of invertebrate communities (Bis *et al.* 2000; Miserendino 2001). Ultimately, a decrease in habitat diversity will lead to a decrease in taxa richness.

A major consideration of any mining operation is the exposure of rock types with acid-generating potential, leading to acid rock drainage (ARD) and associated implications of reduced pH and mobilised dissolved metals. The current mine plan does not show any potentially acid generating rock types in the proposed pit (Green 2010), and therefore ARD is not seen as a potential problem. However, regular monitoring of pH in surface and discharge waters will indicate if a problem is developing.

4.2.2 Aquatic invertebrates

Increased flows will increase the "carrying capacity" of Marillana Creek for macroinvertebrates. An increase in habitat heterogeneity and habitat diversity will result from the inundation of riffle zones, submerged macrophyte beds, and overhanging riparian vegetation. Habitat heterogeneity is known to play a crucial role in the structure and trophic organisation of invertebrate communities (Miserendino 2001). Ultimately, an increase in habitat diversity leads to an increase in taxa richness and abundance. Further, the diversity of aquatic fauna is influenced by complex macrophyte habitats due to their high surface area and spatial heterogeneity (Gregg and Rose 1985, Lombardo 1997, Linhart *et al*. 2002). Bella *et al.* (2005) found that, in particular, Coleoptera species richness was driven by macrophyte cover within ponds in Italy. Aquatic vegetation also provides refugia, a food source and breeding sites for macroinvertebrates. Riffle zones are also known to be biodiversity hotspots. A number of studies have found riffles to contain the greatest diversity, biomass and richness of macroinvertebrate fauna (i.e. Brown and Brussock 1991, Barbour *et al.* 1999, Phillips 2003). The provision of greater areal extent of these habitats, as more of the creek becomes perennial, will likely result in greater abundance and diversity of macroinvertebrates in the creek.

One perceived negative impact of discharge operations is the alteration to the hydrology of the system. Changes to the historic hydrological regime will mean that areas which were once ephemeral will become permanently-flowing. This switch from an ephemeral to permanent freshwater system has implications for fauna specifically adapted to temporary environments. Species which inhabit ephemeral waterbodies must survive in waters which either dry out completely or are reduced to a series of stagnant pools at certain times of the year. Despite these harsh environmental conditions, many invertebrates are found only in temporary waters (Bunn *et al.* 1989). In fact, Williams (1980) suggests that a number of invertebrates actually require a period of desiccation in order for further development to take place. In addition, biota are specifically adapted to the timing of drying and refilling cycles (Balla 1994). Therefore, any variation in the degree of seasonality can lead to changes in invertebrate community structure (Bunn *et al.* 1989) and changes in life history patterns.

Some species, including those that possess short maturation times, endure the dry season as terrestrial adult stages (*e.g.* mayflies, dragonflies, caddisflies and some beetles). Such species can be known as 'temporary residents' since they must reinvade each time a seasonal waterbody becomes inundated. Other species possess life history strategies which enable them to remain within a waterbody once surface waters have evaporated. Such taxa can be known as 'permanent residents'. These 'permanent' residents tend to be the microinvertebrates.

There are a number of strategies by which 'permanent residents' can survive in temporary environments. Some species, for example, have drought-resistant spores, eggs or larval stages (e.g. microcrustacea, many species of nematode, some species of simulid, and some species of *Tasmanocoenis* and *Cloeon* mayflies). Of the microinvertebrates, protozoans have cysts, rotifers have ephippia (resting eggs), cladocerans have diapausing eggs, copepods have nauplii (resistant early larval phase) and ostracods have resistant eggs. Most can survive extended periods of drought (Hairston *et al.* 1995). Other species are capable of burrowing into moist sediments of the hyporheic zone, below stones, or into decomposing wood debris (*e.g.*, nemerteans, oligochaetes, Glossiphonid leeches, some species of chironomids, tabanids, and some mayflies). Many bivalves and gastropods are resistant to desiccation and those species which lack an operculum are able to seal their shells with a mucus plug, known as an epiphragm.

Perennial flows will disadvantage these types of animals with specific drought-resistant strategies. However, it is suggested that 'permanent' fauna of Marillana Creek will not be lost from the system entirely. They will likely still be present in the seasonally flowing reaches upstream of the discharge point, and will re-colonise the historically ephemeral reach from here and nearby temporary creeks following mine-closure.

Other impacts to aquatic invertebrate fauna would occur as a result of aseasonal discharge. This is because aquatic biota of seasonal systems tend to be adapted to long-term average timing of flow events if they occur with sufficient predictability and frequency (i.e. in seasonal creeks of the Pilbara flows tend to occur in response to rainfall between January and May). Life-history and behavioural adaptations have been identified in fish, aquatic insects and riparian plants, and include the timing of reproduction, emergence into an aerial adult stage, diapause, movement to protected areas during floods, drought avoidance by reproducing after floods, and the excavation of deep egg nests to avoid flood scouring (Hynes 1976, Gray 1981, Bunn 1988, Hancock and Bunn 1997, Blom 1999, Barrat-Segretain 2001, Lytle 2002). For some species, such adaptations allow survival by escaping floods (Gray 1981, Lytle 2002) or droughts (Hynes 1970, Hynes 1976). In other species, adaptations enable them to take advantage of floods or droughts by timing their reproduction to coincide with optimal conditions, thereby enhancing the fitness of their offspring (Bunn 1988, Hancock and Bunn 1997, Humphries *et al*. 2002, King *et al*. 2003). Generally, life-history adaptations are such that organisms do not respond directly to individual flood or drought events. Rather, they are synchronised to long-term dynamics of the flow regime (Lytle and Poff 2004). Behavioural adaptations, however, are not coupled with long-term flow dynamics, so organisms are able to react on a per-event basis (Lytle and Poff 2004). It is likely that alterations to hydrology which redistribute flows to different times of the year would greatly affect organisms with life-history adaptations. This is because organisms with these adaptations would implement their specific strategy regardless of whether the appropriate flow/drought/timing of floods occurred, resulting in some fitness cost or even mortality (Lytle and Poff 2004). Unseasonal flows, particularly intermittent aseasonal flows may stimulate 'permanent' residents to break dormancy and commence development, but due to inappropriate temperature regimes or inadequate period of inundation/flow, they may not be able to complete their life cycle and may be lost from the system. In some aquatic fauna, the evolution of life-history strategies can sometimes be quite rapid, but adaptation in response to anthropogenic changes to flow regimes is unknown for any species (Lytle and Poff 2004).

Discharge operations may also impact hyporheic fauna. Anthropogenic alterations to hydrology (i.e. dewatering and discharge) impact hydraulic conductivity and/or hydraulic head patterns, thereby decreasing available hyporheic habitat and the strength of its connection to surface waters. In addition, anthropogenic processes which affect the rates of sediment input and transport can also affect the availability of hyporheic habitat (Edwards 1998), i.e. through the blocking of interstitial spaces (Schubert 2002).

4.2.3 Fish

Increased flows will likely increase the carrying capacity of the creek for fish. A greater area and types of habitat will become permanently inundated thereby increasing habitat availability for fish. This will result in higher abundances of the three fish species which currently inhabit the creek.

With increased flows, pool depths will also increase. In general terms, water depth is an important controlling parameter of habitat availability. It determines the amount of a particular habitat (e.g. woody debris) that is available in the water column, it determines the vertical space in the water column available to mid-water schooling species and it is an important factor in facilitating avoidance of terrestrial predators. Depth can provide relatively stable, sheltered areas whereas shallow areas are particularly sensitive to reductions in water level, and with increasing depth, light penetration decreases and hence visibility is reduced, again providing protection from predators. Deeper pools support larger fish, and can thereby increase fish biomass in the system. In a study of fish species in the DeGrey River, deeper pools were found to contain significantly larger fish than intermediate and small pools (AW Storey unpub. data). In addition, Bain *et al.* (1988) observed that shallow and slow-flowing areas were used by small, young fish of several species, and deep areas were primarily inhabited by larger, older fish. Schlosser (1982a, b), Finger (1982) and Moyle and Baltz (1985) similarly observed these relationships. Therefore, provision of deeper, permanently inundated pools will result in large fish in the system.

In addition, the potential for greater connection with the Fortescue River provides a possible mechanism for colonisation by other native species (not marine vagrants) which are known to occur in that system, i.e. the Indian short-finned eel, bony herring, lesser salmon catfish, undescribed eel-tailed catfish species (*Neosilurus* sp.), barred grunter, Fortescue grunter, empire gudgeon, and the flathead goby. Given that no introduced species are present in the Fortescue, the colonisation by exotic fish species is not considered to be an issue.

There is also the potential for adverse impacts to aquatic fauna, particularly fish, if pumps break down and the discharge to Marillana Creek ceases. Fish kills may result as large fish inhabiting pools along the creek are left in the dry as waters recede.

4.2.4 Other fauna

There is insufficient knowledge of the composition of other water-dependent fauna of Marillana Creek and their water requirements to predict their response to discharge operations. Therefore, only generic comments are made here on other fauna, with more detailed survey work required.

The native flat-shelled turtle or dinner-plate turtle (so named because of the shape of its carapace), *Chelodina steindachneri* (Plate 6), is known from the nearby Weeli Wolli Creek (at Wanna Munna; Streamtec 2004), and may be present in the Marillana Creek system. This species is endemic to Western Australia, where it occurs in coastal drainages from the DeGrey River in the north to the Irwin River in the south, and west to Wiluna, Salt lake drainage (Georges and Thomson 2010). Little is known of its habitat (Cogger 1986). Over much of its range, the flat-shelled turtle lives in streams that are completely dry for long periods and can inhabit some of the harshest environments of any Australian turtle (Legler and Georges 1993). These turtles are adapted to prevent desiccation and survive drought by burrowing into the dried–up river beds. They may aestivate for up to three years. Only one clutch of seven to eight relatively small eggs is laid a year; a pattern that appears to be adapted to a relatively long period of aestivation (Kuchling 1988). Breeding is thought to be triggered by rainfall and flash flooding. In the Pilbara, mating has been observed to coincide with increased water flow after rainfall. Flat-shelled turtles are largely carnivorous and their diets include molluscs, crustaceans and fish.

