



TropWATER

Centre for Tropical Water and Aquatic Ecosystem Research

CENTURY MINE RECEIVING ENVIRONMENT MONITORING PROGRAM (REMP) 2015

VOLUME ONE

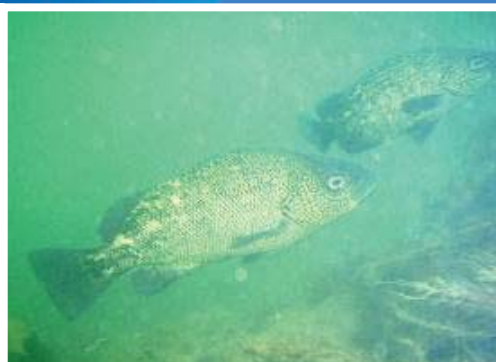
A Report for MMG Century Mine

Report No. 15/42 Vol 1

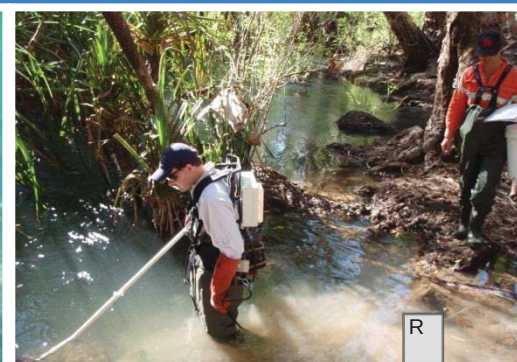
October 2015



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PROGRAM (REMP) 2015**

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A REPORT FOR MMG CENTURY MINE

Report No. 15/42

October 2015

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EXECUTIVE SUMMARY

Since 2005, TropWATER (formerly ACTFR) has been engaged annually by Century Mine (currently MMG Century) to investigate the ecological health and water quality of creeks potentially influenced by mining operations, with particular focus on Page Creek. Prior to 2009 monitoring was generally confined to sites located in the small highly ephemeral creek reaches immediately downstream of the mine-site and within the boundaries of the mine lease. However, following a number of non-compliant discharge events in 2009, the monitoring site network on Page Creek has been extended downstream to the confluence with and into Lawn Hill Creek.

Historical monitoring results indicated gradual ongoing accumulation of mine-related contaminants and increasing ecological impairment in Page Creek between 2005 and 2007, even though there were no reported non-compliant releases of water from the mine during that period. Broadly similar trends were maintained in 2009, although sedimentary contaminant residue concentrations within the 3.5 km section of Page Creek immediately downstream of the mine increased disproportionately that year, presumably due to the non-compliant discharge. Accordingly, prior to the 2009-2010 wet season, MMG Century carried out remediation works which included removing significant quantities of contaminated sediment from the most heavily contaminated sections of Page Creek.

The following year residual impacts were still evident in the reaches of Page Creek immediately downstream of the mine (encompassing sites A01 to E01), however, the highly anomalous sedimentary metals residues that had been detected in that section of the creek in 2009 were no longer present and concentrations had fallen to levels similar to those reported in 2007. That change can be partially attributed to the positive effects of remediation works, but there were also indications that some of the contaminant enriched sediment had been washed downstream and incorporated into the streambed within the lower reaches of the creek. As a consequence sedimentary metals concentrations in that section of the creek had become more uniform and had risen moderately. Since then mine-related impacts have still been evident at most of the Page Creek sites where potentially adverse effects had been reported previously.

In 2009 evidence of zinc and phosphorus enrichment was discovered in the bottom sediments of Lawn Hill Creek at sites located immediately downstream of its confluence with Page Creek. Subsequent monitoring has shown that the spatial distribution of sedimentary contaminants within the Lawn Hill sites closest to Page Creek, are extremely heterogeneous. That has made it difficult to resolve temporal trends, nevertheless, it is apparent that since 2009 zinc concentrations have remained at levels that approach, and in a few cases exceed, the ANZECC 2000 interim sediment quality guidelines (ISQGs) for the protection of aquatic ecosystems (with most of the higher values lying between the ISQG-Low and the ISQG-High). Over the past few years five extra sites have been established to assess the spatial extent of this contaminant enrichment, and monitoring results indicate that zinc concentrations decline quite rapidly with increasing distance downstream of Page Creek, and the levels at the most distant sites have approached reference.

Notably, to date there has been no evidence of any measurable impacts on Lawn Hill Creek's environmental values. Nevertheless, the quantities of contaminated sediment currently contained in Page Creek are sufficient to warrant ongoing monitoring of Lawn Hill Creek to detect any potential changes in its status.

The REMP site network for this program currently comprises nine impact sites and four controls in Lawn Hill Creek, nine impact sites and one control in Page Creek, six impact sites located on other ephemeral/intermittent streams and five ephemeral/intermittent reference sites. It should be noted, however, that the ephemeral sites do not always contain water and have at times only been sampled for sediment. Additional sites have been surveyed in 2015 with a view to refining and incorporating more relevant sites where possible, and ensuring compliance with the Environmental Authority.

Current Status of Receiving Waters

As discussed in the previous reports, the certainty of the conclusions that this report can draw regarding the current status of zinc and phosphorus residues in this study area have been somewhat constrained by the development of a number of issues relating to the reliability and accuracy of the results. The constraints were primarily around issues associated with analytical problems arising with the 2012 sediment program and an aqueous zinc sample contamination problem that was identified in 2014. In response to the analytical issues raised in the 2012 sediment program, local reference standards have been collected and prepared to be used for QC purposes into the future and resolve discrepancies between laboratories and/or methods. At time of writing the QC standards are undergoing certification analyses and are expected to be available for use in the 2016 program.

The development of a potential aqueous zinc sample contamination issue has also constrained the conclusions that can be drawn from this study. Many water quality practitioners throughout the region have reported similar difficulties, leading us to suspect that a batch of contaminated sampling consumables (such as filters) has found its way into the marketplace. A separate assessment of sampling consumables identified variable quality among brands of consumables with respect to their metal “cleanliness”. The assessment has identified some preferred brands for sampling and this should reduce the incidence of sample contamination problems. The analytical issues identified above have been raised in discussions with DEHP and the recommended processes and recommendations have been implemented with their knowledge.

The Lawn Hill Creek sites continue to exhibit high degrees of spatial heterogeneity in the sediments. It is recommended that the intensive sediment sampling program initiated in 2011 at Lawn Hill Creek be continued as a routine monitoring protocol for those sites until existing uncertainties have been resolved and existing risks can be confidently assessed. The current environmental monitoring program is subject to regular review to ensure it meets key environmental monitoring requirements while ensuring cost effectiveness.

Page Creek

Due to the low wet season rainfall all the ephemeral streams were dry at the time of sampling. As such only surface sediments were collected and analysed for the Page Creek sites.

The 2015 sediment results continue to indicate that zinc concentrations in the surface layer of bottom sediment has decreased over the past few years, and this short term trend could potentially continue until there is a flow event large enough to remobilise the underlying sediment layers. All Page Creek sites exceeded ISQG-Low for <2mm WAE zinc, however a number of sites were below the ISQG-High. In the <63µm WAE zinc fraction, one site was below ISQG-Low and another below ISQG-High.

Lawn Hill Creek

The intensive sediment sampling regime undertaken in 2015 demonstrated that zinc concentrations have decreased compared to 2012, with most sites at or below the ISQG-Low. The status of sedimentary phosphorus in Lawn Hill is currently poorly understood due to its extreme spatial heterogeneity and also because of the analytical issues discussed previously. Nevertheless, it is still possible to draw a few important conclusions: 1) phosphorus residues in the bottom sediment are largely insoluble in Lawn Hill Creek waters and do not appear to be readily bioavailable to the species which inhabit the creek; 2) Page Creek is obviously a significant source of phosphorus inputs to Lawn Hill Creek, and; 3) a large, and possibly predominant, proportion of the phosphorus exported from Page Creek originates from natural phosphate deposits.

The 2015 water quality data shows no indication of effects between the upper reference/control sites and lower impact sites that could be attributable to mine influences. There are indications of impacts from grazing (erosion, loss of riparian vegetation, etc) but overall the water quality was typical of these types

of perennial systems. Fish survey results continue to be consistent with previous years, with the two downstream sites (L04 & L05) reporting lower diversity compared to other sites.

The AUSRIVAS model employed for Lawn Hill Creek generated band scores that broadly supported the findings of our own analyses. There were statistically significant differences between control and impact sites from both the AUSRIVAS model and the NMDS statistical analysis. Given the obvious hydrogeomorphological differences between the controls and impacts, and the fact that some of the impact sites are subject to greater pressure from anthropogenic impacts unrelated to mining than are the control sites, some minor variations of that sort are to be expected.

In summary, it can be stated that zinc and phosphorus residues in the bottom sediments of Lawn Hill Creek provide the only evidence of mine-related influences and there are no indications that these have adversely affected the environmental values of the creek.

Other Creeks

Site Cog1, a small pool on Coglán Creek receives seepage water from an adjacent evaporation pond. This site historically reported high concentrations of mine-sourced salts (especially sulphate), and has generally exceeded the drinking water guideline for beef cattle as it did again this year. Available data indicate that these effects have historically been confined to that one site, with Cog2 located further downstream on Coglán Creek having typically been well within reference with respect to all mine-sourced contaminants. Prior to 2012 filterable zinc and manganese concentrations at sites Cog1 were low, but in 2012 and 2013 they increased substantially to levels well above their respective HMTVs. The 2015 results indicate that filterable zinc returned to levels similar to pre-2012, while manganese levels are still well above the ANZECC default TV (1900µg/L Mn).

A detailed sediment survey was undertaken in 2015 in response to elevated manganese at the Coglán Creek compliance monitoring site. This was incorporated as part of a wider assessment into the potential for influences from the Evaporation Dam seepage on the receiving environment. The outcomes indicate most of the metals within the seepage is being intercepted and trapped within the *Typha* dominated systems (including Cog1) immediately downstream of the dam.

Sediment metals were generally within expected ranges at most sites. Bul1 and RM1 exceeded the ISQG-High for <63µm WAE zinc. Bul1 also exceeded the ISQG-High for the <2mm fraction WAE zinc. However, all “other” creek sites were generally close to or below the ISQG-Low for <63µm and <2mm fraction WAE metals.

All sites classified as “other” creeks that were able to be sampled for macroinvertebrates reported below average diversity, richness and SIGNAL scores. This was similar to results for 2013 which had a lower than average wet season and reinforces the conclusion that reduced rainfall rather than mining impacts was the cause of the below average macroinvertebrate results.

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1. INTRODUCTION

Since 2005, TropWATER (formerly the Australian Centre for Tropical Freshwater Research - ACTFR) has been engaged annually by Century Mine (currently MMG Century) to carry out limnological assessments in receiving environments associated with the mine. Key personnel engaged in the 2015 REMP surveys have also worked on this assessment program in previous years.

This report presents the findings of the 2015 Receiving Environment Monitoring Program (REMP) sampling campaign. TropWATER have undertaken limnological surveys annually since 2005 to assess the ecological health and water quality of creeks in the immediate vicinity of the mining operation, with particular emphasis on Page Creek. Control sites situated in the upstream reaches of Page and Cogan Creeks, and other relatively undisturbed sites located on Mitton, Archie, Spring and Lily Creeks, have also been monitored in order to obtain local reference data. In 2006 the limnological monitoring site network was extended to include two additional impact sites on Bullridge Creek.

In 2009 it proved necessary to significantly expand the scope of monitoring activities and alter some of the established methodology in order to meet the requirements of a DEHP (then DERM) Environmental Evaluation (EE) order issued to Century Mine in connection with a wet season discharge incident. This included establishment of three upstream control sites and three downstream impact sites on Lawn Hill Creek, and the implementation of annual dry season sediment surveys to assess the distribution of sediment metals residues within the streambed of Page Creek and Lawn Hill Creek. In 2010 two additional limnological impact monitoring sites were established on Lawn Hill Creek, and in 2011 the site network on Lawn Hill Creek was further expanded by including four additional sites downstream of the Page Creek confluence and another which is situated between the entry points of Bullridge and Page Creeks.

The original program was established on behalf of MMG Century as a voluntary program. It has since become a compliance Receiving Environment Monitoring Program (REMP) under Environmental Authority (EA) EPML0088813. Consequently, the site network and monitoring parameter suites are undergoing review in the 2015 program to ensure it meets the requirements set out in the relevant EA.

1.1 Background

Page Creek is an ephemeral watercourse which drains a significant proportion of the MMG Century Mine catchment area, including the South and West waste rock dumps. The mining process necessitates the removal of significant quantities of potential acid-forming sulphidic waste rock, which is transferred to the South, West or North Waste Rock Dump. Rainwater infiltrates contaminated with sulphate, calcium, magnesium and trace metals (predominately zinc) seep from the toe of these dumps and are collected in sediment dams. Following high rainfall events, release of these waters are permitted (subject to EA conditions and meeting water quality parameters) into Page, North Mitton, Bullridge, and Little Archie Creeks. Page and Bullridge Creeks which flow north and northwest respectively before discharging to Lawn Hill Creek, while Little Archie and North Mitton Creeks flow north to north-east to Archie Creek.

Lawn Hill Creek is a spring-fed creek system and is one of the very few perennial middle-order streams in northern Australia, making it a regionally significant freshwater habitat. It flows into the Gulf of Carpentaria via the Gregory and Nicholson Rivers. The area around MMG Century Mine including Page Creek, Archie Creek, Lawn Hill Creek and the other minor creeks are defined as part of the Gulf Rivers Strategic Environmental Area under Queensland Regional Planning Interests Act 2014 (Queensland Government 2014), although current mining activities are exempt from this Act.

The annual limnological investigations by TropWATER indicate that there has been measurable accretion of mine related contaminants, especially zinc and cadmium, in the bottom sediments of Page Creek since 2005, and in recent years it has become evident that detectable quantities of these contaminants may potentially be entering Lawn Hill Creek.

The uppermost reach of Bullridge Creek, another small tributary of Lawn Hill Creek (approximately 6 km long), contains elevated metals, likely from the Western Waste Rock Dump or associated Sediment Dam 8, but to date impacts have been largely confined to a small ephemeral waterhole located immediately adjacent to the mine-site (Site Bull1), and there has been no indication of impacts further downstream. In 2015, MMG initiated a sediment investigation to determine the extent of metal influence in Bullridge Creek and potential sources of this influence. The outcomes of this investigation have been reported separately and are summarised in Section 1.3 (TropWATER 2015a).

Coglan, North & South Mitton and Little Archie Creeks all drain parts of the mine catchment area. These creeks flow into Archie Creek at different points which then enter the Gregory River more than 80 km downstream. Archie Creek is also a major tributary of the Gregory River.

The section of Coglan Creek immediately adjacent to the Evaporation Dam (designated Cog1) has historically contained water with elevated EC, hardness and sulphate levels, and since 2012 there has also been evidence of aqueous zinc and manganese enrichment. However, these effects have been confined to that one site, and to date there has been no evidence of potentially significant accumulation of mine-sourced contaminants at the downstream Coglan Creek site Cog2. In 2015 an Environmental Evaluation Notice was issued by the Queensland Department of Environment and Heritage Protection (EHP), to assess the potential for receiving environment impacts from multiple seepage locations from the Evaporation Dam. Elevated manganese was also detected at the Coglan Creek compliance monitoring location (C_SW08_REC). A detailed sediment survey was subsequently undertaken on Coglan Creek to determine the extent of seepage influence and assess the potential for environmental harm from elevated manganese. Outcomes of that investigation are contained in a separate report and summarised in Section 1.3 (TropWATER 2015a).

Water quality changes potentially associated with mining operations have been detected at times in Little Archie, Bullridge and Mitton Creeks, but to date evidence of ecological impacts have been very minor and water quality effects have been confined to sites that are situated very close to the mine-site, and within the mining lease. There have been no indications of any ongoing accumulation of mine-related contaminants at any of these sites. However, detailed sediment surveys have also been undertaken on these systems to assess the potential for environmental harm to the receiving environment (TropWATER 2015 b, c, d). Accordingly, even though all of the above-mentioned creeks are monitored annually, Page Creek and Lawn Hill Creek are the major focal points for the REMP.

1.2 Previous Investigations

TropWATER was commissioned in 2005 to undertake annual post-wet season limnological assessments. This was in response to observations by environmental personnel at the mine of a white magnesium sulphate scale being deposited on the streambed within the upper reaches of Page Creek immediately downstream of the mine site during the dry season. The aim of the program was to determine the condition of stream ecosystems each year at a similar stage of the annual hydrological cycle – after wet season rainfall has ceased and before waterholes in the streams have dried out. In order to maintain inter-annual consistency for ecological monitoring purposes it has also proven necessary to allow at least 4 to 5 weeks for recolonisation to occur: 1) after the dry streams are initially refilled by seasonal rain each year; and, 2) if there has been a major flow event intense enough to potentially wash away pre-existing fauna. Prior to 2009, monitoring of Page Creek was generally confined to sites located within the small highly ephemeral reaches immediately downstream of the mine-site and within the boundaries of the mine lease. However, in order to address the requirements of an Environmental Evaluation (EE) Order issued by DERM (now DEHP) in connection with a wet season discharge event in 2009, surveys were extended downstream and into Lawn Hill Creek. There had already been evidence of contaminant accumulation and ecological impairment in Page Creek in previous years prior to any non-compliant releases having been reported, it is therefore uncertain how much of the impact observed in 2009 was actually attributable to the non-compliant discharge event referred to in the EE Order. This uncertainty notwithstanding, the study showed that:

- benthic sediments throughout most of Page Creek contained high enough residues of mine-derived contaminants, and especially zinc, to potentially be ecologically harmful;
- contaminant concentrations at the sites closest to the mine, where ongoing zinc accretion had previously been detected, had increased disproportionately in 2009; and;
- zinc and phosphorus levels in the benthic sediments of Lawn Hill Creek sites located immediately downstream of Page Creek were measurably higher than the levels at Lawn Hill reference sites.

Later in 2009 MMG Century engaged TropWATER to conduct a detailed survey of sediments and aquatic habitats in Page Creek as a precursor to remediation works. This entailed collecting sediment profile samples down to a maximum depth of 500 mm, as well as recording stream morphology data and habitat descriptions, at 109 sampling stations located at selected points along the length of the creek. That study showed that the intrinsic habitat values of the creek were not particularly high. There were two sites that received higher potential value scores than the rest of the creek because they held semi-permanent water and/or saturated bed sands. However, these were in very poor condition due to impacts from anthropogenic pressures unrelated to mining activities, especially cane toads, feral pigs, cattle and horses.

Significant contaminant enrichment was discovered in all sections of Page Creek downstream of the mine, and although the most significant deposits were concentrated in the surficial sediment layers in close proximity to the mine-site, the vertical distribution in downstream reaches was quite heterogeneous. Notably there were a number of sites on Page Creek where elevated zinc levels extended to sediment depths in excess of the maximum sampling depth of 500 mm. This could potentially have been caused by vertical leaching of contaminants previously deposited on the surface sediment. However, subsequent investigations (TropWATER 2013) suggest that it is more likely that basal sands have mixed during high flow events, which would in turn suggest that a significant proportion of the contaminated sediment is potentially mobile under high flow conditions. Accordingly detailed monitoring of contaminant distributions is being conducted each dry season in order to determine how much movement has occurred during each preceding wet season. The findings of those detailed sediment surveys are presented in a separate report annually.

Sediment sampling results for 2010 indicated that the combined effects of remediation works carried out in Page Creek during the 2009 dry season and natural flushing by wet season flows, had been to remove most of the sediment contaminants that had been introduced into Page Creek in 2009. Ostensibly zinc concentrations in the sediments had been restored to the lower, though still substantial levels encountered in 2007. In 2012 metals concentrations in the sediments at the Page Creek impact sites closest to the mine (i.e. A01 to D01) declined further, but these improvements were not evident in the lower reaches of Page Creek; the available data suggesting instead that zinc concentrations in the bottom sediment, and to a lesser extent the water column, in that section of the stream may have gradually been rising since 2009 due to the deposition of slugs of contaminated sediment from the upper reaches.

The rainfall registered at Lawn Hill during the 2010-2011 wet season was the 4th highest in 122 years, making it the wettest year that has been experienced in the study area since monitoring commenced in 2005. There is therefore little doubt that the amount of bed sediment movement that occurred in Page Creek that year would have been significantly greater than normal.

Despite the signs of water and sediment quality deterioration in the lower reaches of Page Creek, all of the sites downstream of site E01 have shown measurable improvements in ecological condition over time between 2009 and 2012, with fish and macroinvertebrate diversities having increased significantly relative to previous surveys, and although invertebrate communities still showed some signs of impairment, most ecological condition indicators trended towards reference.