Plate 6. Flat-shelled, or dinner-plate turtle *Chelodina steindachneri* (photo taken from DEC website).

Aseasonal, intermittent releases could adversely affect tortoise by providing triggers for them to break aestivation at the wrong time of year and may not provide sufficient a period

for them to breed or lay down sufficient energy reserves to survive further aestivation. Generally, tortoise require a sufficient period of inundation to feed to a.) provide energy stores to aestivate over the coming dry period, and b.) provide energy to reproduce, with priority given to the former need.
Many frog species in the Pilbara also aestivate over dry periods to avoid desiccation, emerging following rains to opportunistically mate and lay eggs. Similarly, intermittent releases could adversely affect frog populations by providing triggers for them to break aestivation at the wrong time of year, affecting reproduction success if pool duration is insufficient for off-spring to reach maturity, and ultimately affecting population sizes. However, provision of permanent flows may be advantageous to some frog species, resulting in increased populations. As with fish, these populations would collapse upon mine closure/cessation of discharges. Implications for frog populations are not known and should be assessed specifically. A broader survey of the area would be required to confirm species composition, conservation significance and wider distribution of species.

The increased security in water availability along Marillana Creek may also attract more riparian/terrestrial fauna, such as waterbirds and lizards. The diversity of such fauna tends to be associated with riparian condition. In this case, the combination of increased flows and increase in vegetation health, complexity and diversity, will likely increase the abundance and richness of riparian fauna.

The increase in flows along Marillana Creek may also act as an attractant for feral animals, with associated impacts, such as overgrazing, trampling of banks and vegetation, erosion, increased turbidity and elevated nutrient levels.

4.2.5 Vegetation

Changes to the hydrological regime from discharge operations may adversely affect some species (i.e. through waterlogging), yet preferentially affect other species. While trees can acclimate to changes in surface and groundwater levels, the rate of change must be gradual. Roots of *E. camaldulensis*, for example are known to extend more than 10 metres below the surface, which would enable them to tap the full depth of wetted alluvial soils. Current knowledge of vegetation-hydrology relationships is limited, however studies in the Harding River catchment indicated river red gums close to the river were likely to have shallower rhizospheres (2 - 6 m depth) due to more frequent inundation from surface flow, with optimal requirements for flow once every 1 - 2 years and total or partial rhizosphere inundation for at least 1 - 3 months (R. Froend, Edith Cowan Uni., pers. comm.). Eucalypt vigour may provide a useful indicator of any detrimental changes to flow regime (*e.g.* changes to depth or duration of saturation of alluvial soils) within the Marillana Creek riparian zone.

Discharge operations may also result in increased recruitment of paperbarks (*Melaleuca*), red gums (*Eucalyptus camaldulensis*), western coolabah (*Eucalyptus victrix*) and sedges (i.e. *Typha*) along the waters edge. In fact, *Typha* may become the dominant understorey vegetation in the riparian zone. There is also the potential for colonisation by introduced weed species. Large eucalyptus and melaleuca trees in the middle of the channel in the historically seasonally-flowing channel of Marillana Creek will likely die due to waterlogging associated with permanent inundation. Potential impacts associated with mine-closure/cessation of discharge are discussed in section 4.4.

4.3 Creek realignment

As part of pit development, it will be necessary to re-align sections of Marillana Creek, particularly around the JSW deposit. This will likely require substantial excavation to develop a channel of adequate size, dimensions and elevation to act as a 'natural' creekline to join back into Marillana Creek. This engineered channel will likely remain in perpetuity and become the 'natural' creekline, so careful consideration to channel design and form must be given. All creeklines in the Pilbara are proclaimed water courses, which come under the jurisdiction of the Department of Water. Therefore, it is likely that the Department will require an ecologically sensitive design to the channel (See section 5.3 for a consideration of design features).

The realignment will result in a loss of a section of creek. However, based on surveys to-date (WRM 2009a, 2010a, Streamtec 2004), it is unlikely that this section supports unique species which are not found elsewhere along Marillana Creek. Therefore, there should be no loss of aquatic species resulting from the realignment.

A major consideration of the channel re-alignment is the ultimate fate of silt and sediment mobilised by earthworks and eroded from the re-aligned channel. Siltation/sedimentation of pools is a major threat to the ecology of rivers in arid and semi-arid areas (i.e. Cohen *et al*. 1993, WRC 1997, Prosser *et al.* 2001). Increased suspended sediment concentrations from erosion can change the channel and bed morphology (Schumm 1977, Milhous 1998), smother large woody debris and other benthic and hyporheic habitats (Bartley and Rutherfurd 1999, Rutherfurd 2000), and, coat organic deposits and algae upon which aquatic fauna depend as a food source (Arruda *et al.* 1983, McCabe and O'Brien 1983). Increased sediment loads also increases turbidity which alters the light regime (Kirk 1985), affecting phytoplankton habitat and reducing the rate of photosynthesis, and thus primary production (Hoyer and Jones 1983, Grobbelaar 1985, Davies-Colley *et al.* 1992). Impacts to macroinverterbrate communities include mortality (Newcombe and MacDonald 1991), and decreased abundance and diversity (Quinn *et al.* 1992, Metzeling *et al*. 1995). Fish may also be affected by increased levels of fine sediment through reduced feeding efficiency (Vinyard and O'Brien 1976, Gardner 1981, Berkman and Rabeni 1987), decreased growth rates (Bianchi 1963, Hausle and Coble 1976) and increased disease (Koehn and O'Connor 1990). If siltation is severe, pools will become shallower, water temperatures will increase, as will diurnal changes in oxygen levels, making the pools less suitable for fauna. Eventually, the pools may be totally in-filled. Large flood events may subsequently scour sediment from the pools, but usually this is after the ecological values in the pools have been lost (pools in arid environments are critical refuge habitats for aquatic fauna and flora). The scoured material will then be transported downstream to progressively affect other pools and their resident fauna. If this process occurs along the length of a creek, dramatic losses in biodiversity may eventuate.

4.4 Mine closure

A major issue in terms of impacts to aquatic biota relates to mine-closure and the cessation of discharge into Marillana Creek. Over the period of discharge, the ecological values of the creek will arguably be enhanced, as riparian vegetation recruitment and growth, habitat diversity, richness of aquatic macroinvertebrates, and biomass and abundance of fish, all increase. Upon cessation of discharge, the system will begin to dry out. Ecological communities that have come to depend on the increased flows will be lost. Therefore, it is important to accurately and comprehensively document current condition in order to track change in aquatic communities and to compare ecological condition following cessation of discharge.

Riparian vegetation which will establish during the period of discharge may experience reduced vigour and increased mortality. Impacts are likely to be greater for *Melaleuca* species than *Eucalyptus camaldulensis*, because the latter is considered more tolerant of drought (Streamtec/Froend Bowan & Associates 1998). In an EWR study of the Harding River in the Pilbara, the impact of reduced river flows and reduced groundwater levels on riparian vegetation was examined (Streamtec /Froend Bowan and Associates 1998). *Melaleuca leucadendra* (cadjeput) were found to prefer habitat where the water table was close to the surface and were able to tolerate drought for up to three years (Streamtec/Froend Bowan and Associates 1998). It was suggested that long-term reductions in river flows, concomitant with reductions in groundwater levels (by more than two metres for two years) would result in drought stress, reduced vigour and increased mortality (Streamtec /Froend Bowan and Associates 1998). Mature cadjebut were considered to have limited ability of coping with reductions in groundwater levels by extending their root systems to greater depths. In contrast, *Eucalyptus camaldulensis* (river red gum) were found more commonly upslope, and were believed to have a greater tolerance of dry conditions, but a greater reliance on groundwater. *E. camaldulensis* are able to extend their root systems more than 10 metres below the surface, thus allowing them to access deeper groundwater stores (Streamtec /Froend Bowan and Associates 1998). River red gum require flows every one or two years and rhizospheres must be inundated for at least one to three months. Rhizospheres of young recruits close to the riverbank are likely shallower (2 – 6 m deep), due to shallower water tables and more frequent inundation from surface flow. Therefore, young recruits found close to the riverbank may not survive reduced groundwater and surface flows once discharge ceases.

5 DEVELOPMENTAL CONSIDERATIONS

5.1 De-watering

Impacts on the hyporheic environment, hyporheic fauna and stygofauna from dewatering should be considered. The drawdown area should be adequately modelled to ascertain the extent of potential impacts and ensure no permanent pools are located within the drawdown area.

5.2 Discharge

As discussed above, the structure and function of a riverine ecosystem and many adaptations of its biota are determined by patterns of temporal variation in river flows (Richter *et al.* 1996, Lytle and Poff 2004). This concept is known as the natural flow paradigm (Poff *et al.* 1997). Therefore, it is suggested that discharge operations mimic, as much as possible, the natural flow regime, taking into consideration the magnitude, frequency and timing of flow events.

Little is known of the habitat and hydrological requirements of permanent resident fauna of Pilbara rivers, however, because these rivers have a seasonal, episodic flow regime, it is likely some species have life-history adaptations to the intermittently available surface flows, such as those mentioned in section 4.2.2. Unseasonal availability of surface water, therefore, would pose a problem for such species as it is possible they may not adapt. However, little is known of the water requirements of this aspect of the fauna and how it may react/adapt to unseasonal flows. It would be expected that intermittently available surface water in the wet season would be more readily adapted to than intermittently available water in the dry season.

The main issues to be considered for discharge regimes, where possible, include:

- intermittent, seasonal discharge to mimic, as much as possible, the natural flow regime
- alternate use of discharge points
- low flows to reduce erosion and scouring
- discharge points to be designed to reduce the impact of high energy flows on the creekline and thereby reduce potential impacts on the receiving environment, such as erosion and increased turbidity
- the potential for thermal pollution to Marillana Creek as a result of discharging groundwater of a higher temperature than surface water should be considered in the design and management of discharge operations

5.3 Channel realignment

The new realigned channel in the area around JSW should be designed as an ecologically functioning channel, and not a homogenous, 'trapezoidal' culvert. Design features which would need to be considered include:

- heterogeneity in plan form (meanders as opposed to a straight channel) and longitudinal profile (pools and riffles rather than a single gradient),
- appropriate bank profiles to avoid a steep, incised channel,
- construction of benches upon which riparian vegetation can ultimately establish (or be established using propagation and planting),
- sufficient conveyance capacity to cater for low frequency but high magnitude rainfall/run off events,
- Creation of alluvial bed habitats within the channel to act as dry-season refuges for invertebrate fauna with resistant life stages,
- areas in the channel where silt/sand can deposit to avoid the diversion having a uniform rock substrate, providing ‘habitat’ for spores/eggs of invertebrate fauna to reside,
- stabilisation of banks of constructed channel using natural materials (*i.e.* woody debris, matting, rocks, brushing and revegetation),
- revegetation to limit erosion and sediment loading and reduce the run-off and excessive deposition of fine silts that may smother benthos and hyporheos, and
- point of re-entry of the realignment into the natural channel that avoids excessive velocities from the diversion into the natural creek and so avoid excessive erosion.

6 MONITORING RECOMMENDATIONS

1) Ensure surface water flow gauging stations and groundwater level monitoring bores are maintained. Need to better understand the relationship between changes in surface flow, groundwater levels and antecedent rainfall.
2) Continue the current Marillana Creek Aquatic Sampling Programme in order to document current ecological condition and monitor any changes over time. This involves sampling water quality, microinvertebrate fauna, hyporheic fauna, macroinvertebrate fauna, and fish (diversity and length-frequency/recruitment) of twelve sites along the creek. Sampling is conducted bi-annually, in the wet and dry seasons.
3) Due to the nature of the development, a number of WRM aquatic sampling sites within the vicinity of Reach One will be lost. It is suggested that sites along Yandicoogina Creek be identified and sampled in future surveys as control sites for the development. Any permanent pools would be sampled late wet and late dry, and in the absence of permanent pools, sampling would be conducted in the late wet, only, targeting remnant pools.
4) It is suggested that baseline aquatic fauna studies also be conducted in the Fortescue Marsh to document current condition of the site. In the event that cumulative increased flows from all mining operations ever reach the marshes or affect the hydrology of the marsh, a baseline database will then exist to enable the detection of any impacts.

7 DEVELOPMENT OF TRIGGER VALUES

It is also suggested that trigger values for aquatic indicators could be developed for Marillana Creek, against which future changes could be assessed. Such trigger values have already been developed for Weeli Wolli Creek by the authors (WRM 2010c).

To assist in the detection of change over time, it is desirable to have measures of current condition at Marillana Creek that may be used as a baseline against which future change can be assessed. ANZECC/ARMCANZ (2000) recommends the development and application of system-specific trigger values. Biological indicators and trigger values have been developed and implemented throughout Australia (Hart *et al*. 1999, McAlpine and Humphrey 2001, Khalife *et al.* 2005, Storey *et al.* 2007, WRM 2008, Jones *et al.* 2008) and the world (Miller *et* al. 1988, Langdon 2001, An *et al*. 2002, Schriever *et al.* 2008), with differing management aims. Depending on the condition of the ecosystem, the management focus may vary from maintenance of current ecological health and integrity, to an improvement in ecological health for systems which have experienced considerable disturbance, so that the "condition of the ecosystem is more natural and ecological integrity is enhanced" (ANZECC/ARMCANZ 2000). In the case of Marillana Creek, trigger values for biological and water quality indicators could be developed, which, if met, will show that the current condition, following some degree of 'disturbance', is being maintained. These trigger values can be used for comparison with future data collected along Marillana Creek. The main aim of targets for the creek would be to detect any biological change to the system so that actions can be undertaken to further investigate and determine management procedures, if necessary.

It is important to note that the use of trigger values are not intended as a 'pass-fail' approach to ecosystem management. Their main purpose is to inform managers and regulators that changes in biological condition are occurring and may need to be investigated. In this way, trigger values are precisely that, a 'trigger' for further examination and assessment.

This is a similar approach to that recommended by ANZECC/ARMCANZ (2000) for water quality guidelines. When applying trigger values (TVs), ANZECC/ARMCANZ (2000) state the following:

> "*Trigger values are concentrations that, if exceeded, would indicate a potential environmental problem, and so 'trigger' a management response, e.g. further investigation and subsequent refinement of the guidelines according to local conditions*." (Section 2.1.4); and,
>
> "*Exceedances of the trigger values are an 'early warning' mechanism to alert managers of a potential problem. They are not intended to be an instrument to assess 'compliance' and should not be used in this capacity*." (Section 7.4.4)

It is suggested that guideline values are derived for a range of indicators, including water quality, species richness of microinvertebrates, species richness of macroinvertebrates, functional composition of macroinvertebrates, fish species richness, and recruitment of fish (i.e. see WRM 2010c).

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APPENDICES

Appendix 1a. Microinvertebrate $\log_{10}$ abundance data recorded from Marillana Creek sites in October 2008 and May 2009 by WRM (2010a), where 1 = 1 specimen, 2=2-10, 3=11-100, 4=101-1000, & so on.

Dry season, October 2008.

			Reach One						Reach Two					
Class/Order	**Family**	**Taxa**	**MAR1-1**	**MAR1-2**	**MAR1-3**	**MAR1-4**	**MAR1-5**	**MAR1-6**	**MAR2-1**	**MAR2-2**	**MAR2-3**	**MAR2-4**	**MAR2-5**	**MAR2-6**
PROTISTA														
Ciliophora		*Didinium* sp.	0	0	0	0	0	0	0	0	1	0	1	0
		Euplotes sp.	1	0	0	0	0	0	0	0	0	0	0	0
Rhizopoda														
	Arcellidae	*Arcella discoides*	1	1	1	0	0	0	2	1	0	0	1	0
		Arcella sp. [med., transp., domed]	0	0	0	0	0	0	0	0	0	1	0	0
		Arcella sp. [sm., brn]	0	0	0	0	0	0	0	0	0	1	0	0
	Centropyxidae	*Centropyxis aculeata*	1	0	0	0	0	0	0	2	0	1	0	0
		Centropyxis ecornis	2	3	2	2	3	2	1	1	2	2	2	1
		Centropyxis sp [med.]	1	2	0	0	0	0	0	0	1	1	0	0
		Centropyxis sp [sm, elongate]	0	0	0	0	0	0	0	0	2	0	0	0
		Centropyxis sp [tiny]	0	0	0	0	0	0	0	0	2	0	0	0
	Cyclopyxidae	*Cyclopyxis* sp.	0	0	0	1	0	0	0	0	0	0	0	0
	Difflugiidae	*Difflugia elegans*	0	0	0	0	0	0	0	0	1	1	0	0
		Difflugia gramen	0	0	0	0	0	0	0	0	0	0	0	1
	Euglyphidae	*Euglypha* sp.	0	1	0	0	0	0	0	0	0	0	0	0
	Lesquereusiidae	*Lesquereusia spiralis*	2	2	1	0	2	2	0	0	1	2	1	2
		Netzelia tuberculata	0	0	0	0	0	0	2	0	0	0	0	0
ROTIFERA														
Bdelloidea														
		indet. bdelloid [v. sm.]	1	0	0	0	2	0	0	0	0	0	0	0
Monogononta														
	Atrochidae	*Cupelopagis vorax*	0	0	0	0	0	0	1	0	0	0	0	0
	Epiphanidae	*Microcodides* cf. *chlaena*	0	0	0	0	1	0	0	0	0	0	0	0
	Euchlanidae	*Euchlanis* sp.	0	0	0	0	2	0	0	0	2	0	0	0
		Tripleuchlanis plicata	0	0	0	2	0	0	0	2	0	0	0	0
	Lecanidae	*Lecane bulla*	0	0	2	1	0	0	1	0	1	1	0	0
		Lecane curvicornis	0	0	0	0	0	0	1	0	0	0	0	0
		Lecane cf. *elsa*	0	0	0	0	0	0	0	0	0	1	0	0
		Lecane ludwigii	0	0	1	1	0	0	0	0	0	0	0	0
		Lecane luna	0	0	0	0	0	0	1	0	0	0	0	0
		Lecane (*M.*) a	0	0	0	0	0	0	0	0	2	2	0	0
		Lecane (*M.*) b	0	0	0	0	0	0	0	0	1	1	0	0
	Lepadellidae	*Colurella* sp.	1	0	0	0	0	0	0	0	2	0	0	0
		Lepadella sp.	0	0	0	1	0	0	0	0	0	0	0	0
	Mytillinidae	*Mytilinia ventralis*	0	0	0	0	0	0	1	0	0	0	0	0
	Notommatidae	*Eosphora anthadis*	0	0	0	0	0	0	0	0	0	0	1	0
		Notommata copeus	0	0	2	0	0	0	0	0	0	0	0	0
		Notommata sp.	0	0	0	0	1	0	0	0	0	0	0	0