Bottom sediments within the section of Lawn Hill Creek immediately downstream of Page Creek have shown evidence of zinc and phosphorus enrichment since they were first sampled in 2009. However, there have been no indications that this has measurably impacted on the creek's environmental values;

comparative analysis of water quality, invertebrate and fish data having shown no significant differences between Lawn Hill Creek sites located upstream and downstream of mine influences. There have been no clear indications of temporal changes to the contaminant concentrations in Lawn Hill Creek sediments over the three years since monitoring commenced; however, our capacity to resolve temporal variations has been constrained by unusually high levels of spatial heterogeneity within the contaminated section of the creek. Accordingly, in recent years sampling activities at the key Lawn Hill Creek sites have been intensified substantially to include the collection of multiple spatial replicates.

Monitoring conducted in tributary streams between 2009 and 2011 indicated that most of the phosphorus enrichment within the upper reaches of Page Creek originated from the mine site, however, it is apparent that the sedimentary phosphorus in the lower reaches of Page Creek and further downstream in Lawn Hill Creek can largely be attributed to inputs from natural phosphate deposits, and especially the Mt Jennifer deposit which is situated immediately adjacent to the confluence of the two creeks. Notably the sedimentary phosphorus residues have had no apparent effect on water quality, and to date phosphorus concentrations in the water column have consistently fallen within normal expectations for this region.

1.3 Recent Investigations

In 2015 a detailed assessment of the potential influence of seepage from the Evaporation Dam on the receiving environment was undertaken to determine the extent and identify potential remediation options (TropWATER 2015a). The study determined that elevated sedimentary zinc in the environment downstream from the current seepage interception measures are largely confined to the *Typha* sp. wetlands immediately below the evaporation dam walls, which are acting as a sedimentary sink. Further downstream, zinc loads and concentrations are low with a large dilution capacity present in Coglan Creek and the downstream systems. The investigation into the non-compliant manganese data at the Coglan Creek compliance monitoring site, indicated that this result was more likely associated with the low manganese concentration at the reference site C_SW14_REF than elevated concentrations at the compliance site.

The 2014 and 2015 compliance sediment monitoring indicated elevated metal signatures at some sediment compliance sites (EPML00888813). In response, a series of detailed sediment investigations were conducted. These surveys were conducted on North Mitton Creek, Bullridge Creek and Little Archie Creek within and downstream of the mine lease to assess the potential for mining influences on the receiving environment.

The survey of North Mitton Creek identified an elevated zinc metal load within the upper reaches of the creek. An excavation campaign to remove contaminated sediment was undertaken in late 2014 and early 2015. A second sediment survey was undertaken in April 2015 to determine the effectiveness of these campaigns. The reduction in zinc load from the sediment removal works to date is consistent with the length of creek bed excavated, with recommendations that further excavations are unlikely to result in significant improvement over gains already made.

The detailed sediment survey of Little Archie Creek found elevated metal signatures immediately below the spillway from sediment dam 6 (SD6), however this rapidly attenuated with distance downstream. Similarly the detailed sediment survey undertaken in Bullridge Creek showed similar attenuation with distance from sediment dam 8 (SD8). However, the presence of historical mine workings approximately 1.2 km downstream produced a second localised metal peak, however, the dilution from tributaries attenuated this signature also. These reports have been submitted to MMG Century as a series of individual investigations (TropWATER 2015b, c, d).

2. SITE DESCRIPTION

2.1 Climate

The MMG Century Mine deposit is located in the Gulf of Carpentaria region of north-western Queensland approximately 250km north-north-west of Mount Isa. The climate of the Gulf of Carpentaria region as a whole has been routinely described as dry tropical, yet monsoonal. There is a defined wet season occurring between December and March with minimal rainfall occurring over the remainder of the year. Average rainfall decreases with increasing distance from the coast and accordingly the climate of some of the more inland areas such as the MMG Century Mine site are more aptly described as semi-arid with monsoonal influences (Dames & Moore 1994). The complex and unpredictable El Niño – La Niña Southern Oscillation (ENSO) phenomena exert significant influence on weather variability through time. Yearly weather patterns can range from effectively failed wet seasons through average years to strong wet seasons with pronounced monsoonal or often cyclonic activity. The long-term rainfall record for the Century area demonstrates considerable variability with Dames & Moore (1994) emphasising the uncertainty of typical climatic descriptors such as annual rainfall averages for this environment.

2.2 Surface Hydrology

The creek systems that drain the Century Mine are all ephemeral streams. Page Creek rises to the south of the mine site and flows in a northerly direction over the northern block of the MMG Century Mine deposit to its confluence with Lawn Hill Creek. In order to accommodate the mine workings, the upper reaches of Page Creek underwent a substantial diversion in 1997, and again in 2001, to re-route stream-flow around the western margin of the mine pit. The diversion channel, identified in TropWATER reports as Reach A of Page Creek, was subject to a minor realignment in 2013 and 2014.

Other notable ephemeral systems including Cogan, Bullridge, Mitton, Little Archie and Archie Creeks arise to the west and south-west of the mine site. Most of these highly ephemeral systems share similar land and drainage characteristics, arising from the Argylla land system (Dames & Moore 1994). The exceptions are Mitton Creek and Little Archie Creek, which drain part of the Thornton land system to the north-west of the mine site.

Page Creek, Spring Creek (which flows into Louie Creek) and Bullridge Creek flow in a northerly direction and ultimately discharge into Lawn Hill Creek, while Mitton and Cogan Creeks flow in an easterly path and discharge into Archie Creek (Figure 2.1). Lawn Hill Creek itself arises in the limestone and sandstone hills of Lawn Hill National Park to the west of Century Mine. Spring fed and perennial, it eventually flows into the Gulf of Carpentaria via the Gregory and Nicholson Rivers.

2.2.1 Streamflow Estimates 2014/15

Streamflows are monitored in a number of creeks around the mine lease. At present there are gauges located on Page Creek (2 locations), North Mitton Creek (2 locations), South Mitton Creek, Bullridge Creek, Little Archie Creek and Cogan Creek. The estimates of flow in the 2014/15 wet season were confounded by anomalous data recorded for a number of the sites including North Mitton Creek upstream, Bullridge Creek, Little Archie Creek and South Mitton Creek (T. Marszalek *pers comm*). No flows were recorded at either Cogan Creek or North Mitton Creek downstream, with the latter reinforcing the questionable results obtained for the upstream site. Flow was measured in Page Creek on five occasions but flows were very brief and not sustained (Table 2.1).

Figure 2.1: Location of MMG Century ecological assessment monitoring sites (impact sites in red, control sites in green) in relation to Gulf Rivers Strategic Environmental Area shown as green shaded area (Queensland Government 2014). Yellow lines denote MMG Century mining leases. Map base - Google Earth

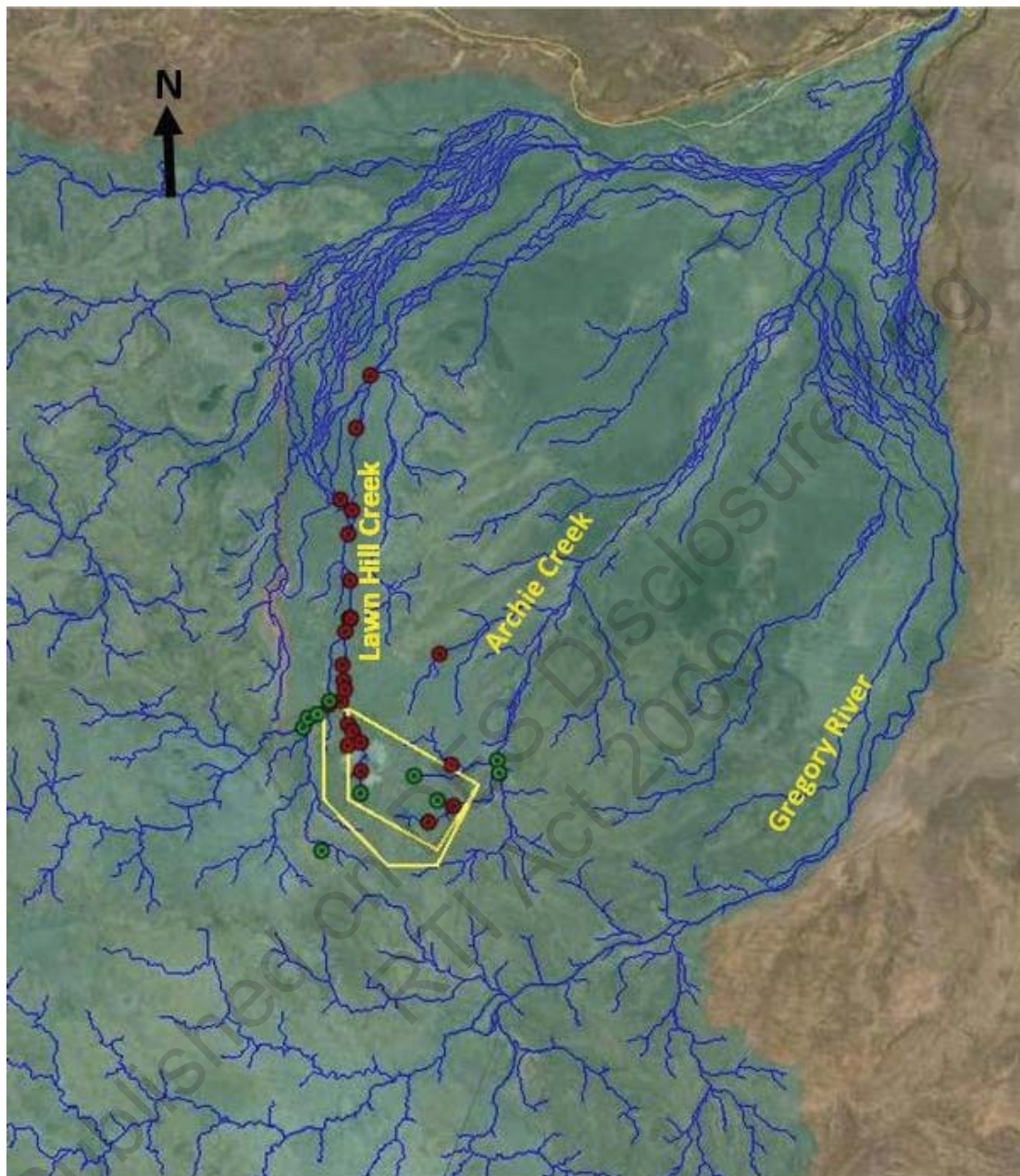


Table 2.1: Estimated streamflow at Page Creek streamflow gauging stations 2014-15 wet season.

Page Creek Upstream		Page Creek Downstream	
Date	Estimated Flow (ML)	Date	Estimated Flow (ML)
9-Jan-2015	0.04	18-Jan-2015	45.6
14-Jan-2015	0.02	19-Jan-2015	4.8
17-Jan-2015	9.8	23-Feb-2015	0.07
18-Jan-2015	17.5	25-Feb-2015	0.4
24-Mar-2015	0.23	4-Mar-2015	0.13

2.3 Survey Conditions and Timing

Long term rainfall records exist for Lawn Hill (1889 to 2015) with a shorter record period available for Century Mine itself (Figures 2.2 & Figure 2.3). Annual rainfall for the 2014-15 wet season was well below average with Lawn Hill recording 315 mm (Figure 2.2) and Century Mine recording 273 mm. Similarly to the 2013 ecological monitoring program there was a lack of surface water at most ephemeral sites across the survey area (Figure 2.2).

Three sampling trips were conducted during March and April in 2015 (Figure 2.3). The first trip was considered a scoping trip to identify and select additional monitoring sites to better characterise the receiving environment downstream of Century mine and was undertaken from 13-16 March 2015. Due to the poor rainfall in the 2014-15 wet season, potential sites could only be provisionally identified as there had been no flow in any of the ephemeral creeks and no pools were present. The second trip targeted ephemeral sites and was undertaken from 27 March to 3 April 2015. An isolated storm passed over the area in the three days prior to the trip but was not sufficient to generate flows in the creeks. Almost all sites on Page, Coglan, Bullridge and Mitton Creeks were dry and could therefore only be sampled for sediment. Ideally biological sampling at these sites should not be undertaken at timeframes shorter than 4 weeks, due to a minimum time period for invertebrate recolonisation to occur at these sites. The perennial Lawn Hill Creek sites were surveyed from 21 to 29 April 2015.

Figure 2.2: Annual wet-season rainfall at Lawn Hill 1889-2015 ranked in order of decreasing total rainfall (mm). Data from Climate Data Online, Bureau of Meteorology. <http://www.bom.gov.au/climate/data>. Bureau of Meteorology station number: 29031, Station name: LAWN HILL

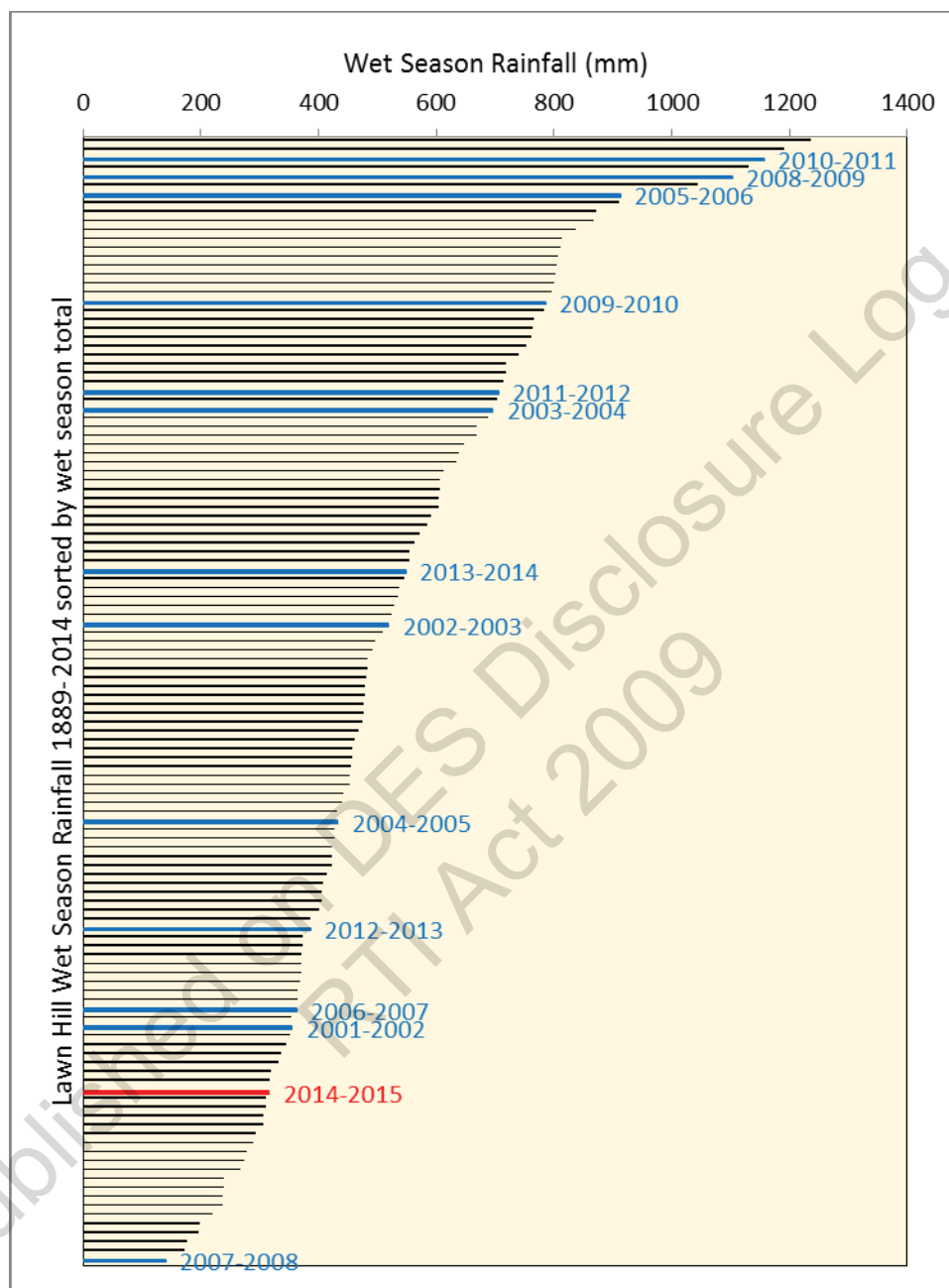
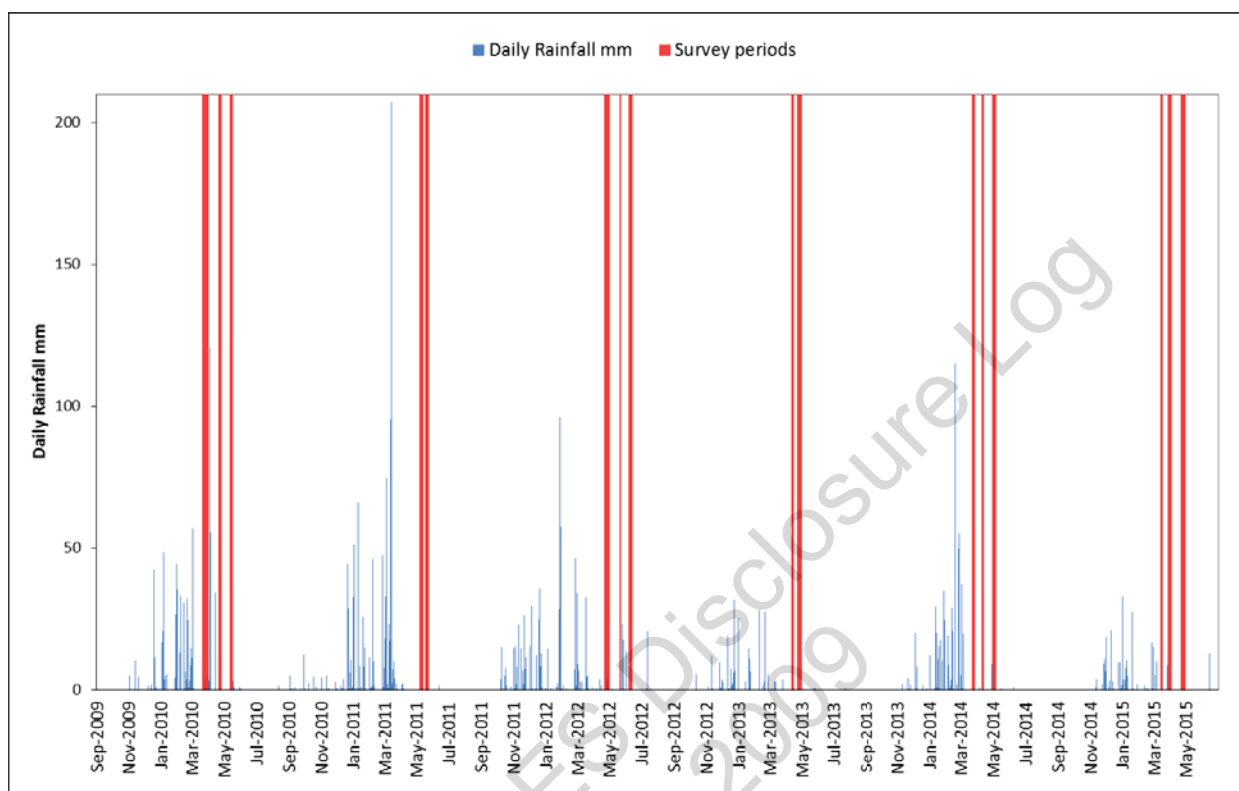


Figure 2.3: Daily rainfall to 9am (mm) at Century Mine, Sep 2009 to June 2015. Red lines represent field survey periods for field surveys. Data from Climate Data Online, Bureau of Meteorology. <http://www.bom.gov.au/climate/data>. Bureau of Meteorology station number: 29167, Station name: CENTURY MINE



3. METHODOLOGY

3.1 Study Sites and Site Groups

The MMG Century Monitoring Program began in 2005 and was expanded in 2009-2011 to include sites within Lawn Hill Creek, as well as adjustments of sites within Page Creek and other adjacent ephemeral creeks. This has also resulted in revisions to site identifications to accommodate the expanded network (Table 3.1).

The Lawn Hill Creek sites were established in 2009 and comprised six sites, three upstream of the confluence of Page Creek and three downstream (Table 3.1, Figure 3.1). In 2010, two additional impact sites were established further downstream on Lawn Hill Creek, and in 2011 two impact sites on anabranches were also included. To isolate possible influences from Bullridge Creek, in 2010 another control site was established upstream of the Page Creek confluence but downstream of Bullridge Creek.

Page Creek within the influence of mining activities is separated into seven reaches labelled A to G from upstream to downstream (Table 3.1, Figure 3.1). Sites within each reach are numbered consecutively from upstream to downstream, commencing at 01.

Sites that are not subject to potential impacts from the mine are prefixed with an “R” to indicate that they are reference sites. The data from these sites are combined to obtain reference values indicative of the natural variability of local waters. Some of these sites also serve as statistical controls for certain specific impact sites. Note, however, that a reference site is only used as a control if it is located in the same watercourse as the impact site in question. For example the reference site located in the upper reach of Page Creek serves as a control for the impact sites located further downstream on Page Creek, but not for impact sites that are located in other streams.

In 2010 the reference site on Lily Creek proved to be inaccessible and the track was found to be in such poor condition that future vehicular access was likely to be impossible. Accordingly an alternative reference site (RSpr1) was established on Spring Creek (a tributary of Louie Creek). In terms of its size, morphology, hydrology and water regime, this site is actually more similar to Page Creek than the other reference sites; hence this is a desirable alteration. It should nevertheless be noted that none of the available reference sites in this study area provide a precise match for the aquatic habitat conditions in Page Creek. In 2009 an unimpacted site on Coglan Creek was identified, which had better water retention than the pre-existing Coglan Creek reference. The Coglan reference, RCog1, was therefore relocated to this site.

It is important to recognise that water regimes and stream morphologies differ substantially across this monitoring network, and consequently it is not always valid to make direct comparisons between sites, especially when interpreting the significance of data relating to water quality and/or aquatic ecosystem condition indicators. This is particularly true of Lawn Hill Creek which flows perennially and cannot therefore be directly compared to other watercourses in the study area, which only flow episodically. Sites on Little Archie and Archie Creek, and Mitton Springs, typically contain permanent water but, during most seasonal dry spells, they either stop flowing or flow so slowly that they effectively become lentic habitats. All of the other sites comprise waterholes and stream reaches that do not normally contain permanent water, although due to the unusually high rainfall experienced between 2009 and 2011, some sites within the lower reaches of Page Creek (Reach F and G) still retained some water late in the dry season. In contrast, in 2013, lower than average rainfall resulted in all the ephemeral sites being dry and some of the permanent pools very reduced in extent.

Depending on the parameter or indicator in question, sites within each of the above-mentioned site groups may not necessarily be directly comparable to one another. For example, sites that are fed by natural groundwater springs (e.g. Mitton Springs and Reach F of Page Ck) have some quite distinctive inherent water quality traits that are not shared with other sites in the region. This variability in water quality can also

be reflected in the stream morphology with field conditions summarised on each survey (Appendix A1, Volume 2).

Table 3.1: Current MMG Century REMP Sites. Sites that held water and able to be comprehensively sampled for biota, water and sediment in the 2015 post-wet season are shaded in light blue. Other sites were dry and sampled for sediment only. *indicates the EA reference or compliance site that is most closely located with the REMP site

Site	Old Site ID	EA Compliance Site Equivalent*	Status	Kilometres upstream of Site L5	WGS84		Stream order	Water regime
					Latitude (S)	Longitude (E)		
<i>Lawn Hill Creek</i>								
RL3	LH ref3	N/A	Reference	47	18°41.37'	138°31.83'	4	perennial
RL2	LH ref2	N/A	Reference	45.5	18°40.61'	138°32.22'	4	perennial
RL1	LH ref1	N/A	Reference	44.3	18°40.35'	138°32.89'	5	perennial
RL0		N/A	Reference	41.7	18°39.48'	138°33.73'	5	perennial
L1a		N/A	Impact	31	18°34.00'	138°35.11'	5	perennial
L1b	LH1	N/A	Impact	31	18°34.05'	138°35.15'	5	perennial
L1c		N/A	Impact	31	18°34.02'	138°35.21'	5	perennial
L2a		N/A	Impact	26.3	18°31.52'	138°35.16'	5	perennial
L2	LH2	N/A	Impact	20.1	18°28.46'	138°35.04'	5	perennial
L3a		N/A	Impact	17.1	18°26.88'	138°35.30'	5	perennial
L3	LH3	N/A	Impact	18.9	18°26.19'	138°34.49'	5	perennial
L4	L4	N/A	Impact	6.8	18°21.44'	138°35.58'	5	perennial
L5	L5	N/A	Impact	0	18°17.96'	138°36.57'	5	perennial
<i>Page Creek</i>								
R01	Page ref1	P_SW17_REF	Control	55.5	18°45.58'	138°35.88'	2	ephemeral
A01	Page1	N/A	Impact	52.7	18°44.12'	138°35.91'	3	ephemeral
C01	Page2	P_SW03_REC	Impact	48.5	18°42.23'	138°35.90'	3	ephemeral
D01	Page3	N/A	Impact	46.5	18°41.49'	138°35.34'	3	ephemeral
E01	Page4	N/A	Impact	45.4	18°41.02'	138°35.02'	3	ephemeral
F01	Page5	N/A	Impact	42.4	18°39.51'	138°34.52'	4	ephemeral
F04	F04	N/A	Impact	41.2	18°38.89'	138°34.72'	4	intermittent
F09	F09	N/A	Impact	39	18°38.15'	138°34.71'	4	intermittent
G01	Page6	N/A	Impact	36.9	18°37.10'	138°34.65'	4	intermittent
G07	Page7	N/A	Impact	32.7	18°34.88'	138°34.84'	4	ephemeral
<i>Other ephemeral and intermittent creeks</i>								
Bul1	Bullridge1	N/A	Impact	48.75	18°42.43'	138°35.00'	1	ephemeral
Bul2	Bullridge2	B_SW01_REC	Impact	42.5	18°39.86'	138°33.66'	3	ephemeral
Cog1	Coglan1	N/A	Impact	N/A	18°47.45'	138°40.44'	3	semi-permanent
Cog2	Coglan2	C_SW08_REC	Impact	N/A	18°46.32'	138°42.49'	4	intermittent
RCog1	Coglan ref1	C_SW14_REF	Control	N/A	18°46.06'	138°41.25'	2	ephemeral
RM1	Mitton Ck	SM_SW05_REF	Control	N/A	18°44.43'	138°39.63'	3	ephemeral
MS	Mitton Spring	NM_SW04_REC	Impact	N/A	18°43.53'	138°42.12'	2	permanent/spring
RAr1	Archie ref1	N/A	Control	N/A	18°44.24'	138°45.55'	5	permanent
RAr2	Archie1	N/A	Control	N/A	18°43.41'	138°45.41'	5	permanent
LAr1	Little Archie	A_SW01_REC	Impact	N/A	18°36.37'	138°41.40'	4	permanent
RSpr1	RSpr1	N/A	Control	64.3	18°49.37'	138°33.18'	3	ephemeral

It is pertinent to note that a number of the reference and compliance sites identified in Schedule C Table 4 of the EA are not necessarily suited for REMP monitoring as they do not retain water for sufficient periods to

enable the ambient monitoring required. To address this, sites have been selected that are close, and where possible, within the same creek reach as the EA site. However for some sites (e.g. LAr1) this is still somewhat distant from the respective EA site. The closest REMP sites to the respective EA reference and compliance sites (Schedule C – Table 4) are identified in Table 3.1.

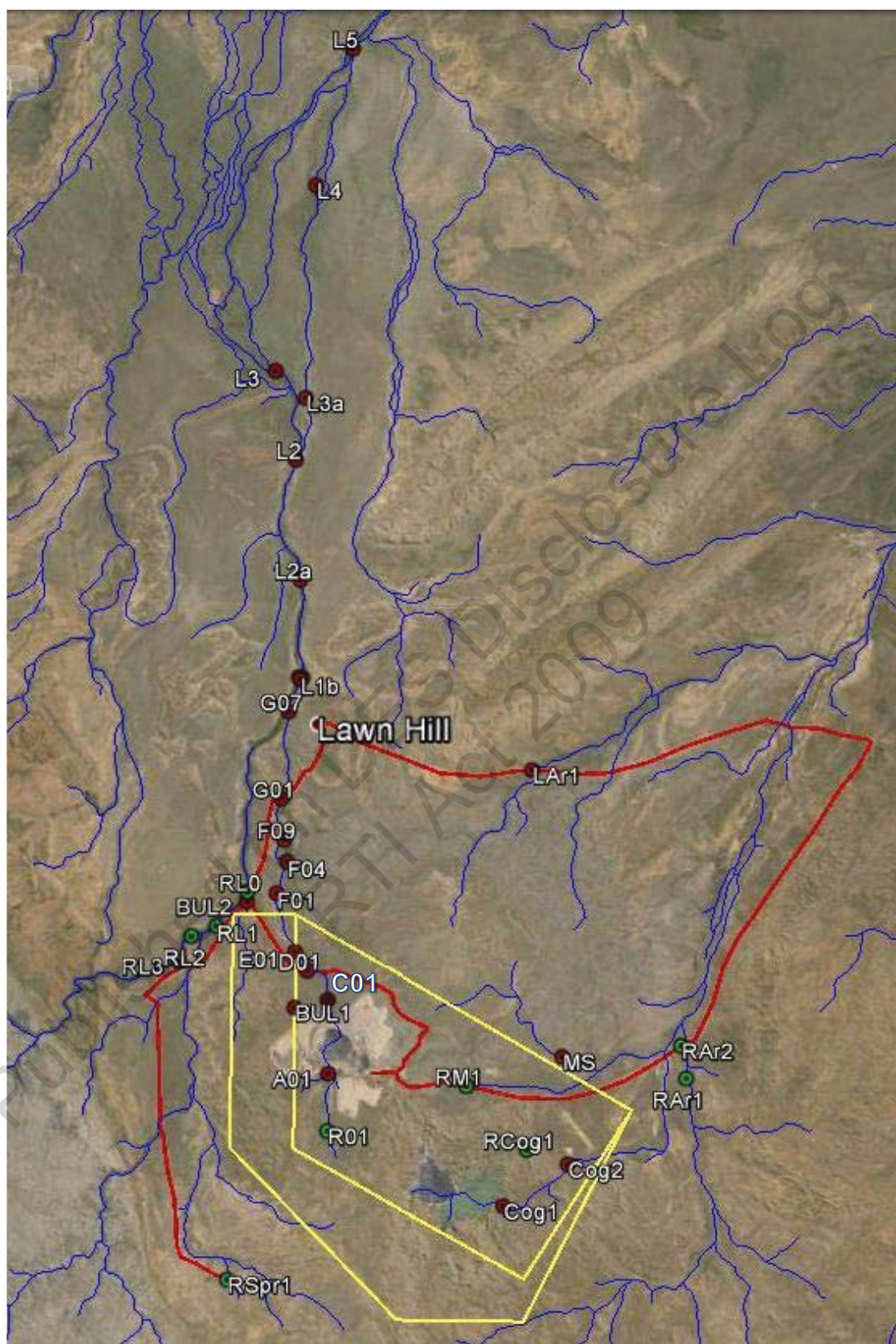
To ensure receiving environments were appropriately targeted under the receiving environment monitoring program (REMP) and meet requirements under Section C19 (c) of the EA, the site locations were reviewed in late 2014. In the 2015 program, additional survey was undertaken along parts of Little Archie, Coglan and North Mitton Creeks to determine if additional sites were present that could be incorporated into the REMP site network. Several potential sites were identified, however, due to the poor wet season conditions only one site (PH-387) was holding water at the time (Table 3.2). The remaining sites have been identified as being potentially suitable but will not be confirmed until they have been subject to more typical wet season conditions to determine if they meet the criteria as suitable REMP sites. To date, no suitable site has been identified for the receiving environment on South Mitton Creek, but further surveys will be undertaken into the future.

Table 3.2: Additional sites surveyed along tributary creeks within MMG Century lease in March 2015 that have potential as future REMP sites. All sites except PH-387 were dry at the time of survey.

Current Site ID	Potential EA Compliance Equivalent	Creek	WGS84	
			Latitude (S)	Longitude (E)
CogB1		Coglan	18°47.219'	138°41.312'
CogC1		Coglan	18°46.890'	138°42.040'
W/P 134		Coglan	18°47.270'	138°41.266'
W/P 135		Coglan	18°47.194'	138°41.339'
W/P 136		Coglan	18°47.257'	138°41.361'
W/P 137		Coglan	18°46.546'	138°42.300'
W/P 138		Coglan	18°46.655'	138°42.298'
W/P 139		Coglan	18°46.886'	138°42.041'
W/P 144		Little Archie	18°39.503'	138°39.470'
PH-099	A_SW01_REC	Little Archie	18°39.287'	138°39.535'
PH-387	A_SW01_REC	Little Archie	18°37.182'	138°40.684'
NM_SW04_REC	NM_SW04_REC	Nth Mitton	18°43.584'	138°39.467'
NMC014		Nth Mitton	18°43.548'	138°38.748'
NMC024		Nth Mitton	18°43.538'	138°39.132'
NMC041		Nth Mitton	18°42.957'	138°41.375'
W/P 131		Nth Mitton	18°43.522'	138°39.104'

Importantly, all the ephemeral waters in the site network dry out at different rates and are at a different stage of the drying cycle each time they are sampled. Such random variation is unavoidable when dealing with ephemeral waters. However, it is important to recognise that the effects of diminishing water levels generally become most pronounced when residual pools reach incipient dryness (for example evapo-concentration rates increase exponentially, edge habitats begin to disappear and limnetic habitats become congested). In the recent years, higher than average rainfall resulted in sites retaining water over a longer period, however in 2013 below average rainfall resulted in all ephemeral sites being dry and even some of the permanent pools (e.g. Mitton Springs) having extremely low water volumes. This merely reflects the natural variability in inter-annual water flows. The rainfall conditions in 2013 are similar to event in 2015.

Figure 3.1: Location of REMP Sites for MMG Century project. Control sites are shown in green and potential impact sites in red. The MMG Century mine leases are outlined in yellow with access road in red.



It is also pertinent to note that Reach A on Page Creek is actually a diversion channel that was constructed in the late nineties and relocated in 2001, with an additional realignment opposite the pit in 2013-14. It would be unrealistic to expect that section of the creek to support the same diversity of aquatic habitats and

biological communities as a natural stream, and this may be reflected in the results that have historically been obtained for biological indicators at Site A01.

To date investigations into the effects of water permanency and flow persistence indicate they can be key discriminators of inherent differences in both biological communities and water quality but are not reliable determinants of sediment quality expectations. This is partly because the hydrodynamic factors that determine the texture of basal sediments are primarily governed by processes which occur during the peak of wet season flow events, and therefore, similar conditions can develop, at least in places, within any stream regardless of its water permanency or flow persistence. Hence, for example, any section of stream that experiences swift turbulent flows during the peak of hydrographic events will generally tend to retain mainly coarse-textured sediments, while sections of stream that do not experience high currents and/or turbulence will tend to accumulate more finely-textured muds.

In non-mineralised catchment areas trace metals are usually preferentially associated with fine sediment grains so there is generally an inverse correlation between sediment particle size and the contaminant concentrations in the sediment (i.e. other factors being equal, coarse sandy sediments report lower concentrations than fine muddy sediments). That is not necessarily the case in mineralised catchments such as those which occur in this study area, because weathering of mineral outcrops can yield quite large metal-bearing particles which tend to accumulate in close proximity to the source until they have broken down sufficiently to be mobilised in swiftflow events. Ostensibly, in areas such as this, sediment quality expectations can vary substantially between individual sites depending on their proximity to natural mineralisation, regardless of their stream-type.

This has two key implications for this report:

- 1) For the purposes of sediment quality assessments, reference sites have not been grouped into stream-types as they have been for other indicators.
- 2) Local and State reference values are employed as benchmarks to assist in assessing various aspects of the sediment composition at impact sites, however, given the existing paucity of baseline data indicative of pre-mining conditions, and the high likelihood that the background concentrations in at least some parts of this naturally mineralised area would have been elevated, assessments focus more heavily on the effect-based interim sediment quality guidelines (ISQG) provided in ANZECC (2000). (Note that the background levels at the available reference sites are generally well below the effect concentrations, hence exceedances of the reference values are not necessarily indicative of significant increases in ecological risk).

3.2 Water Quality

Spot measurements as well as vertical depth profiles of pH, electrical conductivity (EC), temperature and dissolved oxygen (DO) are taken from several locations at each site using a hand-held Hydrolab QUANTA (Multi-probe) field meter. The full profiling data suite is contained in Table A.2, Volume 2. Hydrolab multi-probe data loggers are also deployed in the near-surface water layer (20 to 40cm below the surface) at selected sites to monitor the diel periodicity of these physico-chemical parameters (i.e. the cyclical variations that occur over each 24 hour period are monitored).

Water samples are collected at a mid-channel position and at a depth of approximately 20 to 30cm at each site. Samples are stored on ice in eskies until transported back to the mine-site for further processing, refrigeration and/or freezing, as appropriate. Sampling methodology, sample bottles and preservation techniques and analytical methodology are all in accordance with standard methods (i.e. DERM 2009, APHA 2005, and Standards Australia 1998).

Water samples for total suspended solids (TSS) and chlorophyll *a* are filtered through Whatman glass microfibre (GF) filters as soon as possible after collection. (If express air freight is available samples are filtered in the laboratory, and if not, they are filtered in the field at the end of the work day). GF-C filters

with a nominal pore size of 1.2µm are used for TSS, and GF-B filters with a nominal pore size of 1µm are used for chlorophyll *a*. After filtration chlorophyll *a* samples are preserved with magnesium carbonate, and both TSS and chlorophyll filters are immediately frozen. Samples for nutrient analyses are similarly frozen. The remaining water samples are refrigerated.

All water samples are analysed for a number of parameters with defined analysis methods and detection limits (Table 3.2). Other analyses (e.g. oil / grease) are undertaken only if visible slicks or films are present. Nutrients and biological indicators are analysed by the TropWATER Water Laboratory at James Cook University (JCU). Trace metals samples are subcontracted to NATA-registered commercial laboratories, and different service providers have been used over the years. Theoretically, in the interests of consistency, it would have been preferable to employ the same laboratory each year, but in practice TropWATER have found the reliability of service providers has varied over time which has necessitated some changes. Currently, trace metals analyses are undertaken by Australian Laboratory Services (ALS). Over the years, there have been some minor revisions to the analytical suite to provide a more directed assessment of the water quality for the program.

Table 3.2: Water quality analyses performed in the 2015 limnological assessment

Parameter	APHA Method No.	Reporting Limit
Routine Limnological Water Quality Analyses		
pH	4500-H ⁺ B	-
Conductivity (EC)	2510 B	5 µS/cm
Total Suspended Solids (TSS)	2540 D @ 103 - 105°C	0.2 mg/L
Turbidity	2130 B	0.1 NTU
Total Hardness	2340 B	1mg CaCO ₃ /L
Total Alkalinity	2320 B	1mg CaCO ₃ /L
<i>Major Ion Content</i>		
Bicarbonate/Carbonate/Hydroxide	2320 B (end-point calculation)	1 mg/L
Calcium	3500-Ca B	0.2 mg/L
Magnesium	3500-Mg B	0.05 mg/L
Sulphate	4500-SO ₄ ²⁻ E	1 mg/L
<i>Nutrients</i>		
Total Nitrogen and Phosphorus (TNTP)	Simultaneous 4500-NO ₃ ⁻ F and 4500-P F analyses after alkaline persulphate digestion	25 µg N/L 5 µg P/L
Nitrate	4500-NO ₃ ⁻ F	1 µg N/L
Ammonia	4500- NH ₃ G	1 mg N/L
Filterable Reactive Phosphorus (FRP)	4500-P F	1 µg P/L
Chlorophyll <i>a</i>	10200-H	0.1 µg/L
Phaeophytin		
<i>Trace Metals</i>		
Filterable arsenic, cadmium, copper, iron, manganese, nickel, lead, selenium and zinc	Selected metals listed as potential toxicants in ANZECC (2000) ecosystem protection guidelines	0.05 to 100µg/L
Total arsenic, cadmium, copper, iron, manganese, nickel, lead, selenium and zinc	Acid digestion / ICP-MS	0.05 to 100µg/L

3.3 Sediment Quality

3.3.1 Benthic stream sediment

A plastic or stainless steel hand trowel is used to collect random subsamples of benthic sediment from a number of different locations at each site. The subsamples are collected in a plastic bag to yield a single

composite sample. Subsamples are taken with the aim of representing the general composition of the near-surface sediment layer at each site, as it contains the most recently deposited material and is also the microhabitat most heavily utilised by benthic and demersal biota. (Note that samples representative of deeper sediment layers are collected separately during the annual dry season sediment profiling program).