Class/Order	Family	Taxa	Reach One						Reach Two					
			MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-1	MAR2-2	MAR2-3	MAR2-4	MAR2-5	MAR2-6
COPEPODA														
Cyclopoida														
		?*Tropocyclops* sp.	0	0	0	0	2	0	0	0	0	0	0	0
		?*Microcyclops* [late copepodite only]	0	0	0	0	1	0	0	0	0	0	0	0
		cyclopoid copepodites	0	0	0	2	2	1	2	2	3	2	1	1
		cyclopoid nauplii	0	0	0	1	2	0	0	2	2	1	1	0
CLADOCERA														
	Chydoridae	*Armatalona macrocopa*	2	1	0	0	0	1	0	0	2	1	0	2
		Alona rigidicaudis	0	0	0	0	2	0	0	0	1	0	0	0
		Alona cf. *verrucosa*	0	0	0	1	0	2	0	0	0	1	0	0
		Ephemeroporus barroisi	0	0	0	0	0	0	0	0	2	0	0	0
OSTRACODA														
		Diacypris sp.	0	0	1	0	0	0	0	1	0	0	0	0
		Limnocythere sp.	0	1	0	0	0	0	0	2	2	0	0	0
		juv. ostracods, indet.	0	2	1	0	0	0	2	0	2	2	0	1
		Taxa richness	**9**	**8**	**8**	**9**	**11**	**5**	**10**	**8**	**19**	**16**	**7**	**6**

Wet season, May 2009.

			Reach One						Reach Two					
Class/Order	***Family***	***Taxa***	***MAR1-1***	***MAR1-2***	***MAR1-3***	***MAR1-4***	***MAR1-5***	***MAR1-6***	***MAR2-1***	***MAR2-2***	***MAR2-3***	***MAR2-4***	***MAR2-5***	***MAR2-6***
PROTISTA														
Rhizopoda														
	Arcellidae	*Arcella discoides*	2	1	2	3	1	0	1	1	2	0	0	0
	Centropyxidae	*Centropyxis aculeata*	0	0	2	1	0	0	0	1	0	0	1	0
		Centropyxis ecornis	0	1	2	2	0	0	0	0	0	0	0	0
		Centropyxis sp [med.]	0	0	0	1	0	0	0	0	0	0	0	0
		Centropyxis sp [tiny]	0	0	1	0	0	0	0	0	0	0	0	0
	Difflugiidae	*Difflugia* [sm, ovoid]	0	0	1	0	0	0	0	0	0	0	0	0
	Euglyphidae	*Euglypha* sp.	0	0	1	0	0	0	0	0	0	0	0	0
	Lesquereusiidae	*Lesquereusia modesta*	0	2	0	0	0	0	0	0	0	0	0	0
		Lesquereusia spiralis	0	0	2	2	0	0	0	0	0	0	0	0
		Netzelia tuberculata	0	0	2	2	0	0	0	0	0	0	0	0
	Trinematidae	*Trinema*	0	0	1	0	0	0	0	0	0	0	0	0
ROTIFERA														
Bdelloidea		indet. bdelloid [sm.]	0	1	1	2	0	0	1	0	0	0	0	0
		indet. bdelloid [tiny]	0	0	0	1	0	0	0	0	0	0	0	0
Monogononta														
	Brachionidae	*Keratella tropica*	2	0	0	0	0	0	0	0	0	0	0	0
	Dicranophoridae	*Dicranophorus sp.*	0	0	1	0	0	0	0	0	0	0	0	0
	Epiphanidae	*Microcodides* cf. *chlaena*	0	0	0	0	0	0	0	0	0	0	0	0
	Euchlanidae	*Euchlanis incisa*	0	0	0	1	0	0	0	0	0	0	0	0
		Euchlanis sp.	0	0	0	1	0	0	0	0	0	0	0	0
		Tripleuchlanis plicata	0	2	0	0	0	0	0	0	0	1	0	0
	Lecanidae	*Lecane batillifer*	0	0	1	0	0	0	0	0	0	0	0	0
		Lecane bulla	0	0	0	3	0	0	0	0	0	0	0	0
		Lecane lunaris	1	0	0	0	0	0	0	0	0	0	0	0
		Lecane cf. *thalera*	0	0	0	2	0	0	0	0	0	0	0	0
		Lecane (*M.*) a	0	0	1	0	0	0	0	0	0	0	0	0
		Lecane (*M.*) b	0	0	1	0	0	0	0	0	0	0	0	0
	Lepadellidae	*Colurella* sp.	0	0	1	1	0	0	0	0	0	0	0	0
	Notommatidae	*Cephalodella* cf. *forficula*	0	0	0	2	0	0	0	0	0	0	0	0
		Notommata copeus	0	0	0	2	0	0	0	0	0	0	0	0
	Trichocercidae	*Trichocerca*	0	0	0	0	0	0	0	0	0	0	0	0
	Trichotriidae	*Macrochaetus*	0	0	1	0	0	0	0	0	0	0	0	0
COPEPODA														
Cyclopoida														
		?Tropocyclops sp.	0	0	0	0	0	0	0	0	0	0	0	0
		Thermocyclops decipiens	0	0	0	0	0	0	0	0	0	0	0	0
		cyclopoid copepodites	0	0	0	0	0	0	1	0	0	1	0	1
		cyclopoid nauplii	0	0	2	2	0	0	1	0	0	0	0	0

Class/Order	Family	Taxa	Reach One MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	Reach Two MAR2-1	MAR2-2	MAR2-3	MAR2-4	MAR2-5	MAR2-6
CLADOCERA														
	Chydoridae	*Alona rigidicaudis*	0	0	0	0	0	0	1	0	0	0	0	1
		Alona cf. *verrucosa*	0	0	2	0	0	0	0	0	0	0	0	0
		Chydorus	1	0	0	0	0	0	0	0	0	0	0	0
		Karualona karua	0	0	0	1	0	0	0	0	0	0	0	0
	Daphniidae	*Ceriodaphnia cornuta*	0	0	0	0	0	0	0	0	0	0	0	0
OSTRACODA														
		Limnocythere sp.	0	0	1	0	0	0	0	0	0	0	0	0
		juv. ostracods, indet.	0	1	1	2	0	0	1	0	0	0	0	1
		Taxa richness	**4**	**6**	**20**	**18**	**1**	**0**	**6**	**2**	**1**	**2**	**1**	**3**

Appendix 1b. Microinvertebrate $\log_{10}$ abundance data recorded from regional sites Flat Rocks and Marillana in October 2008 by WRM (2009a).

Phylum/Class/Order	*Family*	*Species/taxa*	*MC*	*FR*
PROTISTA				
Rhizopoda	**Centropyxidae**	*Centropyxis* cf. *ecornis*	2	2
		Centropyxis sp a [sm]	0	3
	Euglyphidae	*Euglypha* sp.	1	2
	Lesquereusiidae	*Lesquereusia spiralis*	3	1
ROTIFERA				
Bdelloidea		indet. contr. bdelloid	0	2
Monogononta	**Brachionidae**	*Keratella tropica*	2	0
	Lecanidae	*Lecane bulla*	0	2
		Lecane lunaris	0	3
		Lecane (*M.*) sp. c	0	1
	Lepadellidae	*Colurella* sp.	0	1
		Lepadella sp.	0	1
	Trichocercidae	*Trichocerca similis*	1	0
	Trichotriidae	*Macrochaetus altamirai*	0	1
CLADOCERA				
	Chydoridae	*Alona rigidicaudis*	0	2
		Alona cf. *verrucosa*	0	2
		Armatalona macrocopa	0	2
	Daphniidae	*Ceriodaphnia* sp.	0	2
COPEPODA			0	0
Cyclopoida		*Mesocyclops* sp. b [small]	0	2
		cf. *Tropocyclops* sp.	2	0
		copepodites	2	3
		nauplii	1	3
OSTRACODA			0	0
		indet. juvenile	1	0
		Taxa richness	**9**	**18**

Appendix 2. List of taxa recorded from hyporheic samples taken from Marillana Creek by WRM (2010a). Categories are P = possible hyporheic, S = stygobitic, O = occasional hyporheic stygophile, X = stygoxene and U = unknown.

Dry season, October 2008.

				Reach One						Reach Two					
Class/Order	**Family**	**Species**	**CAT**	**MAR1-1dry**	**MAR1-2dry**	**MAR1-3dry**	**MAR1-4dry**	**MAR1-5dry**	**MAR1-6dry**	**MAR2-1dry**	**MAR2-2dry**	**MAR2-3dry**	**MAR2-4dry**	**MAR2-5dry**	**MAR2-6dry**
ANNELIDA															
OLIGOCHAETA		Oligochaeta spp.	**P**	0	18	0	0	0	0	0	0	0	4	0	0
CRUSTACEA															
Amphipoda															
Crangonyctoid	**Paramelitidae**	?*Chydaekata* sp.	**S**	0	4	0	0	0	0	6	4	0	5	24	4
Copepoda															
Cyclopoida	**Cyclopodidae**	*Microcyclops varicans*	**X**	0	6	0	0	3	8	0	0	3	2	0	0
		Diacyclops sp. [copepodites]	**P**				3								
		Cyclopodidae: copepodites/males	**X**	0	10	1	9	7	15	0	1	3	5	0	2
ARACHNIDA															
ACARINA		Hydracarina spp.	**U**	0	0	0	0	0	0	1	1	0	0	0	1
COLLEMBOLLA		Collembolla spp.	**X**	0	2	0	0	0	0	0	0	0	2	0	0
INSECTA															
EPHEMEROPTERA	**Baetidae**	*Baetidae Genus 1 WA sp.1*	**O**	0	0	0	0	0	0	0	0	0	0	1	1
COLEOPTERA	**Hydrophilidae**	Hydrophilidae spp.	**U**	0	6	0	0	0	0	1	0	0	1	1	2
	Scirtidae	*Scirtidae* sp. (L)	**X**	0	9	0	0	0	0	0	0	0	11	14	0
DIPTERA		Diptera instar spp.	**X**	0	1	0	0	0	0	0	0	0	0	0	0
	Chironomidae			0	0	0	0	0	0	0	0	0	0	0	0
	Chironominae	*Paratendipes "K1"*	**X**	0	36	2	0	0	0	0	0	0	0	0	0
		Cryptochironomus griseidorsum	**X**	0	0	0	0	0	0	0	0	0	1	0	0
		Polypedilum sp.	**X**	0	0	0	0	0	1	0	0	0	0	0	0
		Tanytarsus sp.	**X**	0	6	4	0	0	6	0	0	0	1	0	0
	Orthocladiinae	Unknown genus (WW08)	**X**	0	0	0	0	2	0	0	0	0	0	0	0
	Tanypodinae	*Paramerina sp.*	**X**	0	22	1	1	0	9	0	0	0	4	3	6
		Procladius sp.	**X**	0	1	0	0	0	0	0	0	0	2	0	0
	Ceratopogonidae	Ceratopogoniinae spp.	**X**	0	16	0	0	0	0	0	0	0	8	8	0
		Ceratopogoniinae spp. (P)	**X**	0	2	0	0	0	0	0	0	0	1	0	0
		Dasyheilenae	**X**	0	0	0	0	0	0	0	0	0	1	0	1
LEPIDOPTERA	**Pyralidae**	Nymphulinae spp.	**X**	0	0	0	0	0	0	0	0	0	1	4	0
		TAXA RICHNESS		**0**	**13**	**4**	**3**	**3**	**5**	**3**	**3**	**2**	**13**	**6**	**7**

Wet season, May 2009.

				Reach One						Reach Two					
Class/Order	**Family**	**Species**	**CAT**	**MAR1-1wet**	**MAR1-2wet**	**MAR1-3wet**	**MAR1-4wet**	**MAR1-5wet**	**MAR1-6wet**	**MAR2-1wet**	**MAR2-2wet**	**MAR2-3wet**	**MAR2-4wet**	**MAR2-5wet**	**MAR2-6wet**
CNIDARIA															
HYDROZOA	**Hydridae**	*Hydra* sp.	**X**	0	2	0	0	1	0	2	0	2	0	0	0
NEMATODA		Nematoda spp.	**U**	0	0	2	0	0	0	0	0	0	0	0	0
ANNELIDA															
OLIGOCHAETA		Oligochaeta spp.	**P**	2	1	2	2	2	2	2	2	2	2	2	2
GASTROPODA															
	Lymnaeidae	*Austropeplea lessoni*	**X**	0	0	0	0	0	0	0	0	1	0	0	0
CRUSTACEA															
AMPHIPODA															
Crangonyctoid	**Paramelitidae**	*?Chydaekata* sp.	**S**	1	2	3	2	3	2	4	3	4	3	3	0
COPEPODA															
Cyclopoida	**Cyclopodidae**	Cyclopidae: copepodites/males	**U**	0	4	9	0	1	0	2	0	2	0	0	0
		Ectocyclops phaleratus	**X**	0	0	4	0	0	0	0	0	1	0	0	0
		Microcyclops varicans	**X**	0	4	0	0	1	0	2	0	0	0	0	0
ARACHNIDA															
ACARINA		Hydracarina spp.	**U**	0	2	2	0	2	1	2	2	2	0	2	0
		Oribatida spp.	**U**	0	0	0	0	0	0	0	0	2	0	0	0
COLLEMBELA		Collembolla spp.	**X**	0	2	0	0	2	0	0	0	1	0	0	0
	Entomobryoidea	Entomobryoidea spp.	**X**	0	0	0	1	0	0	0	0	0	1	2	0
		Poduroidea spp.	**X**	0	0	2	0	0	0	0	0	0	0	0	0
INSECTA															
EPHEMEROPTERA	**Baetidae**	*Genus 1 WA sp. 1*	**O**	0	0	0	0	0	0	1	0	0	0	2	1
	Caenidae	*Tasmanacoenis arcuata*	**X**	0	0	0	0	0	0	1	0	1	0	2	3
COLEOPTERA	**Dytiscidae**	Dytiscidae spp. (L)	**O**	0	0	0	0	0	0	1	0	0	0	0	0
		Limbodessus occidentalis	**O**	0	0	1	0	0	0	0	0	0	0	0	0
		Platynectes decempunctatus	**X**	0	0	0	0	0	0	0	0	0	0	0	1
	Elmidae	*Austrolimnius sp. (L)*	**U**	0	0	0	0	0	0	1	0	0	0	0	0
	Hydraenidae	*Hydraena sp.*	**X**	0	0	1	0	2	0	0	0	0	0	0	2
	Hydrophilidae	Hydrophilidae spp. (L)	**U**	0	0	0	0	0	1	0	0	0	0	0	2
		Enochrus sp. (L)	**X**	0	0	0	0	0	2	2	1	0	2	2	0
		Enochrus mastersii	**X**	0	0	0	0	0	0	0	0	0	0	0	1
		Helochares sp. (L)	**X**	0	2	2	2	2	2	2	0	1	0	2	0
		Laccobius sp. (L)	**X**	0	0	0	0	0	1	0	0	0	0	0	0

Class/Order	Family	Species	CAT	Reach One MAR1-1wet	MAR1-2wet	MAR1-3wet	MAR1-4wet	MAR1-5wet	MAR1-6wet	Reach Two MAR2-1wet	MAR2-2wet	MAR2-3wet	MAR2-4wet	MAR2-5wet	MAR2-6wet
		Paranacaena sp.	X	0	0	0	0	0	0	0	0	0	0	0	1
		Sternolophus sp. (L)	X	2	2	0	0	0	0	0	0	0	0	0	0
	Hygrobidae	*Hygrobia spp.*	X	0	0	0	0	0	0	0	0	1	0	0	0
	Scirtidae	*Scirtidae sp. (L)*	X	2	1	0	0	0	0	2	0	2	0	2	4
HEMIPTERA	**Hebridae**	*Hebrus axillaris*	X	0	0	0	0	0	0	0	0	0	0	0	1
ODONATA															
Anisoptera		Anisoptera sp. (imm)	X	0	0	0	0	0	0	0	0	0	0	2	0
Zygoptera		Zygoptera sp. (imm)	X	0	0	0	0	0	0	0	0	0	0	2	0
DIPTERA	**Chironomidae**														
	Chironominae	*Paratendipes "K1"*	X	2	0	2	0	0	0	0	0	0	0	0	3
		Cryptochironomus griseidorsum	X	2	0	0	0	0	0	0	0	0	0	0	0
		Tanytarsus sp.	X	0	0	3	0	0	0	1	0	0	0	0	0
		WWTS5	X	0	0	13	0	0	0	0	0	2	0	0	1
	Orthocladiinae	*Rheocricotopus sp.*	X	0	0	0	0	1	0	0	0	0	0	0	0
		Cricotopus albitarsis	X	1	0	0	0	0	0	0	0	0	0	0	1
		Thienemanniella sp.	X	2	0	0	0	0	0	0	0	0	0	0	0
		Corynonoeura sp.	X	0	0	0	0	0	0	0	0	0	0	0	1
		Unknown genus (WW08)	X	0	0	0	0	0	0	0	0	0	3	0	0
	Tanypodinae	*Paramerina sp.*	X	6	64	1	0	36	0	26	6	32	1	34	15
		Thienemannimyia sp.	X	2	0	0	0	0	0	0	0	0	0	0	0
		Nilotanypus sp.	X	1	0	0	0	0	0	0	0	0	0	0	3
		Larsia ?albiceps	X	0	0	0	0	0	0	0	0	0	0	1	0
	Ceratopogonidae	Ceratopogonidae (P)	X	0	0	2	0	1	2	2	0	2	0	2	0
		Ceratopogoninae sp.	X	2	2	3	2	2	2	1	2	3	2	3	2
		Dasyheleinae sp.	X	2	3	3	2	1	2	2	0	2	2	3	2
		Forcipomyiinae sp.	X	2	0	1	0	0	0	0	0	0	0	0	0
	Dolichopodidae	Dolichopodidae spp.	X	2	1	2	0	0	0	1	0	0	0	0	1
	Ephydridae	Ephydridae spp.	X	0	0	0	0	0	2	0	0	0	0	0	0
	Simuliidae	Simuliidae spp.	X	0	0	0	0	1	1	0	0	0	0	0	0
	Syrphidae	Syrphidae spp.	X	0	0	0	0	0	0	0	0	0	0	1	0
	Thaumaleidae	Thaumaleidae spp.	X	0	0	0	0	0	0	0	0	1	0	0	0
	Tipulidae	Tipulidae spp.	X	0	2	0	0	0	2	0	0	2	0	0	0
TRICHOPTERA	**Hydropsychidae**	*Cheumatopsyche sp.*	X	0	0	0	0	0	0	1	0	0	0	0	1
	Lepidoptera	Lepidoptera spp. (imm)	X	0	0	0	0	0	0	0	1	0	0	0	2
	Philpotomidae	*Chimarra uranka*	X	1	0	0	0	0	0	0	0	0	0	0	2
		Taxa richness		**16**	**15**	**19**	**6**	**15**	**13**	**20**	**7**	**20**	**8**	**17**	**22**

Appendix 3a. List of macroinvertebrate families recorded from the Marillana Creek regional site during the AusRivAS FNARH surveys (data provided by Adrian Pinder, DEC).