Samples are kept cool and transported to the TropWATER Water Quality Laboratory as soon as practicable. Samples are then forwarded to a NATA-registered subcontract laboratory for preparation and analysis (Table 3.3). This analytical work has been subcontracted to a number of service providers over the life of the project. Theoretically, in the interests of consistency, it would have been preferable to employ the same laboratory each year, but in practice TropWATER have found that reliability of any given service provider has varied over time and this has necessitated some changes. In 2012 a sample from each site was analysed by Australian Laboratory Services (ALS) and QC replicates from six selected sites were analysed by SGS (the previous laboratory provider).

The outcome of this QC assessment indicated that results for weak acid extractable (WAE) zinc and phosphorus values reported by SGS were far lower than both the ALS results and the levels expected based on historical trends. Due to these issues an alternative service provider was engaged for the 2013 - 2015 work.

Table 3.3: Physical and chemical analyses performed on benthic sediment samples collected in as part of the 2015 limnological survey.

- Sieving to reject the plus 2mm fraction
- Sieving to determine the mass percentage passing 63µm
- Weak acid extractions of both the <2 mm and <63 µm sediment fractions, and ICP analysis of the extracts to determine cadmium, lead, phosphorus and zinc concentrations.

Previous sampling has shown that sediments at some impact sites in Lawn Hill Creek are unusually heterogeneous. Since the zinc concentrations at those sites are very close to the sediment guideline values, additional surface transects comprising eight samples per transect were collected at sites L1a to L3. This is additional to the standard surface composite sample collected at each site.

3.3.2 Sediment pore water

Pore water is extracted from a depth of 10 to 20 cm below the surface of the benthic sediment using a stiff plastic tube attached to a plastic syringe. A clean unused disposable plastic tube and syringe is used at each site. A hollow slotted re-usable stainless steel spear is used as an outer casing for the plastic tube at sites where the bottom is too hard for the plastic to penetrate. The outer casing is thoroughly washed with phosphate-free detergent and Milli-Q super high purity water, and dried after each use.

In order to ensure that surface water is not drawn into the syringe, pore water samples are collected from the exposed edges of the bottom sediment at each water body. In most cases this is still well within the main streambed. When present, pore water is also sampled at sites where the surface water has dried out. Samples are centrifuged and filtered (at 0.45 µm) in the TropWATER laboratory and are then submitted to ALS for analysis of filterable Ca, Cd, Mg, Pb and Zn by ICP-MS.

3.4 Aquatic Macroinvertebrates

Macroinvertebrate communities are sampled at each site using a standard dip net (triangular frame: 300mm x 300mm x 300mm, 650mm bag depth, mesh size 250µm). Sampling is stratified across different habitats (bank edges, pool bottoms, macrophytes and riffle/runs) and is dependent on habitat availability.

‘Kick samples’ of benthic (i.e. bottom) habitats within waterholes are the major habitat at ephemeral/intermittent sites. These habitats occupy the main stream channel and comprise stationary or very slowly flowing water over a variety of substrata types (silty, sandy, stony and/or rocky beds). ‘Sweeps’ of

edge habitat (out to a distance of 0.5m from the banks) are routinely conducted at all ephemeral and intermittent waterholes where appropriate structure (root masses, trailing vegetation, undercut banks etc.) is present. The protocol of allowing at least four to five weeks for recolonisation to occur before sampling after flow events means that riffle and run habitats are generally absent from ephemeral/intermittent sites at the time of sampling.

The perennial sites in Lawn Hill Creek contain permanent riffles and/or shallow runs with reasonably similar hydraulic habitat characteristics. Edge and pool bottom habitats are also present at all of these sites but the size, depth and flow characteristics of the pools vary substantially between sites, and in a number of cases are too deep to sample with a standard dip net. In order to facilitate confident comparisons between sites, invertebrate sampling at Lawn Hill Creek sites focuses on riffle and edge habitats rather than pools.

Each year live picking of macro-invertebrates is conducted on-site in accordance with protocols devised at the commencement of this program in 2005. This is a slightly modified version of the Australian River Assessment Scheme AUSRIVAS protocol and involves picking 3 replicates for 15 minutes each to achieve an accumulated picking time of 45 minutes for each habitat type, instead of the more common AUSRIVAS protocol of variable picking times (ranging from 30 minutes to 1 hour) for each microhabitat type dependent upon collection of new species. Specimens collected from each microhabitat are stored in vials and preserved in 70% ethanol until more detailed laboratory processing and identification is carried out. Consistent with established AUSRIVAS protocols samples are identified in the laboratory to family level, except for Chironomidae which are identified to sub-family, and lower Phyla (Porifera, Nematoda, Nemertea, etc.), Oligochaeta (freshwater worms), Acarina (mites), and microcrustacea (Ostracoda, Copepoda, Cladocera) which are not identified further.

Consistent with previous TropWATER limnological surveys, this report utilises a variety of metrics to assess the status of the invertebrate communities at each site. These include standard indices such as taxonomic richness (number of taxa) and SIGNAL (Stream Invertebrate Grade Number Average Level) index which are currently recommended in Queensland Water Guidelines (DERM 2009). SIGNAL index has been demonstrated as one of the more sensitive metrics for discriminating anthropogenic water quality impacts (Metzeling *et al.* 2003). SIGNAL index scores are calculated in accordance with Chessman (1995), by assigning pollution sensitivity grade numbers from 1 (most tolerant) to 10 (most sensitive) to each taxon and then averaging the pollution sensitivity grade numbers of all taxa present in a sample. The sensitivity grades utilised in this study were obtained from the AUSRIVAS web site and are principally sourced from Chessman (2003). These are used to calculate SIGNAL2.iv scores.

Each year more detailed multivariate statistical analyses of macroinvertebrate community relationships is performed. Non-metric multi-dimensional scaling (NMDS) analysis was performed in R version 3.1.2 using the vegan package (Oksanen *et al.* 2008) to ordinate macroinvertebrate groups from biotic similarity matrices using the Bray-Curtis index on abundance data (Clarke & Warwick, 2001). NMDS is particularly suited for use with ecological data due to minimal assumptions regarding data distribution and data normality, and is generally regarded as one of the more defensible ordination techniques currently used in community ecology (McCune and Grace, 2002).

In 2009 the macroinvertebrate data analysis methodology was broadened to also include the standardised AUSRIVAS macroinvertebrate community assessment protocol. The Australian River Assessment Scheme (AUSRIVAS) was developed by the Cooperative Research Centre for Freshwater Ecology (Davies 2000; Simpson & Norris 2000) as a tool to assess the health of inland riverine environments using the resident macroinvertebrate community. AUSRIVAS is based around predictive models, largely derived from the British RIVPACS models (River Invertebrate Prediction and Classification System) concept outlined in Wright (1995) & Wright *et al.* (2000). From an array of macroinvertebrate and other environmental data collected from a multitude of 'reference' sites, these models predict the aquatic macroinvertebrate fauna expected to occur at a site in the absence of environmental stress, such as pollution or habitat degradation, to which the macroinvertebrate fauna actually collected at a particular 'test' site can be compared to indicate

the overall ecological health of the site. AUSRIVAS macroinvertebrate predictive models have been developed for each state and territory over a number of seasons (autumn, spring or combined) for the main habitat types found in Australian river systems, including riffle, edge and pool habitats.

Invertebrate data are assessed by applying AUSRIVAS analysis models for 'Queensland'; 'Regional'; 'Western'; 'Autumn' which were run for pool, riffle/run and edge habitats where appropriate. In addition to invertebrate community data, a range of non-biological habitat predictor variables (latitude/longitude, altitude, physico-chemical data, habitat descriptors etc.) describing a particular test site are required to provide the necessary geographic and ecological context to run AUSRIVAS models. Data for these variables are either collected onsite using AUSRIVAS field sampling datasheet templates (site location, substrate quantification) or are subsequently derived from desktop assessments (stream order, altitude, climatic variables). The specific meteorological and climatic variables (temperature, rainfall etc.) used to classify test sites for AUSRIVAS model runs are taken from long-term Queensland Bureau of Meteorology data summaries collected at the nearby Lawn Hill meteorological station. Data collated from the months of December through to April are utilised to derive values for the 'wet season' rainfall and temperature related predictor variables required for model runs. Data from the months of May through to November are used to define 'dry' season conditions/variables.

3.5 Fish and Crab Survey

Fish and crab survey are undertaken using multiple methods. This is due to the variability and diversity of sites, especially the Lawn Hill Creek sites which are much larger than the Page, Coglean, Mitton and Bullridge Creeks. Backpack electrofishing capabilities are constrained to shallower pools and low-moderate conductivity levels. The current approach is to use multiple techniques designed to suit site specific conditions. These include:

- back-pack electrofishing (Smith Root Model LR24),
- cast netting (10-12 casts/site, 8-foot drop, $\frac{3}{4}$ inch mesh size),
- seine netting (25m net length, 11mm stretched mesh size),
- underwater observation (snorkelling), and
- angling.

Prior to 2009 crab catch was quite limited, even at sites that contained significant numbers of crab burrows. All of the burrows that were excavated during the detailed Page Creek sediment and habitat surveys in September 2009 were either empty or contained cane toads. This raised questions about the status of the crab population, hence since 2010 baited traps have been deployed at all sites that contained sufficient water to do so, in order to capture freshwater crabs as well as fish.

As a result there has been increased frequency of crab observations, however, experience has shown that traps deployed at sites that almost certainly support significant crab populations do not always capture specimens. These crabs aestivate in burrows during dry spells, so the apparently unreliable capture efficiencies may simply indicate that the animals having already become dormant. However, the ecology of this species is too poorly understood to be certain of that. Given that these crabs are arguably the most prominent inhabitant of small ephemeral waterways in this region, and therefore an obvious candidate as an impact indicator, research to determine key aspects of its life history, and to develop efficient non-destructive monitoring techniques, is clearly needed. (Note that the process of excavating crab burrows to determine if they are occupied by crabs is a highly laborious and destructive exercise that is entirely unsuitable as a routine monitoring method.)

Unless required for detailed identification, all native fish and crabs are identified and released immediately. Exotics and any natives that are retained are euthanised in accordance with JCU animal ethics permit guidelines and preserved. All captured fish specimens are identified according to Allen *et al.* (2002).

4. ENVIRONMENTAL OBJECTIVE DEVELOPMENT

4.1 Environmental Value Assessment

The environmental value assessment for the receiving environment downstream of MMG Century Mine has been developed and assessed in accordance with ANZECC methodology (ANZECC 2000). The decision making process for this is a risk based framework incorporating the identified ecological and human use values, water quality objectives and protection levels.

Within the REMP environmental values have been assessed at individual site scales to reflect the differences that can occur throughout the site network. For example recreational water uses have been identified as an EV for the region and are applicable to Lawn Hill Creek sites, but this EV is not considered appropriate for small highly ephemeral stream sites within the mine lease area.

In conducting this assessment, potential risks were evaluated in consideration of the downstream environmental values of each of the creek systems. Under the National Water Quality Management Strategy, environmental values are defined as the “*particular values or uses of the environment that are important for a healthy ecosystem or for public benefit, welfare, safety or health and which require protection from the effects of pollution, waste discharges and deposits.*”(ANZECC 2000).

Table 4.1: Environmental values considered relevant for this program under the Environmental Protection (Water) Policy 2009 (EPP(Water) 2009).

Environmental Values as described under EPP (Water) and 2009 considered appropriate for this assessment.	
 aquatic ecosystems	 primary recreation
 crop irrigation	 secondary recreation
 industrial use	 visual appreciation
 stock watering (including wildlife)	 raw drinking water
 human consumption	 cultural and spiritual values

Under the protection of aquatic ecosystems, there are three levels of protection afforded based on the ecological condition, High ecological value (HEV), slightly to moderately disturbed (SMD) and highly disturbed (HD) (ANZECC 2000, EPP (Water) 2009). The catchments surrounding the MMG Century mine lease can be considered to be slightly to moderately disturbed. At a creek reach or site level only some of the environmental values identified above (Table 4.1) are likely to be relevant. Based on existing and historical use patterns, the following are proposed environmental values for surface water monitoring sites in the MMG Century REMP program (Table 4.2).

Table 4.2: Summary of proposed environmental values for surface water sites sampled as part of this assessment. Note: for brevity, sites have been grouped by creek.

Creek System	Sites	Proposed environmental values	Comments
Page Creek	R01, A01, C01, D01, E01, F01, F04, F09, G01, G07	   	
Coglan Creek	Cog1, Cog2, RCog1	   	
North & South Mitton Creeks	MS, RM1	   	
Little Archie Creek	PH-387, LAr1	    	
Archie Creek	RAr1, RAr2	    	
Bullridge Creek	Bul1, Bul2	   	
Spring Creek	RSpr1	   	
Lawn Hill Creek	RL3, RL2, RL1, RL0, L1a, L1b, L1c, L2a, L2, L3a, L3, L4, L5	        	

4.2 Ecological Value Assessment

Ecosystem protection is generally considered to be applicable to all waters by default. However, in this study we have endeavoured to assess the relative ecological value/importance of each site in order to better understand what levels of protection should be applicable. This was done by appraising the potential ecological value, condition and conservation status of aquatic habitats and riparian communities at each individual site. In the absence of any pre-established methods for classifying the ecological values of ephemeral stream habitats at small spatial scales, sites have been assessed using a Potential Aquatic Habitat Value (PAHV) rating scheme devised by TropWATER (under its former title ACTFR) in 2008. The criteria used in this scheme are consistent with the principles taken considered by the Technical Advisory Panel as part of the Aquatic Conservation Assessment of Great Barrier Reef (GBR) catchments conducted by DERM (now EHP) in 2009.

This is a potential value rating system and so, does not take current condition into account – i.e. a high score indicates that the site has the inherent natural capacity to perform valuable ecological functions provided it is not excessively disturbed. The actual existing ecological values are dependent on both the PAHV score and the current condition score. As a general rule PAHVs change slowly over time while current conditions can change substantially over very short time frames, hence they are assessed separately.

Note that the PAHV scoring criteria primarily relate to instream aquatic habitat values. Palustrine wetlands and other floodplain habitats are not directly included in the primary criteria but their presence is taken into consideration. Specifically, if an intermittent stream reach has connectivity to an off-stream wetland with a higher PAHV score, the instream site is assigned the same high score as the associated off-stream wetland. Similarly, scores are increased if rare aquatic species are potentially present, or if the potential value of riparian vegetation is higher than normal due to a distinctive community composition and/or unusually high

plant biomass (potentially indicative of utilisation of water reserves associated with the stream). Such modifications are recorded and explained in site summaries.

This scheme is specifically designed for application in the inland bioregions of the dry and wet-dry Queensland tropics. Ratings largely reflect relative differences in the rarity of each aquatic habitat type throughout the region. Accordingly, the lower ratings assigned to sites which only provide viable habitat for specialised desiccation resistant biota do not necessarily indicate that those communities are less valuable than others, but rather that habitats of that sort are very common throughout the region (in fact many desiccation resistant organisms such as cryptograms and specialised microcrustacea are not confined to waterways and are capable of exploiting large areas of the terrestrial landscape during the wet season). Highly ephemeral waterways and wetlands with the potential to support rare or unusually diverse or productive “keystone” cryptobiota communities exist in some regions, although they are not known to occur in this study area. If there was any evidence of such biological communities being present, such sites would be assigned high PAHV scores.

In addition to PAHV scores, the current ecological and geomorphological condition of sites were also assessed based on evidence of biophysical damage due to impacts from weeds, introduced species, damage or loss of riparian vegetation through livestock disturbance, and water or sediment quality deterioration unrelated to mining activities. PAHV are rated from 1 – 10 (Table 4.3) while ecological and geomorphological condition is rated from 1 to 5 with 1 representing poor condition and 5 representing excellent condition. Full condition assessments are detailed in Volume 2 of this report (Appendix A.3). Condition assessments were undertaken at non-Lawn Hill sites only for the 2014-15 wet season as this process is still in refinement (Table 4.4).

Table 4.3: Potential Aquatic Habitat Value (PAHV) descriptions

Score	Definition
10	Permanent hydraulic habitat in a large perennial river
9	Permanent hydraulic habitat in a perennial tributary stream (regionally rare) and/or intermittent hydraulic habitat in a large perennial river
8	Large permanent waterhole and/or extensive permanent hyporheic habitat in an intermittent stream (reliable oases/drought refugia and/or potential focal point for wetland vegetation)
7	Small permanent waterhole in an intermittent stream (unreliable oases/drought refugia for aquatic fauna and flora, and/or a source of water for terrestrial fauna and riparian flora)
6	Seasonally intermittent waterhole with potentially persistent hyporheic habitat. Holds surface water long enough for some non-specialised invertebrates to complete their life cycle and contains sufficient subsurface water reserves to potentially provide drought refuge for burrowing species and hyporheic invertebrates
5	Seasonally intermittent waterhole with no potentially persistent hyporheic habitat. Holds surface water long enough for some non-specialised invertebrates to complete their life cycle <u>but does not contain significant subsurface water reserves</u>
4	Ephemeral hydraulic habitats only capable of opportunistic colonisation by specialised fauna but supporting distinctive riparian vegetation, and/or containing potentially persistent hyporheic habitats (subsurface drought refugia).
3	Ephemeral hydraulic habitats capable of opportunistic colonisation by fauna and/or of supporting distinctive riparian vegetation, but hyporheic habitats are not persistent.
2	Highly ephemeral waterway that supports no specialised riparian vegetation or habitat for aquatic fauna. Hydraulic habitats are too transient for seasonal colonisation by fauna but vegetation in the riparian zone may be denser than surrounding land, and some riparian geomorphic elements may be present (distinct banks and streambeds).
1	Waterway devoid of natural riparian features - includes highly ephemeral watercourses that retain terrestrial vegetation and soil characteristics. Vegetation is largely indistinguishable from surrounding landscape. Includes constructed drains that contain no distinctive hydraulic habitat features.

The potential aquatic habitat values (PAHV) of the non-Lawn Hill Creek sites range from 1 to 5, with the geomorphological condition rating typically 2 to 4 (Table 4.4). The ecological condition among the Page Creek sites was 2 – 3 with some sites subject to grazing and other impacts from cattle and wild pigs. Grazing and other livestock activity was responsible for bank erosion, stream bed disturbance/water quality deterioration at a number of sites.

Lawn Hill Creek is a regionally important freshwater ecosystem with a PAHV score of 10. The Lawn Hill Creek reference sites are situated downstream of Lawn Hill Gorge National Park and are subject to some grazing pressure, although in most places direct access by livestock is limited by the nature of the terrain surrounding that section of the creek. By contrast the downstream monitoring sites are situated on a floodplain and are directly accessible to livestock. Consequently the intensity of grazing pressures and associated weed invasions tends to increase with distance downstream from Page Creek.

Table 4.4: Summary of initial PAHV, ecological condition, geomorphological condition scores for Non-Lawn Hill Creek sites. NA – not assessed

Site	Site Type	PAHV	Geomorphological Condition Rating	Ecological Condition Rating	Comments
R01	Control	4	2	2	Pigs
A01	Impact	1	2	2	
C01	Impact	4	3	3	
D01	Impact	5	3	3	
E01	Impact	5	3	2	Cattle, Pigs
F01	Impact	5	4	2	Cattle, Pigs
F04	Impact	4	2	3	Cattle
F09	Impact	4	2	3	Cattle
G01	Impact	3	2	3	Cattle
G07	Impact	NA	NA	NA	
Cog1	Impact	5	1	3	
Cog2	Impact	5	4	3	Cattle
RCog1	Control	3	3	2	
RAr1	Control	7	4	4	
RAr2	Control	7	1	1	Cattle
PH-387	Impact	8	4	3	Cattle, Pigs
LAr1	Impact	5	4	3	Cattle
Bul1	Impact	1	1	1	
Bul2	Impact	3	2	3	Cattle, <i>Parkinsonia aculeata</i>
MS	Impact	NA	NA	NA	
RM1	Control	3	2	3	
RSp1	Control	6	3	2	Cattle

The most significant weed species identified was *Parkinsonia aculeata* which was present in the vicinity of Bul2. It was also identified at another potential site (PH-099). This is classified as a weed of national significance under the national weeds strategy (Australian Weed Strategy 2006).