Wet season, March 1998.

Phylum/Class/Order	Family
Oligochaeta	indeterminate
Acarina	indeterminate
Mollusca	
Gastropoda	Planorbidae
Crustacea	
Amphipoda	Paramelitidae
Insecta	
Ephemeroptera	Baetidae
	Caenidae
Odonata	Aeshnidae
	Coenagrionidae
	Corduliidae
	Isostictidae
	Libellulidae
Hemiptera	Belostomatidae
	Corixidae
	Gerridae
	Notonectidae
	Pleidae
Coleoptera	Dytiscidae
	Gyrinidae
	Hydrophilidae
Diptera	Chironominae*
	Tanypodinae*
	Ceratopogonidae
	Culicidae
No. of families	23

* = subfamily of Chironomidae

Appendix 3b. List of macroinvertebrate taxa recorded from Flat Rocks by Streamtec (2004) between 2001 and 2003. Presence/absence data, where 1 = present, 0 = absent.

Class/Order	*Family*	*Species/taxa*	*FR dry-01*	*FR wet-02*	*FR wet-03*	*FR dry-03*
MOLLUSCA						
GASTROPODA						
	Planorbidae	*Gyraulus* sp.	1	1	0	1
	Lymnaeidae	*Austropeplea lessoni*	1	1	1	1
	Ancylidae	*Ferrissia petterdi*	0	0	0	1
ANNELIDA						
Oligochaeta		Oligochaeta spp.	0	1	0	1
ARACHNIDA						
ACARINA		Acarina spp.	1	1	1	1
INSECTA						
EPHEMEROPTERA	**Baetidae**	Genus 1 WA sp. 1	1	0	1	0
		Cloeon sp.	1	1	1	1
	Caenidae	*Tasmanocoenis arcuata*	1	1	1	1
ODONATA						
Anisoptera	**Hemicorduliidae**	*Hemicordulia tau*	1	0	0	0
	Gomphidae	*Austrogomphus gordoni*	1	0	0	1
	Lindeniidae	*Ictinogomphus dobsoni*	0	0	0	1
	Libellulidae	*Orthetrum caledonicum*	0	0	1	0
		Diplacodes haematodes	1	1	1	1
	Aeshnidae	*Hemianax papuensis*	0	1	0	0
Zygoptera	**Coenogrionidae**	*Coenagrionidae* spp.	1	1	0	1
		Ischnura pruinescens	0	0	0	1
HEMIPTERA	**Veliidae**	*Microvelia* sp.	0	0	0	1
	Mesoveliidae	*Mesovelia* sp.	0	1	0	0
	Pleidae	*Plea brunni*	1	1	0	1
	Corixidae	*Micronecta* sp. UK1	1	0	1	1
	Notonectidae	*Anisops* sp.	1	0	1	0
	Naucoridae	Naucoridae spp.	0	1	0	1
	Gerridae	*Limnogonus (L) fossarum*	1	1	1	1
	Hebridae	*Merragata hackeri*	1	1	0	0
DIPTERA		Diptera sp. UD2	1	0	0	0
	Dolichopidae	Dolichopodidae sp.	0	0	1	0

Class/Order	Family	Species/taxa	FR dry-01	FR wet-02	FR wet-03	FR dry-03
	Simuliidae	*Simulium ornatipes*	1	1	1	1
	Chironomidae	Chironomidae spp.	1	1	1	1
	Ceratopogonidae	Ceratopogonidae spp.	1	1	1	1
	Culicidae	*Anopheles* sp.	1	0	1	1
		Aedomyia catastica	0	1	0	1
		Culex sp.	1	1	1	1
	Stratiomyidae	Stratiomyidae sp.	1	1	0	1
	Tabanidae	*Tabanus* sp.	1	0	0	1
LEPIDOPTERA	**Pyralidae**	Pyralidae sp.	1	1	1	1
TRICHOPTERA	**Ecnomidae**	*Ecnomus* sp.	1	0	1	1
	Leptoceridae	*Leptocerus atsou*	1	0	0	0
		Oecetis sp. 1	1	1	0	1
		Triplectides ?australicus	1	0	0	1
		Triplectides ciuskus seductus	1	1	0	1
	Hydroptilidae	*Orthotrichia* sp.	1	1	0	0
		Hellyethera ?vernoni	0	1	0	1
	Hydropsychidae	*Cheumatopsyche* sp.	1	0	1	1
COLEOPTERA	**Dytiscidae**	*Cybister tripunctatus*	0	0	1	0
		Hydroglyphus fuscolineatus	0	0	1	0
		Hydroglyphus leai	0	1	1	1
		Hydroglyphus orthogrammus	0	0	1	1
		Hydroglyphus trilineatus	0	0	0	1
		Hydrovatus sp. (L)	1	1	0	1
		Necterosoma regulare	1	0	1	0
		Sternopriscus sp.	1	0	0	1
		Sternopriscus sp. (L)	0	0	0	1
		Tiporus tambreyi	1	1	0	0
	Hydrophilidae	*Berosus australiae*	1	0	0	0
		Helochares sp.	0	1	0	0
		Regimbartia attenuata	0	0	0	1
		Paracymus sp.	0	0	0	1
		Hydrophilidae sp. (L)	0	1	0	1
		Laccobius matthewsi	0	0	0	1
	Hydrochidae	*Hydrochus* sp.	1	0	0	1
	Hydraenidae	*Hydreana* sp.	0	0	0	1
		Octhebius sp.	0	0	0	1
	Carabidae	Carabidae sp. PB1	0	1	0	0
		Taxa richness	**37**	**31**	**24**	**45**

Appendix 3c. Macroinvertebrate log_{10} abudance data recorded from Marillana Creek by WRM (2010a).

October 2008.

Class/Order	Family		Reach One MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	Reach Two MAR2-1	MAR2-2	MAR2-3	MAR2-4	MAR2-5	MAR2-6
CNIDARIA														
Hydrozoa		*Hydra* sp.	0	1	0	2	0	1	0	0	0	2	0	0
ANNELIDA														
OLIGOCHAETA		Oligochaeta spp.	3	0	2	0	1	4	0	0	3	3	2	3
MOLLUSCA														
GASTROPODA	**Ancylidae**	*Ferissa petterdi*	0	0	0	0	0	0	0	0	0	0	1	0
	Lymnaeidae	*Austropeplea lessoni*	0	2	0	3	3	4	1	2	3	2	2	2
	Planorbidae	*Gyraulus hesperus*	0	0	0	0	0	3	1	2	2	2	0	2
ARACHNIDA														
ACARINA		Hydracarina spp.	3	0	0	4	2	0	2	4	3	3	4	3
ORIBATIDA		Oribatida spp.	0	0	0	2	2	0	0	0	0	0	1	0
INSECTA														
EPHEMEROPTERA	**Caenidae**	Caenidae spp. (imm.)	0	0	0	3	0	2	2	0	0	3	0	0
		Tasmanocoenis arcuata	4	2	3	3	2	2	2	0	3	4	2	3
	Baetidae	Baetidae spp. (imm.)	0	0	0	4	3	2	2	0	0	0	4	0
		Baetidae Genus 1 WA sp.1	4	1	3	4	2	0	4	4	3	4	4	4
		Cloeon sp.	0	0	0	0	4	3	0	0	0	4	0	0
ODONATA														
Anisoptera		Anisoptera spp.(imm)	2	0	0	2	3	0	0	0	0	2	2	0
	Libellulidae	Libellulidae spp. (imm.)	1	0	0	2	0	2	0	0	1	0	0	2
		Diplacodes haematodes	2	2	2	0	2	0	0	0	2	2	0	2
		Nannophlebia injabandi	0	0	0	0	0	0	0	0	0	0	1	0
		Orthetrum caledonicum	0	2	0	0	0	0	0	0	0	0	0	2
		Zyxomma elgneri	2	0	0	2	0	0	0	0	0	0	2	0
HEMIPTERA	**Belostomatidae**	*Diplonychus eques*	0	1	0	0	0	0	0	0	0	0	0	0
	Corixidae	Corixidae spp. (imm.)	0	0	0	0	0	1	0	0	0	0	0	0
	Gerridae	Gerridae spp. (imm.)	0	0	0	0	0	2	0	0	0	0	0	0
		Limnogonus fossarum gilguy	0	0	0	0	0	0	0	0	0	0	2	0
		Rhagadotarsus anomolus	0	3	0	0	0	0	0	0	0	0	0	0
	Hebridae	Hebridae spp. (imm.)	0	0	0	0	0	1	0	0	1	1	2	0
		Hebrus axillaris	0	1	0	0	0	0	1	0	0	1	0	1
	Nepidae	*Laccotrephes tristis*	0	0	0	0	0	1	0	0	0	0	0	0
	Naucoridae	*Naucoris subopacus*	1	0	0	0	0	2	0	0	0	0	2	1
	Notonectidae	*Anisops* sp. (F)	0	0	0	0	0	2	0	0	0	0	0	0
	Pleidae	*Paraplea brunni*	0	0	1	0	0	0	0	0	0	0	0	0
	Velidae	Veliidae spp.(imm.)	0	0	0	0	2	2	0	0	0	0	2	0
		Microvelia australiensis	0	0	0	0	0	0	0	0	0	0	1	0