5. RESULTS AND DISCUSSION

5.1 Water Quality - General Laboratory Analyses

Water quality results for 2015 are compared to local historic reference data (2005-2014) as well as ANZECC 2000 Livestock Drinking Water Guidelines (LDWG) where appropriate (Tables 5.1a and 5.1b). The 80th percentile of the reference data is also listed, as this is the statistic which ANZECC (2000) and DERM (2009) recommend using as a default trigger value when assessing the median concentrations at impact sites (as determined through repetitive sampling over a scientifically meaningful time frame such as a season). The additional reference values (LDWG) have been included as they assist to put the tabulated results into context with proposed environmental values (livestock), but since only one individual spot sample has been collected at each impact site, it is not possible to meaningfully assess compliance with the 80th percentile reference. (Note for example that, even if impact and reference sites were precisely matched – which is almost never the case in any real world situation – at least 20% of samples collected at test sites will exceed the 80th percentile reference value, even if they are in pristine condition).

The reference values for Lawn Hill Creek have been obtained through statistical analysis of data collected at the upstream control sites since 2009. These sites are not pristine, as they are located within areas that are utilised recreationally and, like virtually all waterways in this region, they are potentially subject to at least mild pressure from non-mining influences including grazing and exotic flora and fauna. In terms of the natural factors that influence ambient water quality, the control sites are reasonably well-matched to the impact sites immediately downstream of the Page Creek confluence, so the reference data provide indications of the water quality that could be expected at Lawn Hill Creek impact sites if they were not subject to any anthropogenic impacts additional to those that are present at the control sites. It should be noted, however, that there are generally very obvious signs (such as increased weediness, bank erosion, pug marks and excrement) of increased livestock pressures with distance downstream. Therefore exceedances of the reference values are not necessarily indicative of impacts from the mine. For example, the total suspended solids and turbidity levels at sites L4 and L5 have often been slightly elevated due to livestock impacts. This is even more likely after lower than average wet seasons as experienced in 2015, when lack of alternative surface watering points concentrate stock.

Reference values for creeks other than Lawn Hill have been derived from data collected at ephemeral and intermittent reference sites since 2005. It must be stressed that those sites, and their corresponding impact sites, contain a mixture of waterbody types, none of which are particularly well-matched to one another, due to spatio-temporal variations in flow, standing water levels, waterbody size, substrate type, morphology and water source (e.g. surface water driven vs groundwater-dependent sites). In terms of its morphology and aquatic habitat characteristics, the Spring Creek reference site is more similar to impact sites within the upper and middle reaches of Page Creek than any other available reference site, but as data from this site has only been collected since 2009, there are insufficient data to derive a statistically meaningful guideline value from this site alone. Hence, it has been necessary to pool the data from all reference sites, and as a result the guideline values for ephemeral and intermittent creeks provide only a coarse, and somewhat speculative, indication of the water quality expectations of the non-perennial impact sites. Assuming that annual monitoring continues in the future it may be feasible to develop type and/or site-specific reference values with time, but in the interim it is important to recognise the limitations of the existing reference values.

The Lawn Hill Creek reference data have been segregated from the ephemeral reference dataset because they do not provide any indication of the natural water quality expectations of other creeks in the area. In fact if elevated EC and hardness levels similar to those that are naturally maintained in Lawn Hill Creek were to occur at the ephemeral creek sites, it would in most cases be diagnostic of anthropogenic influences and would represent a significant departure from natural conditions. Nevertheless this does not mean that the ecosystem would be harmed by such alterations, because most of the aquatic biota that seasonally colonise these ephemeral streams originate from Lawn Hill Creek, and are tolerant of, or adaptable to harder, more saline water. Hence results that exceed the ephemeral/intermittent reference values may be indicative of

anthropogenic influences but, unless they also significantly exceed the Lawn Hill reference values, they are very unlikely to be harmful to the ecosystem.

Similar to recent years, in 2015 a number of the Lawn Hill sites were above the local historic reference values for turbidity (Tables 5.1a & 5.1b). The Total Suspended Solids (TSS) results were also above the local reference maximum at the most downstream Lawn Hill site L05. The local reference maximum was exceeded for electrical conductivity, hardness, alkalinity, magnesium and calcium at the new site located on Little Archie Creek PH-387 (Table 5.1a). This site is considered to be spring-derived and these conditions are likely to be typical of this site. However, these exceedances are unlikely to potentially adversely affect sensitive freshwater biota species. This is supported by the magnesium calcium ratios (Figure 5.1) which are within the optimum range to minimise potential toxicity of these ions (Butler 2008).

The only result to exceed the LDWGs was sulphate at Cog1 (a stagnant instream pool adjacent to the evaporation dam on Coglan Creek). This is consistent with historic results with the elevated concentrations of sulphate, conductivity, hardness and major ions, and comparatively low alkalinity levels indicative of seepage from the adjacent evaporation dam. This site is within the fenced mine lease and as such livestock do not have access to the site. This site as well as the wider Coglan Creek system was subject to a detailed assessment of the influences of the adjacent Evaporation Dam in 2015 (TropWATER 2015a).

Figure 5.1: Magnesium (Mg) to calcium (Ca) ratios for 2015. Red lines indicate upper (9) and lower (0.04) limits that are recommended for minimisation of potential toxic effects (from Butler 2008).

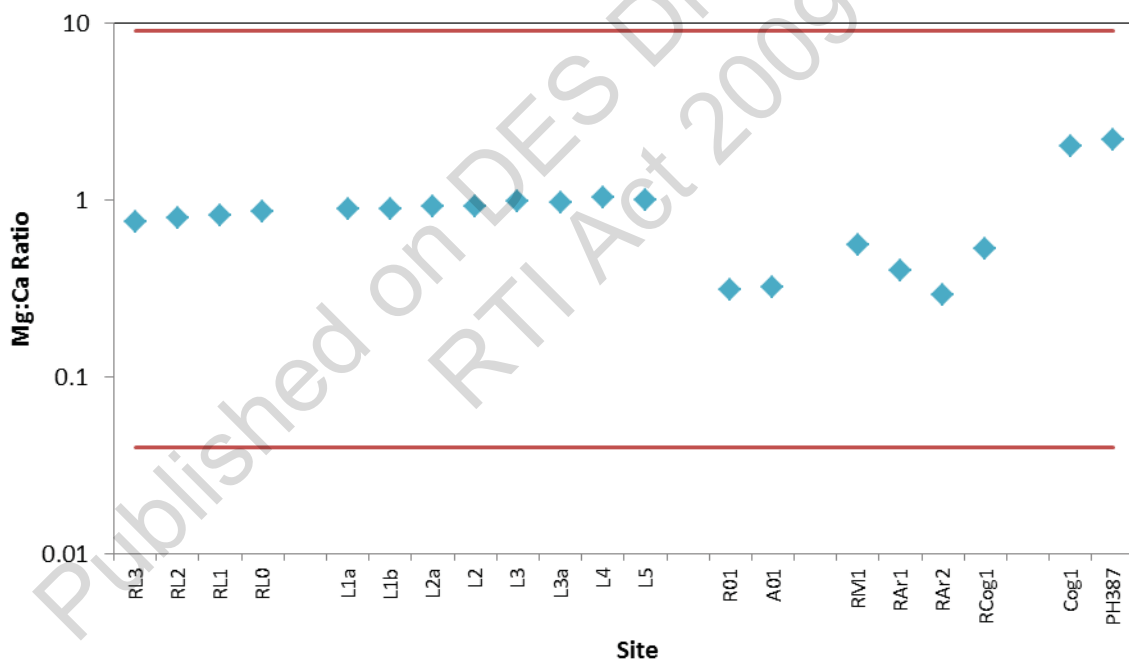


Table 5.1a: Laboratory results for water quality parameters other than metals for 2015. Values in blue are greater than the local historic reference data maximum. Sites greyed were dry at sampling. Values in red exceed ANZECC 2000 livestock guidelines (LDWG). NA indicates no applicable guideline

Site	pH	EC (µS/cm)	Total Hardness (mgCO ₃ /L)	Total Alkalinity (mgCO ₃ /L)	Total Suspended Solids (mg/L)	Turbidity (NTU)	Calcium (mg/L)	Magnesium (mg/L)	Sulphate (mg/L)
<i>Lawn Hill Creek</i>									
RL3	7.97	578	334.5	359	7.5	1.9	60	45	2
RL2	8.09	574	342.7	352	2.5	2.1	60	47	3
RL1	8.03	561	328.6	347	8.2	1.4	56	46	3
RL0	8.12	554	323.6	342	4.1	2.2	54	46	3
L1a	8.04	540	318.6	329	2.2	3.8	52	46	2
L1b	8.14	539	318.6	330	6.0	4.4	52	46	2
L1c									
L2a	8.30	540	313.6	336	5.6	5.3	50	46	3
L02	8.22	547	313.6	328	7.2	4.8	50	46	2
L3a	8.17	526	312.7	324	9.1	4.0	48	47	2
L03	8.16	523	308.6	325	2.9	6.3	48	46	2
L04	8.31	502	294.5	308	11	16	44	45	2
L05	8.32	514	303.6	319	15	12	46	46	2
Lawn Hill Ref 80%ile	8.15	658	380	376	5.7	2.5	66	53	3
Lawn Hill Ref max	8.37	693	388	400	13.0	4.2	70	56	20
<i>Others Creeks</i>									
Bul1									
Bul2									
Cog1	7.57	12190	6915	213	10	19	642	1290	8420
Cog2									
RCog1	8.40	188	80	80	6.7	250	17	9	12
RM1	9.21	194	86	99	38	110	18	10	10
MS									
RAr1	6.86	67	20	29	6.2	12	5	2	6
RAr2	8.48	231	88	107	6.8	9.4	24	7	20
LAr1									
RSpr1									
PH-387	8.32	855	378	555	15	13	33	72	<1
<i>Page Creek</i>									
R01	6.70	136	60	65	42	55	16	5	<1
A01	7.94	266	108	80	5.6	45	28	9	56
C01									
D01									
E01									
F09									
G07									
Local Ref 80%ile	7.76	186	72	66	24.6	73.4	16	7	14
Local Ref max	9.21	383	201	149	200	400	31	30	170
Livestock DWGs	NA	5970	NA	NA	NA	NA	1000	2000*	1000

*The LDWG guideline for magnesium is a low reliability value based on anecdotal observations of effects on stock.

Table 5.1b: Laboratory analysis results for water quality parameters other than metals for 2015. Values in blue are higher than the maximum of the local historic reference data. Sites in grey were dry at sampling. NA indicates no applicable guideline

Site	Total Nitrogen (µg N/L)	Total Filterable Nitrogen (µg N/L)	Ammonia (µg N/L)	Nitrate (µg N/L)	Total Phosphorus (µg P/L)	Filterable Reactive Phosphorus (µg P/L)	Chlorophyll-a (µg/L)	Phaeophytin (µg/L)
<i>Lawn Hill Creek</i>								
RL3	158	96	11	4	1	11	3	4
RL2	161	138	9	2	1	11	3	4
RL1	113	107	10	5	1	10	4	5
RL0	129	117	9	2	1	12	3	4
L1a	189	171	19	5	1	12	3	4
L1b	156	137	11	2	1	12	2	5
L1c								
L2a	162	110	7	16	<1	15	3	4
L02	213	100	9	44	1	14	3	4
L3a	171	148	8	1	<1	13	4	5
L03	166	144	7	<1	1	13	3	5
L04	303	244	21	20	2	26	3	6
L05	230	154	11	5	<1	21	3	5
Lawn Hill Ref 80%ile	170	116	15	35	2	26	5	11
Lawn Hill Ref max	385	138	23	80	2	40	6	17
<i>Others Creeks</i>								
Bul1								
Bul2								
Cog1	1482	1047	27	5	1	32	3	11
Cog2								
RCog1	468	410	11	11	1	68	12	14
RM1	1184	506	8	12	1	307	8	28
MS								
RAr1	696	524	19	11	1	71	6	36
RAr2	1095	865	15	16	1	63	10	38
LAr1								
RSpr1								
PH-387	2265	1559	40	11	2	154	13	56
<i>Page Creek</i>								
R01	2057	1146	15	11	1	256	26	58
A01	341	288	5	17	1	15	4	5
C01								
D01								
E01								
F09								
G07								
Local Ref 80%ile	880	475	17	20	2	113	11	35
Local Ref max	2304	1146	239	145	2	427	40	58
Livestock DWGs	NA	NA	NA	90295	NA	NA	NA	NA
95% AWQGs (toxicants)#	NA	NA	900	7200*	NA	NA	NA	NA

AWQGs for toxicants are the default trigger values for protection of 95% of aquatic species (ANZECC 2000).

* This is the revised trigger value for nitrate-N from Hickey et al (2002).

Due to the low rainfall experienced in the 2014/15 wet season there was limited opportunity to assess water quality at most non-Lawn Hill Creek sites. Comparisons with historical data indicate that overall water quality did not substantially deviate from previous years (Figures 5.2 – 5.7). The box-plots display current year results as red markers points and the historical data for each site as boxplots. Each box denotes the 20th, 50th and 80th percentile of the historical dataset (the 50th percentile being the median). Boxplot whiskers denote the minimum and maximum values, and the number of data points (n values) for each site are shown in blue beneath the x-axis. The local reference values listed in the previous tables are also plotted – the maximum appearing as an unbroken reference line and the 80th percentile as a dotted line.

Total nitrogen values were at the higher end of the range for a number of the sites that were able to be sampled (Table 5.1b & Figure 5.7). However, they did not exceed the local reference maximum for the reference sites RM1 and RSpr. This effect was also identified in the 2013 program and may be a normal consequence of low rainfall years. Investigations carried out in connection with the Century EIS (Dames and Moore 1994) and during the dewatering program (Ecotone, numerous reports mid to late 1990's) showed that most of the limestone groundwater aquifers in this region contain about 800 µg N/L of nitrate which is rapidly assimilated and converted to organic nitrogen when released into stream ecosystems. Accordingly, elevated nitrogen levels at spring-fed sites like RSpr1, PH-387 or MS could be a natural cumulative effect resulting from inflows of groundwater on the tail of the hydrograph when surface flow is almost absent, and this may also be the case for LAr1, which has a number of upstream springs (including PH-387) within the catchment.

The elevated nitrogen was not reflected in increased phytoplankton at any site (Table 5.1b). Similar to historic results, filterable reactive phosphorus (FRP) represented a very minor portion of the total aqueous phosphorus pool indicating that most phosphorus contained in bottom sediments is sparingly soluble in water.

Figure 5.2: Electrical conductivity for 2015 (in red) compared to historical data (2005-2014). Local reference maxima and 80th percentile are shown in blue as solid and dashed lines respectively.

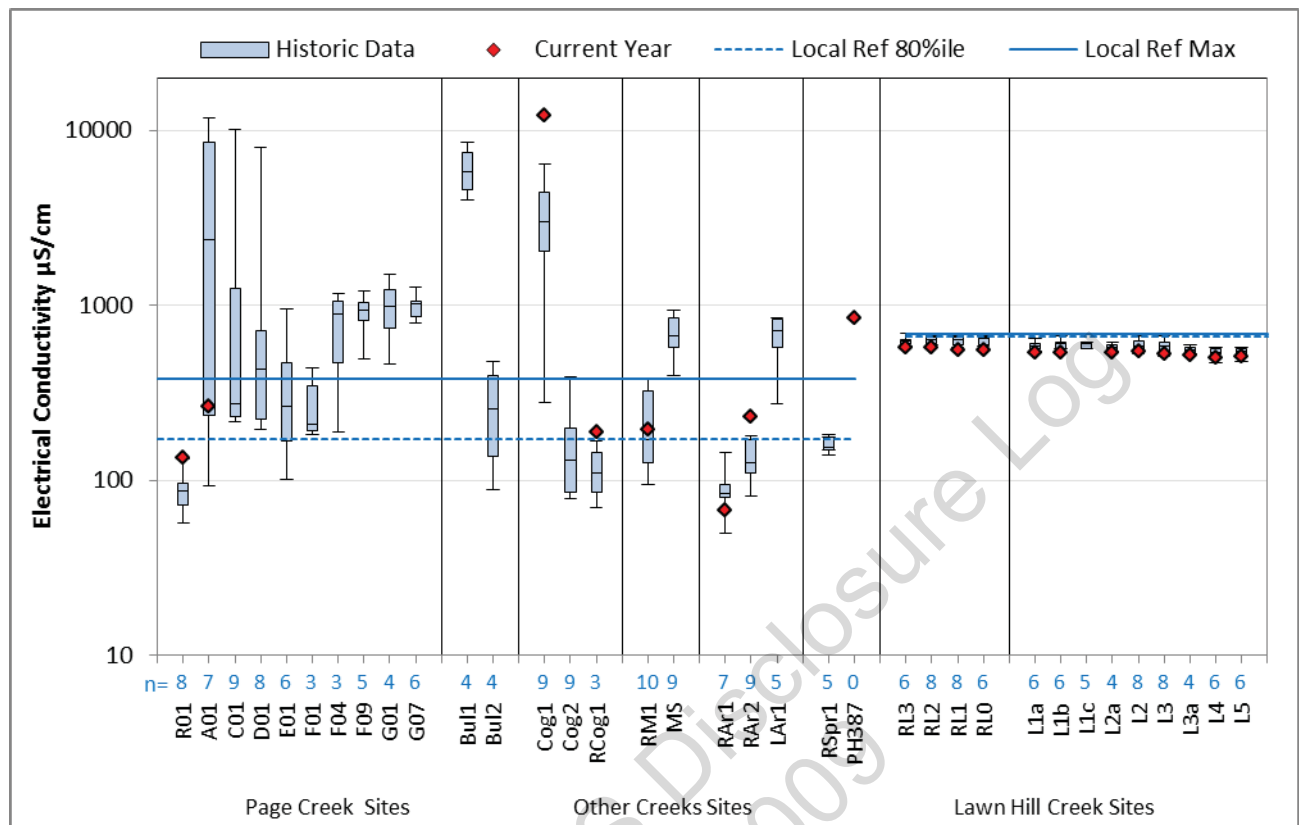


Figure 5.3: Measured hardness for 2015 (in red) compared to historical data (2005-2014). Local reference maxima and 80th percentile are shown in blue as solid and dashed lines respectively.

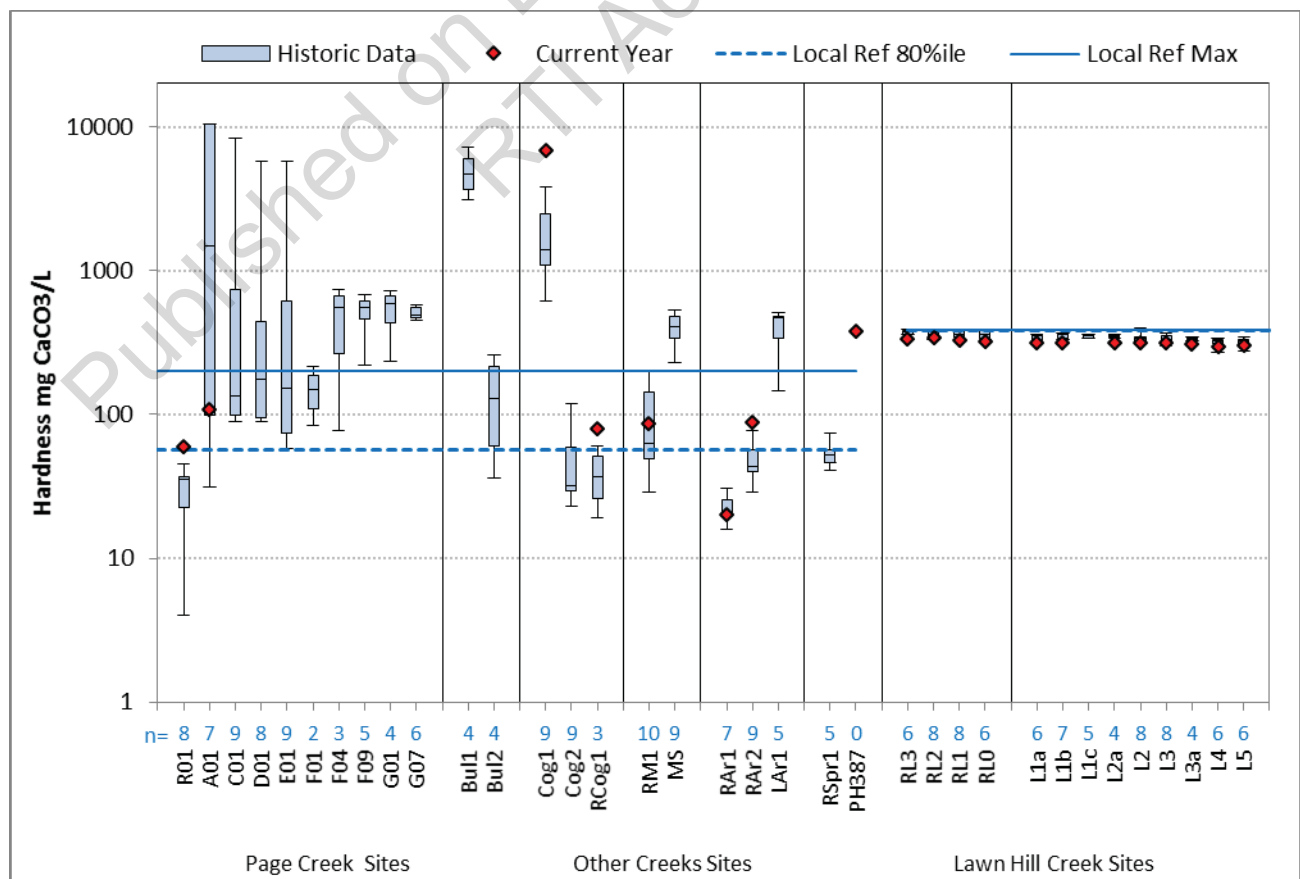


Figure 5.4: Measured magnesium for 2015 (in red) compared to historical data (2005-2014). Local reference maxima and 80th percentile are shown in blue as solid and dashed lines respectively.