Class/Order	Family		Reach One						Reach Two					
			MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-1	MAR2-2	MAR2-3	MAR2-4	MAR2-5	MAR2-6
COLEOPTERA	**Dytiscidae**	*Platynectes* sp. (L)	0	1	1	2	0	0	0	0	0	2	0	0
		Platynectes decempunctatus var decemp.	0	0	0	0	0	0	2	0	1	0	2	0
		Tiporus tambreyi	0	0	0	0	0	0	0	0	0	1	0	0
	Elmidae	*Austrolimnius* sp. (A)	0	0	0	1	0	0	0	0	0	1	0	0
		Austrolimnius sp. (L)	0	0	0	3	0	1	1	2	3	0	2	1
	Gyrinidae	*Aulonogyrus strigosus*	0	0	2	0	0	0	0	0	0	0	0	0
		Aulonogyrus/Macrogyrus sp. (L)	0	0	0	0	0	0	0	0	1	1	0	0
		Dineatus australis	0	0	0	0	0	0	0	0	0	0	0	2
	Hydraenidae	*Hydraena sp.*	0	1	0	0	0	0	1	0	0	0	0	0
	Hydrophilidae	*Berosus* sp. (L)	0	0	0	1	2	0	0	0	1	3	0	0
		Berosus dallasae	0	0	2	1	0	0	0	0	0	0	0	0
		Coelostoma sp.	0	2	0	0	0	0	0	0	1	2	0	0
		Helochares sp. (L)	2	2	1	1	3	2	2	1	2	2	1	2
		Helochares tatei	0	0	0	0	0	2	0	1	0	2	0	1
		Laccobius bili	0	0	1	0	0	0	0	0	0	0	0	0
		Paracymus pygmaeus	0	0	0	0	0	2	0	0	0	0	0	1
		Sternolophus sp. (L)	0	0	0	0	0	2	0	0	0	0	0	0
	Hydrochidae	*Hydrochus* sp.	0	0	1	0	0	0	1	1	1	2	0	2
	Scirtidae	Scirtidae spp. (L)	2	2	0	3	0	1	0	1	2	0	2	1
DIPTERA	**Chironomidae**	Chironomidae spp. (P)	2	2	3	4	3	3	2	2	2	3	2	3
		Paramerina sp.	2	1	0	3	3	0	0	0	2	2	3	3
		Thienemannimyia sp.	0	0	0	2	0	0	2	2	3	3	2	3
		Nilotanypus sp.	1	0	0	3	0	0	0	1	2	1	2	1
		Larsia ?albiceps	2	2	2	2	3	0	2	2	3	1	3	3
		Procladius sp.	0	0	0	0	0	0	0	0	0	0	0	1
		Ablabesmyia hilli	0	1	1	0	0	0	0	0	2	0	2	1
		Rheocricotopus sp.	3	2	2	3	0	0	3	2	1	2	3	1
		nr. Parametriocnemus	0	0	1	2	0	0	0	0	0	0	0	0
		Cricotopus albitarsis	2	2	3	0	0	0	3	3	2	3	4	3
		Thienemanniella sp.	3	1	1	3	2	0	3	3	2	2	4	2
		Corynonoeura sp.	2	1	3	4	3	0	2	0	0	1	3	3
		Paratendipes "K1"	0	3	1	3	2	0	2	1	0	1	0	0
		Chironomus sp.	0	1	0	0	0	3	0	0	0	0	0	2
		Cryptochironomus griseidorsum	2	2	2	2	2	1	2	0	1	0	2	2
		Polypedilum nubifer	0	0	2	0	0	0	1	0	0	0	0	0
		Dicrotendipes sp1	0	0	2	0	0	0	0	0	1	0	1	0
		Dicrotendipes sp2	0	1	0	0	2	0	1	1	1	0	3	0
		Cladopelma curtivala	0	0	0	0	0	0	1	0	0	0	0	2
		Polypedilum watsoni	0	0	0	0	1	0	0	0	1	0	0	1
		Paracladopelma sp "M1"	0	0	0	0	0	0	2	0	0	0	0	0
		Polypedilum sp.	0	1	0	0	0	0	0	0	2	0	0	1
		WWC17	0	0	0	0	0	0	0	0	0	0	0	1

Class/Order	Family		Reach One MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	Reach Two MAR2-1	MAR2-2	MAR2-3	MAR2-4	MAR2-5	MAR2-6
		Tanytarsus sp.	1	3	3	3	3	3	2	2	2	1	1	3
		Paratanytarsus sp.	0	2	2	2	0	0	2	0	0	0	3	0
		Cladotanytarsus sp.	0	0	0	2	2	0	2	0	0	0	0	0
		WWTS5	1	2	2	3	0	0	3	0	0	0	3	0
	Ceratopogonidae	Ceratopogoniinae spp.	2	2	3	3	4	2	2	1	2	2	3	3
		Dasyheilenae spp.	3	2	0	3	4	2	0	4	3	4	2	0
		Forcypomiinae spp.	0	0	0	0	2	0	0	0	1	0	2	0
		Ceratopogonidae spp. (P)	0	2	2	3	1	2	0	2	2	2	2	2
	Culicidae	*Anopheles* sp.	0	0	0	0	0	0	0	0	0	1	0	0
		Culicidae spp. (P)	0	0	0	0	0	0	0	0	0	0	0	1
	Dolichopidae	Dolichopodidae spp.	3	0	2	3	2	0	2	2	2	2	2	2
	Ephydridae	Ephydridae spp.	0	0	2	0	0	2	0	0	2	0	1	1
	Simuliidae	Simulidae spp (P)	1	2	0	0	0	0	2	2	0	2	0	2
		Simulidae spp.	3	3	0	0	0	0	3	3	3	3	2	2
	Stratiomyidae	Stratiomyidae spp.	0	2	0	0	0	2	1	0	3	0	2	1
	Tabanidae	Tabanidae spp.	0	0	0	0	0	2	0	0	2	0	1	0
	Tipulidae	Tipulidae spp.	0	0	2	0	2	2	0	0	0	0	0	0
TRICHOPTERA		Trichoptera spp. (P)	1	0	0	1	0	0	0	2	0	1	1	1
	Ecnomidae	*Ecnomus* sp.	0	0	2	2	0	0	0	0	0	3	1	2
	Hydropsychidae	*Cheumatopsyche wellsae (spAV11)*	4	3	2	4	2	1	4	4	4	4	5	4
	Hydroptilidae	*Hellyethira* sp	0	2	2	0	2	0	0	0	1	0	3	1
	Orthotrichidae	*Orthotrichia spp.*	1	0	0	0	0	0	0	0	0	0	0	0
	Leptoceridae	Oecetis spp.	2	0	0	2	0	0	0	1	0	0	0	2
		Triaenodes spp.	0	0	0	2	0	0	0	0	0	0	0	0
		Triplectides australis	0	0	0	1	0	0	0	0	0	0	0	0
		Triplectides ciskus seductus	2	0	0	2	0	0	0	0	2	0	3	1
	Philopotamidae	Philopotamidae spp. (imm.)	0	0	0	0	0	0	2	0	0	0	0	0
		Chimmara sp.	4	3	1	3	0	0	4	3	3	3	2	3
LEPIDOPTERA	**Pyralidae**	*Nymphulinae cf sp. 3*	2	3	3	3	3	0	2	3	2	3	0	2
		Nymphulinae cf sp. 37	2	0	0	0	0	0	1	0	2	3	0	0
		Nymphulinae spp. (imm.)	0	0	0	0	0	0	0	3	0	2	3	0
		Taxa richness	**35**	**40**	**36**	**46**	**33**	**34**	**40**	**31**	**47**	**47**	**52**	**52**

May 2009.

			Reach One						Reach Two					
Class/Order	*Family*	*Taxa*	*MAR1-1*	*MAR1-2*	*MAR1-3*	*MAR1-4*	*MAR1-5*	*MAR1-6*	*MAR2-1*	*MAR2-2*	*MAR2-3*	*MAR2-4*	*MAR2-5*	*MAR2-6*
ANNELIDA														
OLIGOCHAETA		Oligochaeta spp.	0	0	2	2	2	0	0	2	0	1	2	0
MOLLUSCA														
GASTROPODA	**Planorbidae**	*Gyraulus hesperus*	0	0	0	0	0	0	3	1	1	0	0	0
	Ancylidae	*Ferrissia petterdi*	0	0	2	0	0	0	2	0	0	0	0	0
CRUSTACEA														
AMPHIPODA	**Paramelitidae**	*?Chydaekata* sp.	0	0	2	0	0	0	0	3	2	0	0	0
ARACHNIDA														
ACARINA		Hydracarina spp.	3	3	4	3	4	3	3	2	2	3	4	4
ORIBATIDA		Oribatidae spp.	2	0	2	0	0	0	0	0	0	0	0	0
INSECTA														
EPHEMEROPTERA	**Baetidae**	Baetidae spp (dam)	0	0	0	0	0	0	2	0	0	0	0	0
		Genus 1 WA sp. 1	3	3	3	4	4	3	3	5	5	5	4	4
	Caenidae	*Tasmanacoensis arcutata*	2	4	4	2	2	3	1	0	2	3	0	4
ODONATA														
Anisoptera		Anisoptera spp. (imm)	0	0	0	0	0	0	0	0	0	0	1	0
	Aeshnidae	Aeshnidae spp. (imm)	0	0	1	0	0	0	0	0	0	0	0	0
	Gomphidae	*Austrogomphus gordoni*	0	0	1	0	0	0	0	0	0	0	1	0
	Libellulidae	*Diplacodes haematodes*	0	2	2	2	2	0	0	0	1	0	0	0
		Nannophlebia injabandi	0	2	0	0	0	0	3	0	0	0	3	0
Zygoptera	**Coenagrionidae**	Coenagrionidae spp.	0	0	1	0	0	0	0	0	0	0	0	0
HEMIPTERA	**Gerridae**	*Limnogonus fossarum gilguy*	0	0	1	1	0	0	1	0	0	2	0	1
	Mesoveliidae	*Mesoveliidae spp. (imm)*	0	0	0	0	0	0	0	0	0	1	0	0
	Naucoridae	*Naucoris subopacus*	0	0	1	0	0	0	0	0	0	0	0	0
COLEOPTERA	**Dytiscidae**	*Platynectes decempunctatus var decem.*	0	1	0	0	0	0	0	0	0	0	0	0
		Platynectes sp. (L)	0	0	0	2	2	2	0	0	0	0	0	0
		Tiporus centralis	0	0	1	0	0	0	0	0	0	0	0	0
	Elmidae	*Austrolimnius* sp (A)	0	0	2	3	3	2	1	1	0	2	0	1
		Austrolimnius sp. (L)	0	0	1	3	4	3	2	2	0	2	2	0
	Gyrinidae	*Aulonogyrus strigosus*	0	0	0	0	0	0	0	0	1	0	0	0
		Dineutus australis	0	0	0	0	0	0	0	0	2	0	0	0
	Hydrophilidae	Hydrophilidae spp. (L)	0	0	1	1	1	2	0	1	1	1	0	1
		Berosus dallasae	0	0	0	0	0	0	0	1	0	0	0	0
		Helochares tatei	0	0	0	0	0	0	0	0	1	0	0	0
		Helochares sp. (L)	1	0	0	0	0	0	1	0	1	0	0	1
	Scirtidae	Scirtidae spp. (L)	2	0	0	2	0	1	0	3	3	2	3	3
DIPTERA	**Ceratopogonidae**	Ceratopogoniinae spp.	2	3	2	2	3	2	2	2	1	3	2	2
		Dasyheleinae spp.	0	0	0	0	0	2	0	0	0	0	0	0
		Forcipomyiinae spp.	0	0	0	0	0	0	0	0	0	0	1	0