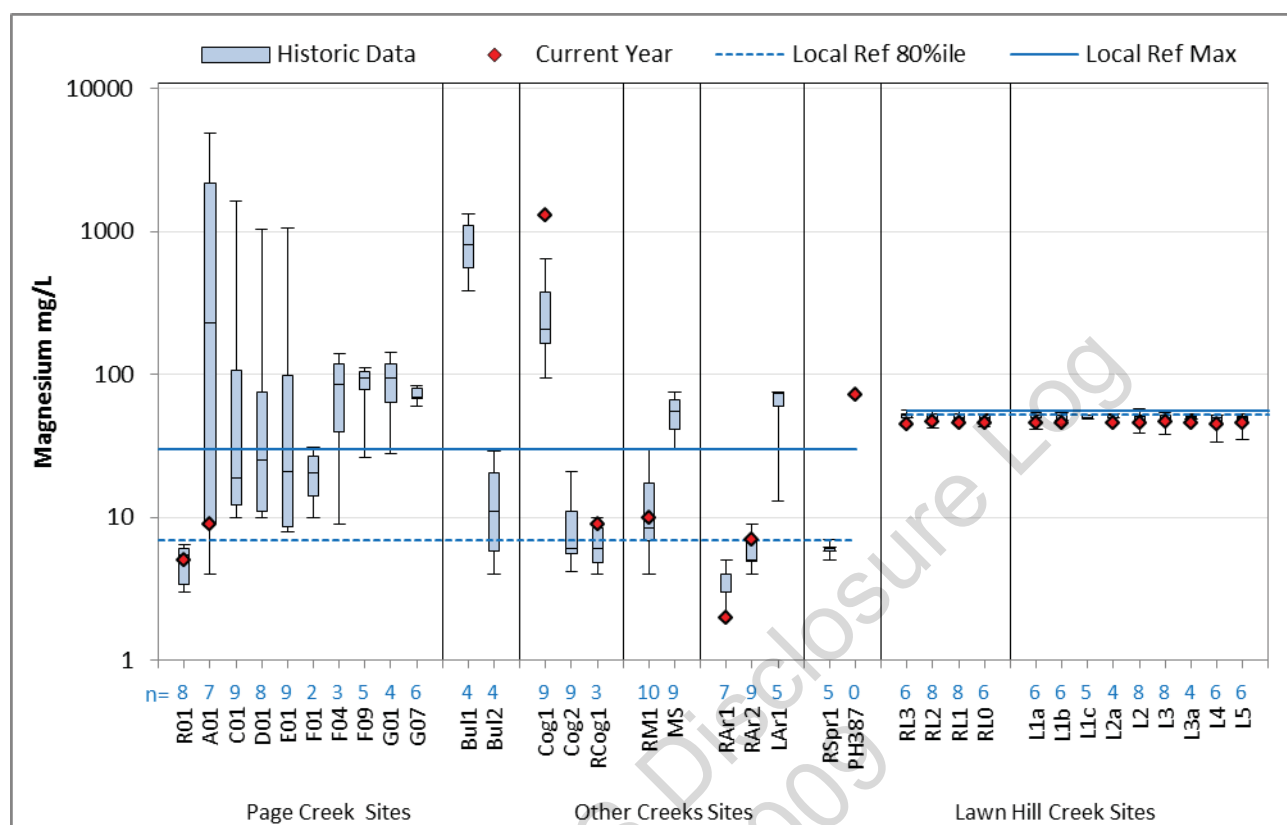


Figure 5.5: Measured calcium for 2015 (in red) compared to historical data (2005-2014). Local reference maxima and 80th percentile are shown in blue as solid and dashed lines.

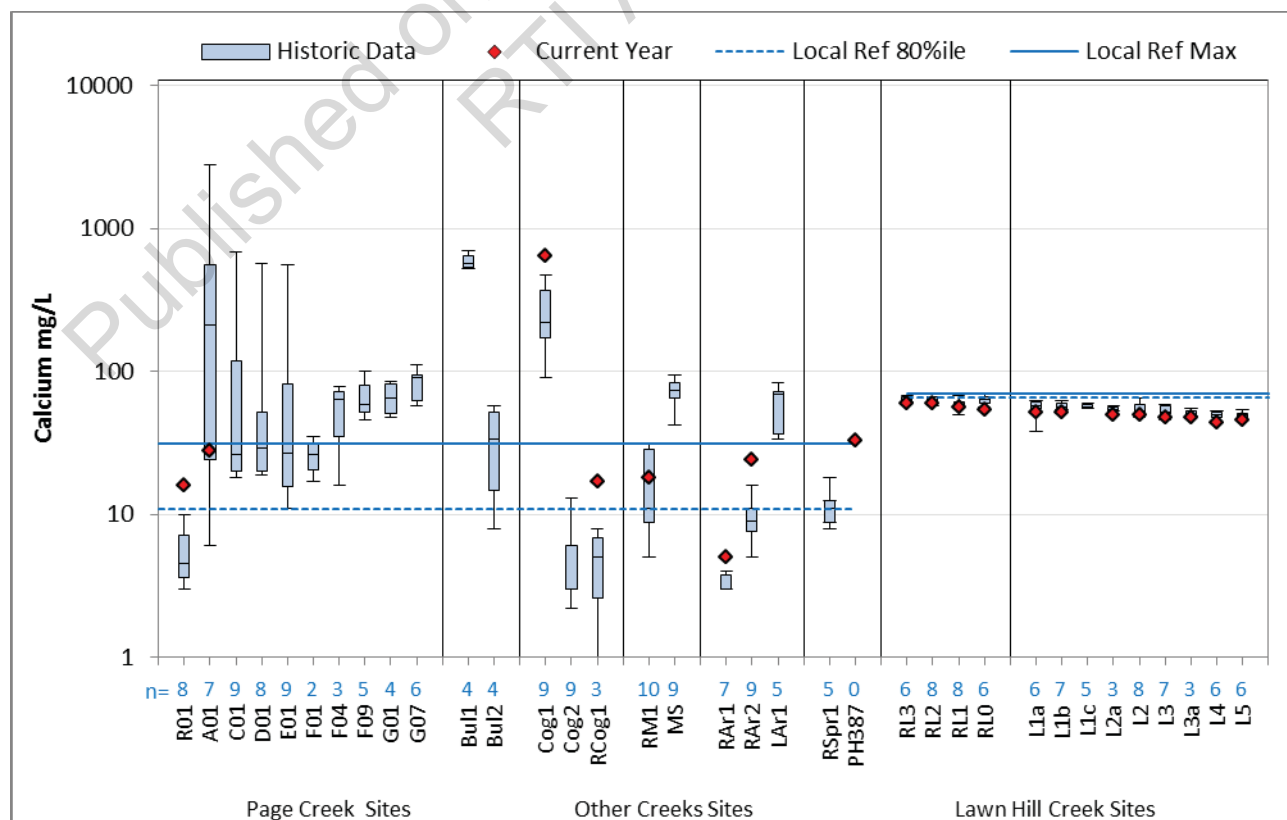


Figure 5.6: Measured sulphate for 2015 (in red) compared to historical data (2005-2014). Local reference maxima and 80th percentile are shown in blue as solid and dashed lines respectively.

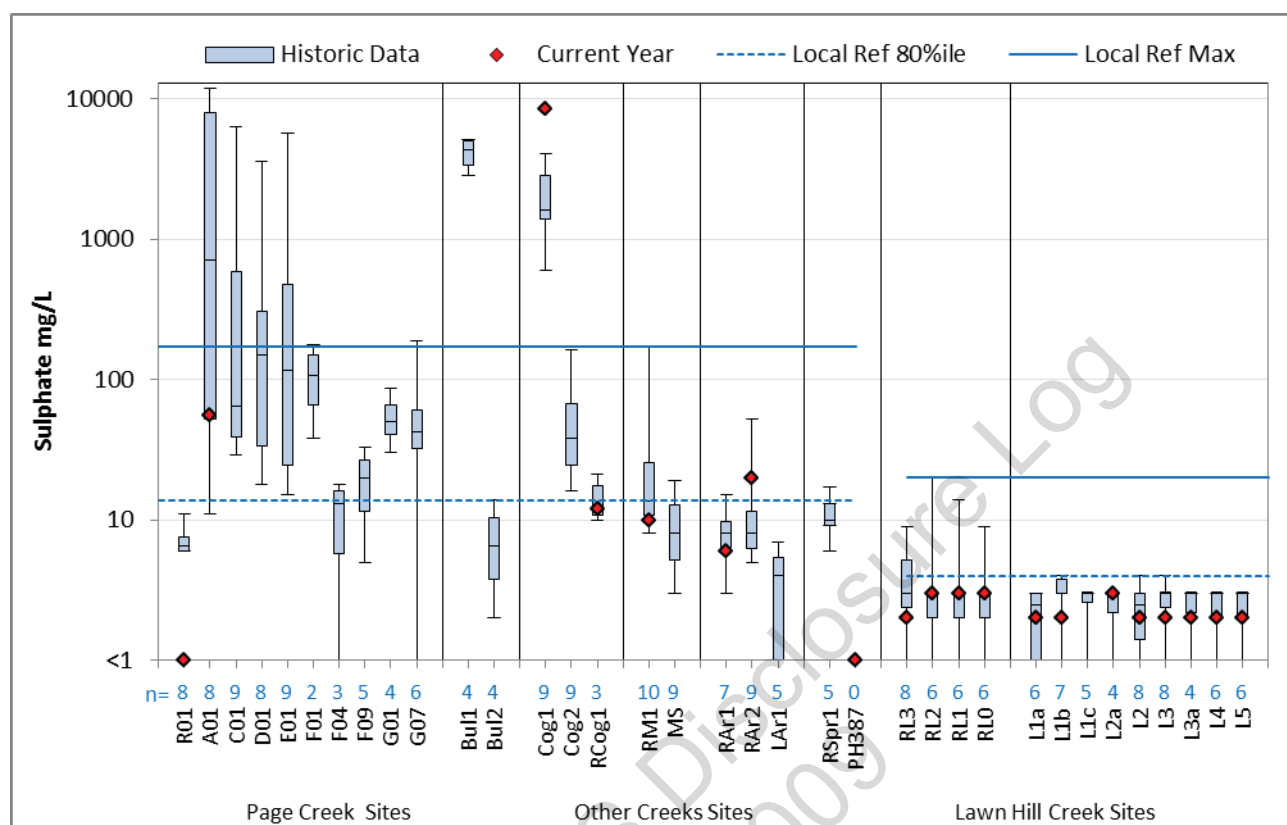
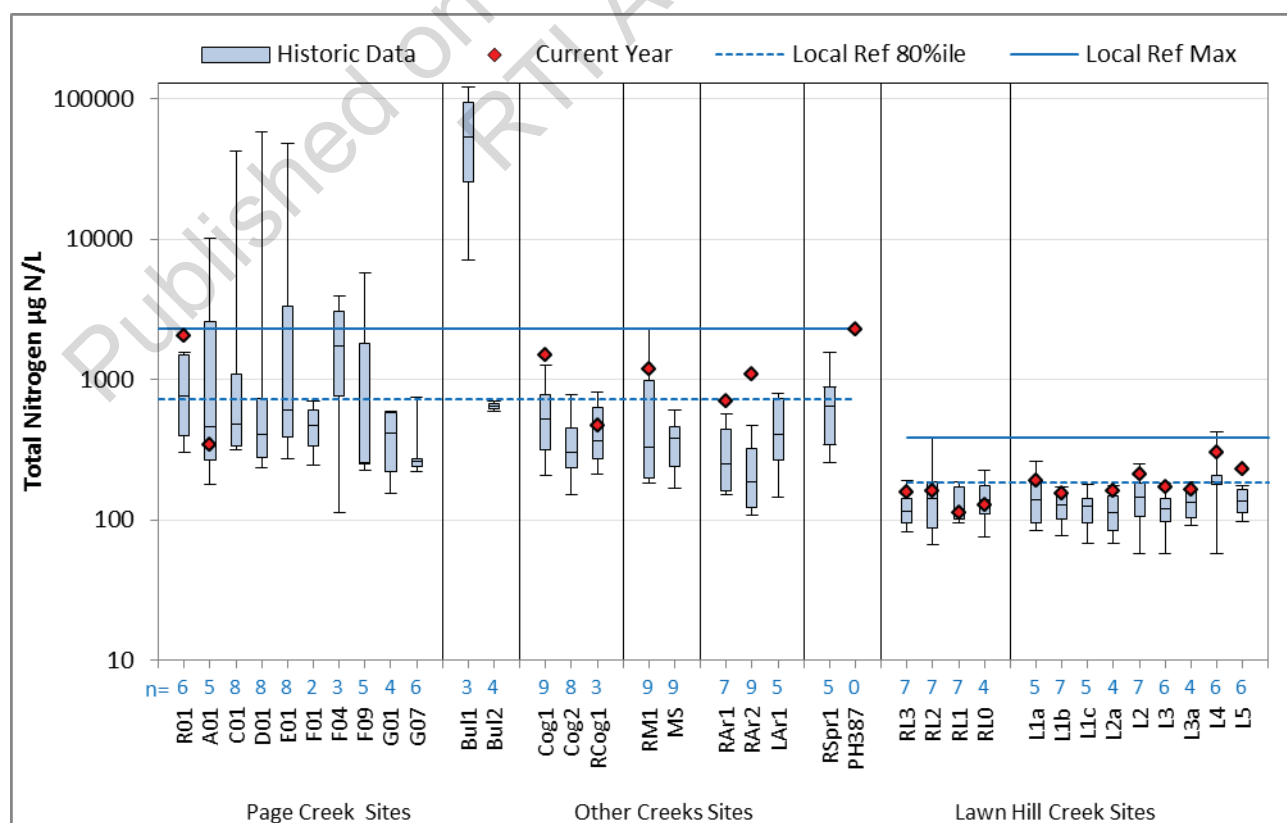


Figure 5.7: Total nitrogen for 2015 (in red) relative to the 2005-2014 historical range. Local reference maxima and 80th percentile are shown in blue as solid and dashed lines respectively



5.2 *In Situ* Field Measurements

Due to the lower than average rainfall over the 2014/15 wet season, water data loggers were only able to be installed at two locations. Dissolved oxygen (DO), pH, temperature and electrical conductivity were logged for a minimum of 24 hours at 20 minute intervals (Table 5.2 & Figures 5.8 – 5.11). The logging data reflect the diel water quality fluctuations occurring at the time of sampling. Diel periodicity is driven by natural variations in solar radiation, but the fluctuations in DO and pH ultimately stem from the production and consumption of oxygen and carbon dioxide by aquatic biota.

The data discussed in this section have been collected in order to:

- 1) Check for evidence of inhibited photosynthetic production that could potentially be diagnostic of phytotoxic water quality effects, and;
- 2) Determine if there are any anomalous DO or pH values with the potential to cause biological impacts that could otherwise be misconstrued as being a mine-related impact.

To aid data interpretation, the following points should be noted:

- All aquatic organisms respire, thereby consuming dissolved oxygen and producing carbon dioxide. The latter dissolves in water to form carbonic acid and consequently reduces pH values. Hence, in order for a water to maintain stable DO and pH values the oxygen must be replaced and the excess carbon dioxide must be removed.
- Swiftly flowing waters are often sufficiently well-mixed to be able to achieve adequate gas exchange with the overlying air, but slow flowing and/or stagnant waters are generally too poorly aerated to prevent gas concentrations from fluctuating.
- Plants and algae undertake photosynthetic processes during daylight hours, producing surplus oxygen and consuming carbon dioxide. Hence both DO and pH levels can increase during daylight hours, and in very productive poorly aerated waters, these concentrations can reach very high levels (e.g. DO saturation levels greater than 200% and pH values higher than ten are possible in extreme cases).
- At night, plants and algae (which must respire) consume more oxygen than they produce, with carbon dioxide as the excretory product. Consequently DO and pH levels often begin to fall. Dissolved oxygen levels can potentially fall to very low concentrations overnight, generally reaching a minimum early in the morning. Minimum values of zero are not uncommon in very productive still waters. However, carbon dioxide rarely reduces the pH of natural surface waters to levels much below neutral, except in rare cases where acid buffering compounds such as tannic or humic acids are present in large quantities. Once pH starts reaching high levels during the day, daily minimum values may gradually increase from day to day until the pH eventually stabilises at a persistently high value.
- The effects of diel changes in carbon dioxide levels on pH may be largely suppressed in waters with high alkalinity. However, if biological activity is high, pH values can fluctuate substantially over periods of days to weeks, due to the cumulative effects of bicarbonate consumption (which produces hydroxyl ions and ultimately carbonates, as a by-product).
- If factors such as aeration and flow are similar, the amplitude of the diel DO fluctuations are indicative of relative differences in photosynthetic production rates, and the mean DO concentration is indicative of the background respiration rate.

The balance between the processes described above can vary between different parts of the same waterbody. Notably waters near the bottom can be much more poorly aerated and, if the water is deep and/or turbid enough to prevent sunlight from penetrating, photosynthetic production can also be inhibited. In this study depth profiles have been conducted at each site using a hand-held field meter in order to determine if there was evidence of stratification of that kind. The profiling data (Appendix A.2, Volume 2), reflect the spatial variability that existed at the time of sampling. However, it is important to recognise that stratification

patterns can fluctuate over the course of a day, so the profiling data should be interpreted in conjunction with the diel cycling data shown here.

Table 5.2: Summary of data logger results for temperature and electrical conductivity at all non-Lawn Hill Creek sites monitored in 2015.