			Reach One						Reach Two					
			MAR1-1	MAR1-2	MAR1-3	MAR1-4	MAR1-5	MAR1-6	MAR2-1	MAR2-2	MAR2-3	MAR2-4	MAR2-5	MAR2-6
	Chironomidae	Chironomidae spp. (P)	0	0	0	0	0	2	2	0	1	0	0	0
		Paramerina sp.	0	2	3	2	2	0	0	0	0	2	2	2
		Thienemannimyia sp.	1	3	1	2	2	1	0	1	2	3	2	3
		Nilotanypus sp.	2	2	1	1	2	1	2	1	0	2	1	2
		Larsia ?albiceps	2	2	2	1	1	1	0	0	1	2	0	3
		Procladius sp.	0	0	0	0	0	0	0	1	0	0	0	0
		Ablabesmyia hilli	0	0	0	0	0	1	0	0	1	0	0	0
		Rheocricotopus sp.	3	3	0	3	3	3	3	2	3	3	2	3
		Cricotopus albitarsis	3	2	3	3	3	3	1	3	3	3	3	3
		Thienemanniella sp.	3	2	0	3	3	2	2	2	3	3	3	3
		Corynonoeura sp.	1	0	3	0	0	0	1	0	0	0	0	1
		Paracladopelma "K2"	0	2	0	0	1	0	0	0	0	0	0	0
		Paratendipes "K1"	0	2	0	1	0	0	1	0	0	0	0	2
		Cryptochironomus griseidorsum	0	2	0	2	1	1	1	0	0	0	0	2
		Dicrotendipes sp1	2	2	3	3	3	2	0	0	1	0	2	2
		Dicrotendipes sp2	0	0	2	0	2	0	0	0	1	1	2	2
		Tanytarsus sp.	2	1	0	0	1	2	0	0	1	0	0	1
		Cladotanytarsus sp.	0	0	0	0	0	0	0	0	0	2	0	0
		WWTS5	2	2	0	2	0	0	2	1	2	2	2	2
	Dolichopodidae	Dolichopodidae spp.	0	3	0	2	2	3	2	0	2	1	0	0
	Simulidae	Simulidae spp.	3	4	1	3	3	4	3	3	4	3	2	2
		Simuliidae sp (P)	0	0	0	0	0	0	2	1	1	0	0	0
	Syrphidae	Syrphidae spp.	0	0	0	0	0	2	0	0	0	0	0	0
	Tabanidae	Tabanidae spp.	0	1	0	1	0	2	0	0	2	0	0	0
	Tanyderidae	Tanyderidae spp.	0	0	0	0	1	0	0	0	0	0	0	0
TRICHOPTERA	**Ecnomidae**	*Ecnomus sp.*	0	0	2	0	0	0	0	0	0	0	0	1
	Hydroptilidae	Hydroptilidae sp (imm)	1	0	1	0	0	0	0	0	0	0	0	0
		Hellyethira sp.	0	0	2	2	2	0	0	0	0	0	0	2
	Hydropsychidae	*Cheumatopsyche wellsae*	4	4	1	4	4	0	5	5	0	4	4	4
	Leptoceridae	*Oecetis sp.*	0	0	0	0	0	0	1	0	0	0	0	1
		Triplectides ciuskus seductus	0	0	0	0	0	0	0	0	0	0	0	1
	Philopotamidae	*Chimarra* sp.	3	4	0	3	3	0	4	3	0	3	3	3
LEPIDOPTERA	**Nymphulinae**	*Nymphulinae sp. 3*	3	4	3	4	4	4	0	3	3	3	3	4
		Nymphulinae sp. 18	1	0	0	0	0	0	0	0	1	0	3	2
		Nymphulinae sp. 37	0	0	0	0	0	0	0	0	0	0	2	3
		Taxa richness	**23**	**26**	**32**	**30**	**29**	**26**	**27**	**23**	**30**	**26**	**25**	**33**

Appendix 3d. Macroinvertebrate log_{10} abudance data recorded from Flat Rocks and Marillana Creek regional sites by WRM (2009a).

Dry season - October 2008.

Class/Order	*Family*	*Species/taxa*	*MC*	*FR*
TURBELLARIA		Turbellaria spp.	0	1
NEMATODA		Nematoda spp.	0	1
CNIDARIA				
HYDRAZOA		*Hydra* sp.	0	2
MOLLUSCA				
GASTROPODA	**Ancylidae**	*Ferrissia sp.*	0	2
	Lymnaeidae	*Austropeplea lessoni*	2	3
	Planorbidae	*Gyraulus hesperus*	2	0
ANNELIDA				
OLIGOCHAETA		Oligochaeta spp.	3	2
ARACHNIDA				
ACARINA		Acarina spp.	2	2
INSECTA				
EPHEMEROPTERA		Ephemeroptera spp (dam.)	0	2
	Caenidae	*Tasmanocoenis arcuata*	2	2
	Baetidae	Baetidae spp. (imm.)	2	2
		Baetidae Genus 1 WA sp.1	2	0
		Cloeon sp.	3	0
ODONATA				
Zygoptera		Zygoptera sp damaged	0	2
Anisoptera	**Gomphidae**	*Austrogomphus gordoni*	1	2
	Libellulidae	*Diplacodes haematodes*	2	2
		Orthetrum caledonicum	1	1
HEMIPTERA	**Naucoridae**	*Naucoris* sp.	0	2
COLEOPTERA	**Dytiscidae**	*Hydroglyphus orthogrammus*	0	2
		Tiporus tambreyi	1	0
	Hydraenidae	*Hydraena sp.*	1	0
		Limnebius sp.	0	1
	Hydrophilidae	*Berosus* sp. (L)	2	0
		Berosus dallasae	1	0
		Helochares sp. (L)	2	0
		Helochares tatei	1	0
	Hydrochidae	*Hydrochus* sp.	2	1
	Ptiliidae	Ptilidae spp.	1	0
	Scirtidae	Scirtidae spp. (L)	2	0
DIPTERA	**Chironomidae**	Chironomidae spp. (P)	2	3
	Tanypodinae	*Paramerina sp.*	2	1
		Thienemannimyia sp.	2	0
		Larsia ?albiceps	3	3
		Procladius sp.	0	3
		Ablabesmyia hilli	2	0
	Orthocladinae	*Rheocricotopus sp.*	3	0
		nr. Parametriocnemus	2	0
		Cricotopus albitarsis	1	0
		Thienemanniella sp.	1	0
	Chironominae	*Chironomus sp.*	0	2
		*Parachironomus*sp. (?K2)	1	0
		Cryptochironomus griseidorsum	2	0
		Polypedilum watsoni	0	1
		Polypedilum sp.	1	0

Class/Order	*Family*	*Species/taxa*	*MC*	*FR*
		Dicrotendipes sp2	2	2
		Tanytarsus sp.	3	3
		Paratanytarsus sp.	3	2
		Cladotanytarsus sp.	2	3
	Ceratopogonidae	Ceratopogoniinae spp.	3	3
		Ceratopogonidae spp. (P)	2	0
	Culicidae	*Anopheles* sp.	0	1
		Culex sp.	0	2
	Stratiomyidae	Stratiomyidae spp.	2	2
	Tabanidae	*Tabanus* sp.	2	2
	Tipulidae	Tipulidae spp.	2	0
TRICHOPTERA	**Ecnomidae**	*Ecnomus* sp.	0	1
	Hydropsychidae	*Cheumatopsyche wellsae (spAV11)*	3	0
	Hydroptilidae	*Hellyethira* sp.	2	0
	Leptoceridae	Leptoceridae spp. (imm)	1	0
		Oecetis sp.	1	1
		Triplectides ciskus seductus	2	1
	Philopotamidae	*Chimmara* sp. AV17	2	0
LEPIDOPTERA	**Pyralidae**	*Nymphulinae cf sp. 3*	3	0
		TAXA RICHNESS	**48**	**37**