Site	Date/Time In	Date/Time Out	Min Temp (°C)	Max Temp (°C)	Mean Temp (°C)	Min EC (µS/cm)	Max EC (µS/cm)	Mean EC (µS/cm)
RAr1	28/03/2015 12:20	30/03/2015 08:15	28.61	35.35	30.36	67	70	69
Cog1	28/03/2015 15:20	30/03/2015 14:00	27.93	34.44	30.36	12283	12526	12422

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RTI Act 2009

Figure 5.8: Data logger results for dissolved oxygen (DO) and pH at site **Cog1** (March 2015)

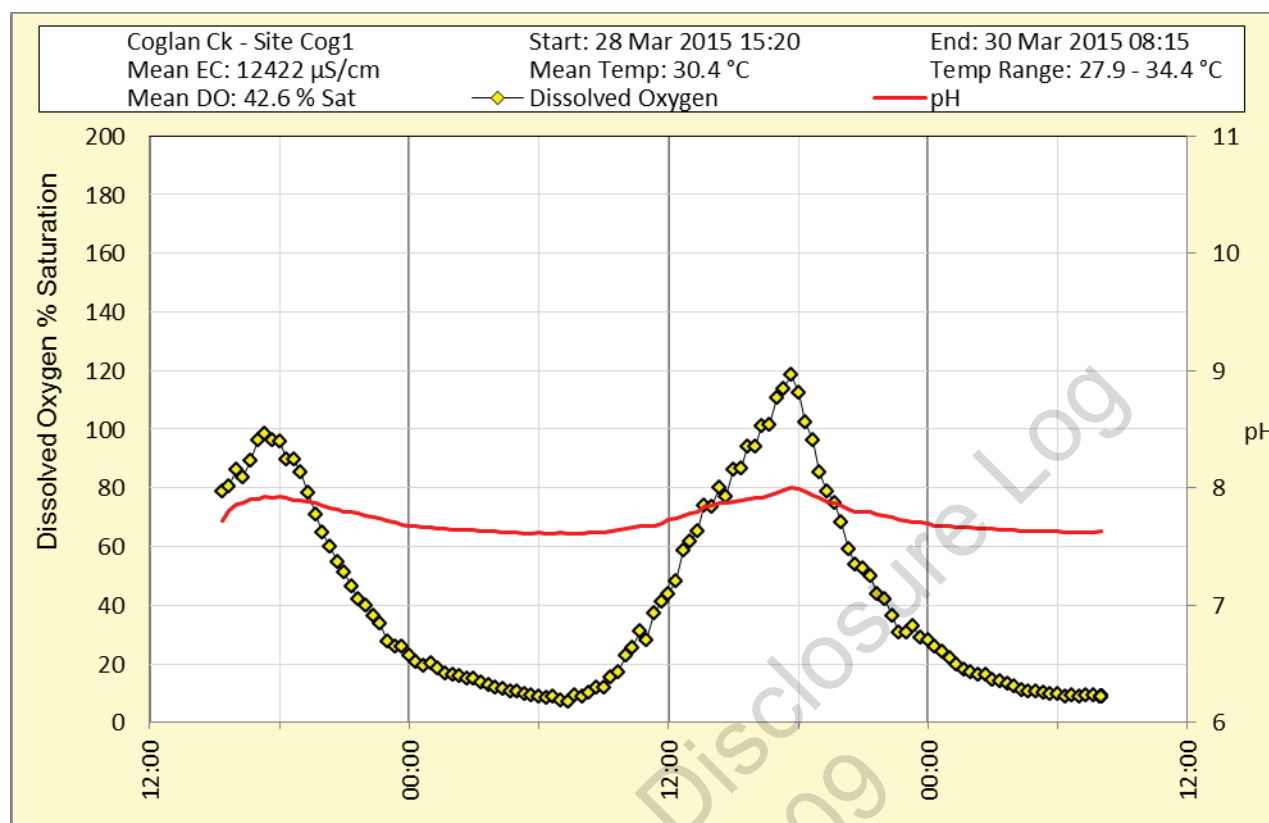


Figure 5.9: Data logger results for dissolved oxygen (DO) and pH at site **RAr1** (March 2015)

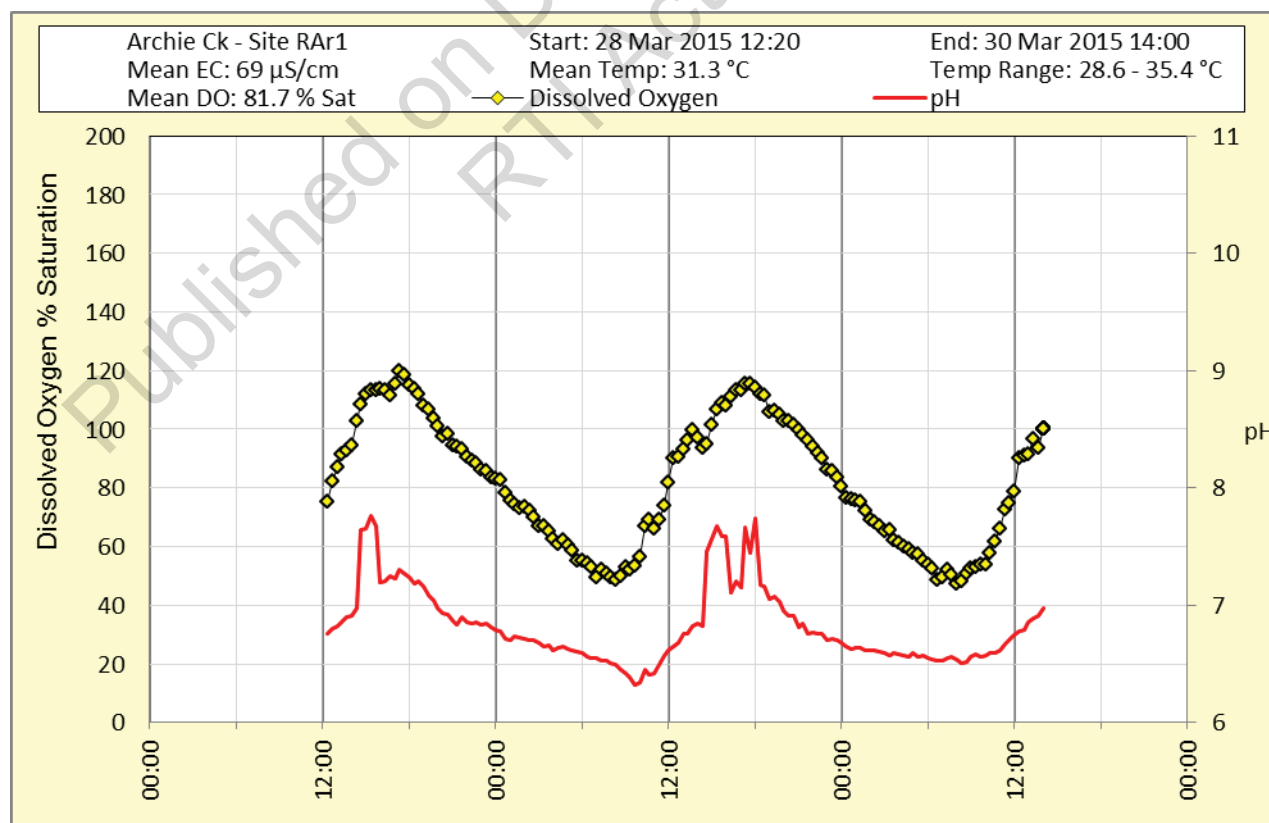


Figure 5.10: Data logger results for temperature and EC at site **Cog1** (March 2015)

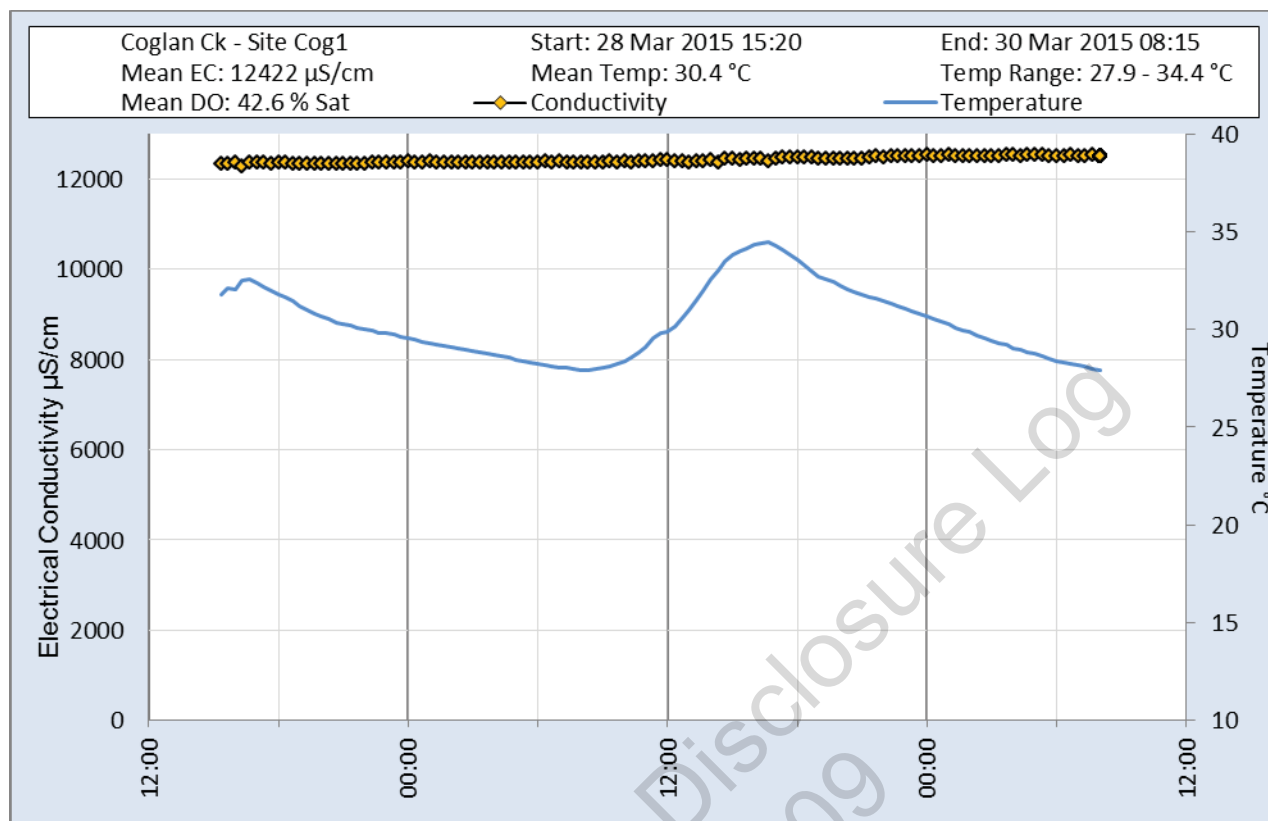
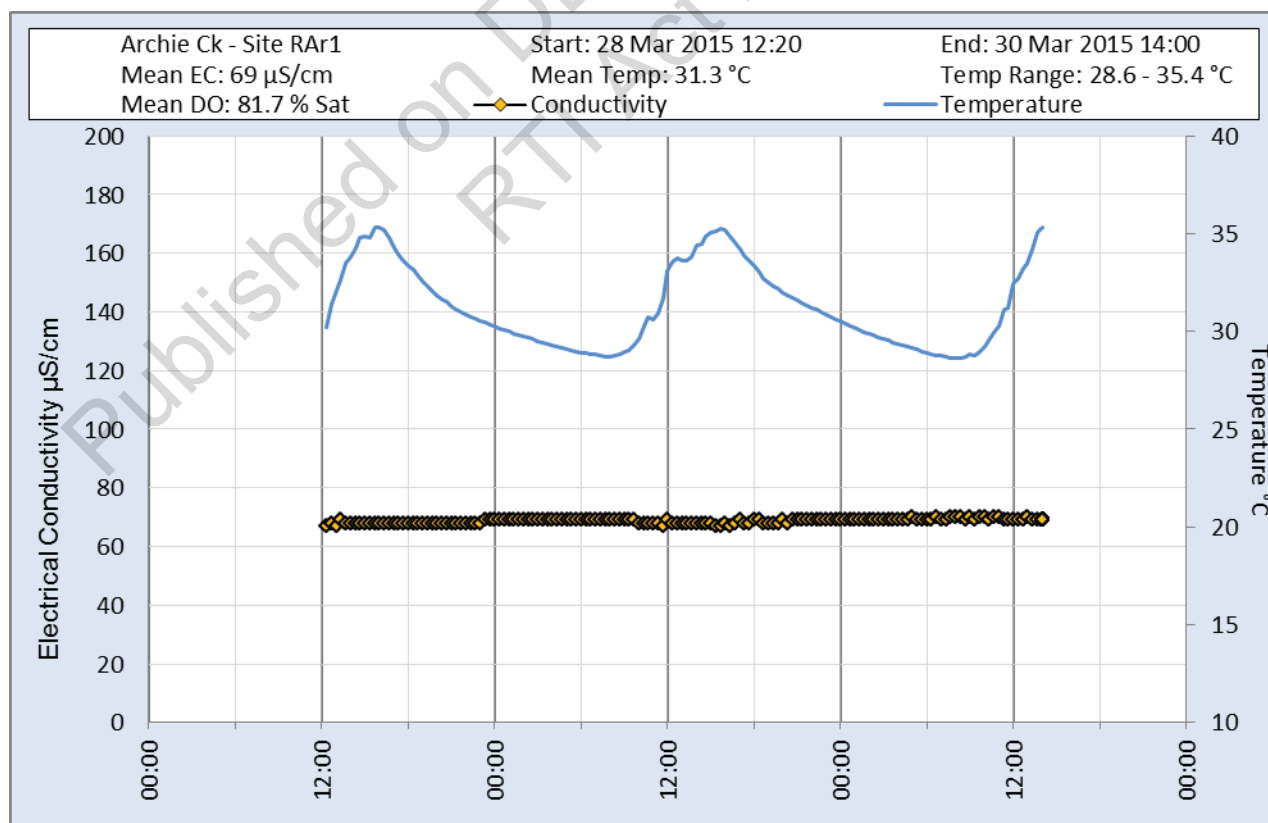


Figure 5.11: Data logger results for temperature and EC at site **RAr1** (March 2015)



In the following discussions, unless otherwise advised, comments relating to the normal ambient DO expectations of local waters and/or the hypoxia (i.e. DO deficiency) tolerances of local ecosystems have been derived from Butler & Burrows (2007).

The Hydrolab logging data for DO was variable at both sites (Figures 4.2.8 – 4.2.9), and exhibited strong diel periodicity (Figures 4.2.8 – 4.2.9) which is indicative of normal photosynthetic productivity by phytoplankton and/or benthic algae. Hence there was no indication of any substantial suppression of algal productivity.

RAr1 had a minimum dissolved oxygen saturation greater than 40% and maximum values greater than 100% which is sufficient to support local aquatic species. However, at site Cog1 the minimum daily dissolved oxygen saturation fell as low as 7.3% which is low enough to potentially impair biological communities, particularly sensitive local fish species such as hardyheads and bony bream. These species may need to rise to the water surface in order to avoid asphyxiation. In this region though, even hypoxia-sensitive fish species are well adapted to cope with brief episodes of moderate hypoxia provided that such incidents only occur during the night or very early in the morning when the fish can rise to the surface without exposing themselves to hazards associated with bright sunlight (e.g. overheating, sunburn and exposure to predation).

Many benthic invertebrates are unable to rise to the surface to obtain oxygen and must therefore contend with the sometimes lower DO levels at the bottom. Available data suggests that benthic invertebrates inhabiting dry tropics ephemeral habitats can tolerate prolonged exposure to DO values as low as 10 to 15%. Water quality profiles conducted at the datalogging sites indicate that in this case the sites were shallow enough to prevent the water column from stratifying, and this linked with the logging results indicates that the benthos would have been adequately oxygenated to support normal invertebrate communities.

The lower dissolved oxygen at Cog1 can potentially be attributed to the presence of decaying vegetation and detritus within the waterbody. The bottom sediments of these systems can support dense populations of microbial organisms which are a primary source of oxygen demand in natural waterholes. Consequently breakdown of this material by benthic microbial communities can be oxygen demanding leading to reduced dissolved oxygen concentrations in the overlying water column.

The Hydrolab logging records and depth profiling data both indicate that pH levels were within acceptable limits at all sites, ranging from 6.3 to 8.0. The Archie Creek reference site RAr1 reported the lowest readings at pH 6.3 (Figures 4.2.9). On occasions in the past a number of sites have reported daily maximum pH values well in excess of 9 due to the development of cyanobacteria blooms (which increase pH due to bicarbonate utilisation). The absence of pH values above 8.6 suggests that cyanobacteria levels this year were generally low to moderate. The temperature readings recorded by dataloggers exhibited a typical diel pattern (Figure 4.2.10 & 4.2.11).

Lawn Hill Creek supports such reliable baseflows (and consequently maintains such high re-aeration rates) that diel variations in DO and pH are generally very moderate and it is not necessary to routinely deploy dataloggers at those sites. However, manual depth profiling measurements are routinely carried out as part of the REMP at multiple sampling stations at each Lawn Hill Creek site (Table A.2, Volume 2). Comparisons between morning and afternoon profiling data will provide indications of the levels of diel periodicity in Lawn Hill Creek. If increases in diel variability are encountered it would be recommended to deploy dataloggers in Lawn Hill Creek, but this is an unlikely event.

The results of the 2015 dissolved oxygen profiling showed no significant diel cycling in Lawn Hill Creek. The results also indicate that the Lawn Hill sites were well-mixed, exhibiting little variation with depth. Surface DO levels ranged from 73% to 107% across all of the Lawn Hill Creek sites. All of these values are well within the ranges that are typical of a mixed surface water layer within a healthy perennial stream.

Within-site pH variations (between depths and between measuring stations) were minimal at all Lawn Hill

Creek sites. Between-site variations were generally moderate with values varying from 7.7 to 8.2 across all sites. All the results fall within the normal range expected under baseflow conditions in groundwater-driven streams in this region of Australia.

5.3 Aqueous Metals

Surface water samples collected in 2015 were analysed for a range of filterable metals and metalloids (Table 5.3). A number of parameters that have historically proven to be of low concern with respect to mining impacts and which to date have not exhibited any indication of temporal changes in natural background metals concentration signatures (see previous reports) have not been analysed this year.

Manganese however is one element that has historically exceeded the ANZECC (2000) trigger value (TV) for 95% protection of aquatic ecosystems on occasion at a number of sites. In 2015, manganese at site Cog1 exceeded the reference maximum (1490 µg/L), as well as the ANZECC (2000) trigger value of 1900 µg/L.. Nickel was also above the local reference maximum (2 µg/L) at Cog1 but the value was below the ANZECC (2000) hardness modified trigger value for 95% protection of aquatic ecosystems (99 µg/L). The selenium reference level was exceeded at the new REMP site PH-387 but at this stage it is unknown if the value is within the normal range for this site.

All other elements were below the maximum reference values at all sites (Table 5.3).

Table 5.3: Surface water analysis results 2015 for filterable metals which have proven in the past to be of low risk with respect to exceeding ANZECC 92000) TV. Results that are above local reference max are highlighted in blue. Values greater than the ANZECC 2000 TV for 95% protection of aquatic ecosystems are highlighted in red. N/A indicates not analysed

Site	Copper (µg/L)	Iron (µg/L)	Manganese (µg/L)	Nickel (µg/L)	Selenium (µg/L)
Lawn Hill Creek					
RL3	<1	N/A	2	<1	<10
RL2	<1	N/A	3	1	<10
RL1	<1	N/A	3	<1	<10
RL0	<1	N/A	2	<1	<10
L1a	<1	N/A	4	<1	<10
L1b	<1	N/A	4	<1	<10
L1c	N/A	N/A	N/A	N/A	N/A
L2a	<1	N/A	2	<1	<10
L02	<1	N/A	2	<1	<10
L3a	<1	N/A	<1	<1	<10
L03	<1	N/A	2	<1	<10
L04	<1	N/A	4	<1	<10
L05	<1	N/A	1	<1	<10
Lawn Hill Ref 80 th Percentile	<1	50	5	<1	<10
Lawn Hill Ref Max	2	153	6	1	<10
Lawn Hill Ref n	25	25	32	29	25
Other- Reference/Control					
R01	<1	320	1490	1	<10
RAr1	1	1330	69	<1	<10
RAr2	3	25	15	<1	<10
RM1	3	25	4	2	<10
RSpr1	N/A	N/A	N/A	N/A	N/A
RCog1	9	25	5	<1	<10
Page Creek Impact					
A01	2	25	126	<1	<10
C01	N/A	N/A	N/A	N/A	N/A
D01	N/A	N/A	N/A	N/A	N/A
E01	N/A	N/A	N/A	N/A	N/A
F01	N/A	N/A	N/A	N/A	N/A
F04	N/A	N/A	N/A	N/A	N/A
F09	N/A	N/A	N/A	N/A	N/A
G01	N/A	N/A	N/A	N/A	N/A
G07	N/A	N/A	N/A	N/A	N/A
Other Creeks Impact					
Bul1	N/A	N/A	N/A	N/A	N/A
Bul2	N/A	N/A	N/A	N/A	N/A
Cog1	<1	200	4440	12	<10
Cog2	N/A	N/A	N/A	N/A	N/A
LAr1	N/A	N/A	N/A	N/A	N/A
PH-387	9	4	<0.1	<5	20
MS	N/A	N/A	N/A	N/A	N/A
Local Ref 80 th Percentile	50	268	58.6	1	<10
Local Ref Max	810	1330	1490	2	<10
Local Ref n	41	47	48	47	30

In 2014, an analytical issue emerged with a few samples reporting filterable metals results higher than the corresponding total metals result. This has occurred most frequently for zinc. A separate assessment undertaken in 2014/15 has indicated that certain brands of sampling consumables can contribute measurable concentrations of certain metals including zinc. Recommendations have been made to avoid the use of certain brands of sampling consumables to reduce this contamination risk. In 2015, there was one sample where filterable zinc exceeded the total zinc result (Table 5.4).

Historically zinc, and to a lesser extent cadmium, have been the parameters of principle concern in this study area. In line with DERM (now EHP) directives, arsenic and lead have also been treated as priority contaminants, but to date there has been no evidence of significant enrichment of those two contaminants in the receiving environment. In 2015, filterable and total arsenic, cadmium and zinc concentrations were at or below the reporting limit at all Lawn Hill Creek sites (Table 5.4). Lead was detected at one Lawn Hill site only (RL1) and at concentrations just above the reporting limit. In the non-Lawn Hill Creek sites, filterable arsenic, lead, zinc and cadmium were below the reporting limit or below ANZECC 2000 default trigger values (Table 5.4).

Particulate metals are not typically bioavailable, but particles can potentially release filterable bioavailable forms of metal into the water column if water quality conditions change, so total metals values must be taken into consideration when conducting risk assessments. However, the metals which are tied up in particulate form at any given time are not immediately bioavailable and are therefore substantially less toxic than filterable forms. Hence ANZECC (2000) guidelines recommend using filterable metals values when assessing compliance with trigger values.

Two non-Lawn Hill Creek sites (RCog1 and A01) reported filterable zinc above the default trigger value ($8\mu\text{g/L Zn}$), however they were below the hardness modified trigger value (HMTV). Both sites were holding water from an isolated rain event the previous week, and as such the water quality data is to be considered more typical of “pre-flush” conditions than ambient conditions. The results for both sites were low to typical compared to previous years (Figure 5.16).

The filterable and total zinc results for site Cog1 continue to be lower than reported in 2012 and 2013. It is important to note that in 2014, the sampling point was relocated approximately 300m downstream from the previous site due to overgrowth of *Typha* sp. at the original sampling location. An outcome of the 2013 report was a decision to undertake a detailed assessment to determine the likely source/s and potential fate of the elevated zinc. This was incorporated into a wider review of seepage from the adjacent Evaporation Dam which has been reported separately (TropWATER 2015a). That report provides a more detailed examination of the status of environmental impacts in the vicinity of Cog1.

Table 5.4: Total and filterable concentrations of arsenic, lead, cadmium and zinc in surface water samples collected in 2015. Filterable metal results that exceed ANZECC 2000 TV for 95% protection of freshwater ecosystems (using hardness modified TVs - HMTVs - where relevant) are highlighted in red. Total metal results that are above the local reference maximum are highlighted in blue. Note: where filterable results have exceeded total metal results for the same element, the filterable result has been identified with an *. N/A indicates that no water was available.

Site	Filterable Metals (µg/L)				Total Metals (µg/L)				HMTV (µg/L) Zinc
	Arsenic	Lead	Cadmium	Zinc	Arsenic	Lead	Cadmium	Zinc	
Lawn Hill Creek									
RL3	<1	<1	<0.1	<5	<1	<1	<0.1	<5	62
RL2	<1	<1	<0.1	<5	<1	<1	<0.1	<5	63
RL1	<1	2	<0.1	<5	<1	<1	<0.1	<5	61
RL0	<1	<1	<0.1	<5	<1	<1	<0.1	<5	60
L1a	<1	<1	<0.1	<5	<1	<1	<0.1	<5	60
L1b	<1	<1	<0.1	<5	<1	<1	<0.1	<5	60
L1c	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
L2a	<1	<1	<0.1	<5	<1	<1	<0.1	<5	59
L02	<1	<1	<0.1	<5	<1	<1	<0.1	<5	59
L3	<1	<1	<0.1	<5	<1	<1	<0.1	<5	59
L03a	<1	<1	<0.1	<5	<1	<1	<0.1	<5	58
L04	1	<1	<0.1	<5	<1	<1	<0.1	<5	56
L05	<1	<1	<0.1	<5	<1	<1	<0.1	<5	57
Lawn Hill Ref 80 th Percentile	<1	<1	<0.1	<5	<1	<1	<0.1	6.8	
Lawn Hill Ref Max	<1	3	<0.1	41	2	2	0.8	36	
Lawn Hill Ref n	29	29	32	32	29	29	29	29	
Other- Reference/Control									
R01	7	1	<0.1	*	7	8	<0.1	22	15
RAr1	3	1	<0.1	<5	3	1	<0.1	<5	6
RAr2	3	<1	<0.1	<5	3	<1	<0.1	<5	20
RM1	2	<1	<0.1	<5	2	34	0.1	54	20
RSpr1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RCog1	1	<1	<0.1	12	2	6	<0.1	27	18
Page Creek Impact									
A01	1	<1	0.1	16	1	15	0.2	92	24
C01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F09	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G01	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Other Creeks Impact									
Bul1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bul2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cog1	1	<1	<0.1	7	26	<1	<0.1	7	72
Cog2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LAr1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PH-387	8	<1	<0.1	<5	9	4	<0.1	<5	20
MS	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Local Ref 80 th Percentile	10	<1	<0.1	4	2	3	<0.1	30	
Local Ref Max	133	3	0.6	50	7	34	0.3	62	
Local Ref n	47	47	48	48	46	46	46	46	

Historically cadmium, manganese and zinc have been the only contaminants to report trigger value exceedances potentially linked to the mine. In order to conveniently assess the relative risks associated with each of these filterable metals the results have been converted into exceedance factors by dividing each raw concentration value by its respective TV or HMTV (Table 5.5). The risk can be inferred as the greater the exceedance factor the greater the potential for environmental risk. Only values larger than one are shown, hence blank cells indicate cases where the result complied with the respective trigger value (with hardness modification where applicable). Grey cells indicate cases where analyses were not performed (either because the site had dried out that year or it had not yet been included in the monitoring network). As no exceedances have been reported in Lawn Hill Creek, those sites have not been included in the table.

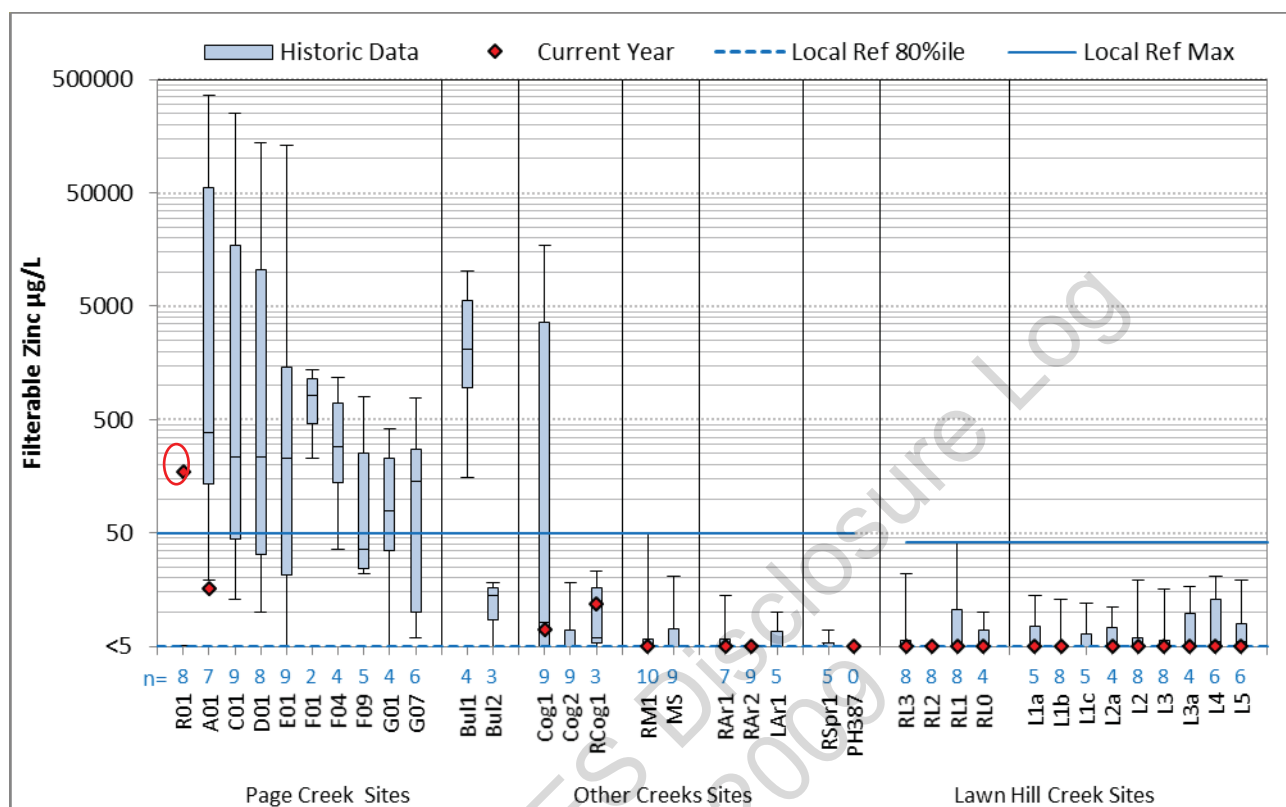
Table 5.5: Exceedance factors for all of the TV breaches that have been reported for filterable cadmium, manganese and zinc since April 2005. Exceedance factors are derived by dividing each metal concentration result by its respective TV (hardness modified for cadmium and zinc). Blank cells indicate that the result complied with the TV and grey cells denote instances where a site was not sampled.

Site	Cadmium										Manganese										Zinc									
	2005	2006	2009	Mar-10	May-10	2011	2012	2013	2014	2015	2005	2006	2009	Mar-10	May-10	2011	2012	2013	2014	2015	2005	2006	2009	Mar-10	May-10	2011	2012	2013	2014	2015
R01																														*
A01	27	1.5		5	8						83	2									968	16		20	35					
C01		86	54		4							6.2	151									522	3457	9	23	3.3	1.9		1.8	
D01		52	33		3							3	100									415	1894	17	29		1		*	
E01			36		4							4	78									34	1797	22	52				*	
F01					2																			12	33					
F04																								67		2.8				
F09																								11		1.6				
G01																								1	1	5.7				
G07																								2	4	11			2.1	
Bul1		2	2.4		3								2									37	140	2	20					
Bul2																								2						
Cog1								1										5	2	3.8	2.3						116	241		
Cog2																														
RCog1																													*	
RM1																									1				6.3	
MS																														
RAr1																									3					
RAr2																														
LAr1																														
PH387																														
RSpr1																														

* Represents those sites with filterable results higher than total results and hence are considered suspect

Similar to 2013, there was very limited surface water present in Page Creek sites in 2015. Those sites holding water were the result of a localised rain event occurring a week prior to sampling. Overall, historic data indicate there have been improvements in the aqueous metals status of Page Creek over time since 2009.

Figure 5.16: Filterable zinc (<0.45 μm fraction) in surface waters in 2015 compared to historic data (2005 – 2014). Current year data is identified as a red diamond. Sites circled in red have filterable zinc higher than the corresponding total zinc concentration and are considered unreliable until the source of contamination is resolved.



5.4 Sediment Quality

Composite surface sediment samples were collected at all sites including those holding no water at time of sampling. In 2014 the analytical suite for sediments was refined to better determine potential ecological impacts. Samples were analysed for mass percentage passing 63 μm (<63 μm fines %), and weak acid extractable (WAE) metals in the <2 mm and <63 μm sediment fraction. The analysis results obtained for these parameters in 2015 are shown in Table 4.3.1.

In 2015, the proportion of fines (<63 μm) in the sediment samples ranged from 3% at a number of sites (Lar1, RSpr1, RL3) to 34% at Cog1 (Table 4.3.1). As such, the composition of the fine sediment fraction is by no means representative of the overall composition of the sediment that is actually present at many of these study sites. For these reasons historically it has not been valid to directly compare the <63 μm total dissolved metals (TDM) results to ANZECC (2000) interim sediment quality guidelines (ISQGs) for the protection of aquatic ecosystems. Instead, to obtain a more realistic estimate of the concentrations of potentially bioavailable metals that are actually present at each site, it is necessary to analyse the whole <2 mm sediment fraction and employ a less aggressive acid extraction. The weak acid extraction method employed in this study uses 1 M HCl acid which is the procedure recommended in the ANZECC 2000 guidelines. The WAE results obtained from this analysis can validly be compared directly to the ISQGs. (Note that HCl is by definition a strong acid, so this method should really be referred to as a dilute acid digestion. However, the term weak acid has been retained in order to maintain consistency with ANZECC terminology).

To complement the <2mm WAE data, in 2014 it was decided to also undertake WAE analysis of the fines (<63 μm) to determine the concentration of potentially bioavailable metals that aquatic organisms and in particular, benthic biota may ingest (Tessier *et al.* 1984). The analytical method employed is the same as for the <2mm sediment.

In 2012 it was necessary to have the sediments analysed at a different laboratory than had been used previously due to concerns about sample-matrix analytical bias. The zinc results obtained at impact sites were slightly lower than expected but they were still reasonably consistent with historical expectations, and QC duplicates analysed at another laboratory were in acceptable agreement. In contrast the reference sites reported considerably higher levels than ever before. It therefore appeared that the results were subject to a sample-matrix-dependent analytical bias.

The <2mm WAE phosphorus results for 2012 were even more anomalous than the TDM zinc values. Once again the effects were matrix or sample-type dependent, with all reference sites reporting values that were more than an order of magnitude higher than previous years, while impact sites yielded results that were generally consistent with the historical data.

There are unresolved inconsistencies in the relationship between the reference data for 2011 and earlier with the results for 2012 and later. Until these uncertainties have been resolved the post-2011 values will be excluded from the historical reference dataset. In order to help determine the source of the apparent analytical inconsistencies, and ensure that they do not occur again, matrix-matched quality control standards are being prepared using sediments collected from the study area. The first of these is currently undergoing certification analysis at multiple laboratories and should be available for use in the 2016 monitoring program.

At present there is limited historic WAE <63µm data available to compare 2015 results (Figure 5.17). All reference sites except RM1 were below the ISQG-Low concentration of 200 mg/kg Zn. RM1 exceeded the ISQG-High level in the <63µm fraction (Figure 5.17). All the Page Creek sites except R01 and G01 exceeded the zinc ISQG-Low. Site G07 exceeded zinc ISQG-Low but did not exceed the zinc ISQG-High (Table 5.6 & Figure 5.17).

Similar to results for <63µm TDM zinc from 2012 results, the “other creek” impact sites WAE zinc <63µm data were slightly elevated compared to the limited historic WAE data. Only sites BUL1 and BUL2 exceeded the zinc ISQG-Low, with all other non-Page Creek sites were below the ISQG-Low (Figure 5.17). However, the sediments at most of the non-Page Creek sites are still largely uncontaminated and could therefore actually be subject to the same high bias as the reference sites. This reinforces the requirement for development of certified quality-control standards to address potential inconsistencies.

The Lawn Hill Creek impact sites reported decreased <63µm WAE zinc concentrations with distance downstream of the junction with Page Creek. Notably, sediments in that section of Lawn Hill Creek are notoriously heterogeneous and cannot be reliably assessed with a single composite sample. The metals status of that section of the creek has been assessed more closely by conducting transect sampling, the results of which are discussed later in this section of the report.

Similar to the zinc data, the <63 µm WAE cadmium results have very limited historical data available at present. Detectable <63 µm WAE cadmium was only present at some Page Creek impact sites and Bull (Figure 4.3.2). There was attenuation in cadmium in the lower reaches of Page Creek and the spatial pattern through Page Creek was similar to that seen for <63 µm WAE zinc (Figure 5.17 & Figure 5.18). Since the zinc and cadmium in Page Ck have always been closely correlated, and there has been no indication of analytical bias for cadmium, these results support the contention that the zinc levels in the near-surface sediment layer of the Page Creek streambed have declined over the past few years. This may be due to mixing with underlying bed sediments (dilution), mobilisation downstream or dilution from tributary stream sediments.

Table 5.6: 2015 surface sediment results. Metal concentrations are in mg/kg. WAE (<2 mm) metals results that exceed the ANZECC ISQG-high are shown in red, while those that exceed the ISQG-low are blue. N/A not analysed; na – not applicable

Site	< 63µm Fines (%)	WAE Metals <2mm (mg/kg)				WAE Metals <63um (mg/kg)				Contribution <63um to the <2mm fraction (mg/kg)				% Contribution of <63um metals to the <2mm fraction			
		Cadmium	Lead	Phosphorus	Zinc	Cadmium	Lead	Phosphorus	Zinc	Cadmium	Lead	Phosphorus	Zinc	Cadmium	Lead	Phosphorus	Zinc
Lawn Hill Creek – u/s Page Creek																	
RL3	3	<1	3	80	4	<1	14	180	16	-	0.5	6.1	0.5	-	16	8	14
RL2	8	<1	3	100	4	<1	11	190	13	-	0.9	16.0	1.1	-	31	16	27
RL1	17	<1	8	100	7	<1	15	170	11	-	2.5	28.4	1.8	-	31	28	26
RL0	7	<1	8	80	19	<1	16	110	35	-	1.1	7.6	2.4	-	14	9	13
Lawn Hill Creek – d/s Page Creek																	
L1a	5	<1	9	380	97	<1	13	120	144	-	0.7	6.2	7.5	-	8	2	8
L1b	6	<1	12	1120	171	<1	16	130	178	-	0.9	7.7	10.5	-	8	1	6
L2a	19	<1	10	110	97	<1	11	120	118	-	2.1	23.2	22.8	-	21	21	23
L2	21	<1	11	110	137	<1	10	110	113	-	2.1	23.4	24.1	-	19	21	18
L3a	23	<1	8	80	46	<1	10	80	45	-	2.3	18.6	10.5	-	29	23	23
L3	15	<1	9	110	106	<1	12	140	133	-	1.8	20.4	19.4	-	19	19	18
L4	21	<1	7	80	21	<1	10	100	26	-	2.1	21.2	5.5	-	30	27	26
L5	16	<1	7	70	12	<1	10	80	13	-	1.6	13.1	2.1	-	23	19	18
Other Sites – Reference / Control																	
R01	6	<1	12	<50	11	<1	32	<50	38	-	1.9	-	2.2	-	15	-	20
RCog1	6	<1	6	70	36	<1	9	90	37	-	0.5	5.0	2.0	-	8	7	6
RAr1	14	<1	6	<50	9	<1	8	70	12	-	1.1	9.6	1.6	-	18	-	18
RAr2	2	<1	50	540	46	<1	74	910	101	-	1.3	16.4	1.8	-	3	3	4
RM1	8	<1	85	670	162	1	275	2520	539	0.1	22.8	209	44.7	-	27	31	28
RSpr1	3	<1	3	90	4	<1	10	150	18	-	0.3	3.9	0.5	-	9	4	12
Page Creek																	
A01	17	<1	37	<50	246	1	104	100	567	0.2	18.1	17.4	98.7	-	49	-	40
C01	11	2	39	1180	711	2	123	1350	1020	0.2	13.9	153	115	11	36	13	16
D01	6	2	36	5100	544	2	92	4500	554	0.1	5.2	256	31.6	6	15	5	6
E01	10	4	28	330	1020	3	46	490	1700	0.3	4.6	49.5	172	8	17	15	17
F01	11	<1	13	240	324	2	35	160	632	0.2	3.7	17.1	67.6	-	29	7	21
F04	11	<1	16	220	237	1	30	280	426	0.1	3.3	30.8	46.9	-	21	14	20
F09	12	2	16	270	819	2	27	130	719	0.2	3.2	15.3	84.8	12	20	6	10
G01	13	<1	11	210	410	<1	16	90	106	-	2.0	11.5	13.6	-	19	5	3
G07	14	2	13	1800	703	1	20	210	337	0.1	2.7	28.4	45.5	7	21	2	6
Other Creeks																	
Bul1	16	3	74	1140	2720	3	102	1160	3470	0.5	15.9	181	541	16	22	16	20
Bul2	13	<1	12	60	81	<1	31	140	222	-	4.2	18.8	29.7	-	35	31	37
Cog1	34	<1	2	<50	10	<1	8	60	34	-	2.7	20.4	11.6	-	136	-	116
Cog2	20	<1	6	60	41	<1	6	80	45	-	1.2	15.7	8.8	-	20	26	22
PH-387	10	<1	13	920	20	<1	14	380	22	-	1.5	39.5	2.3	-	11	4	11
MS	6	<1	14	240	102	<1	25	310	135	-	1.5	18.6	8.1	-	11	8	8
LAr1	3	<1	5	100	2	<1	13	190	15	-	0.4	5.5	0.4	-	8	6	22
ISQG-Low	na	1.5	50	na	200	na											
ISQG-High	na	10	220	na	410												

Figure 5.17: Plots of <63µm WAE sediment zinc results (mg/kg) for 2015 compared to 2010 data.

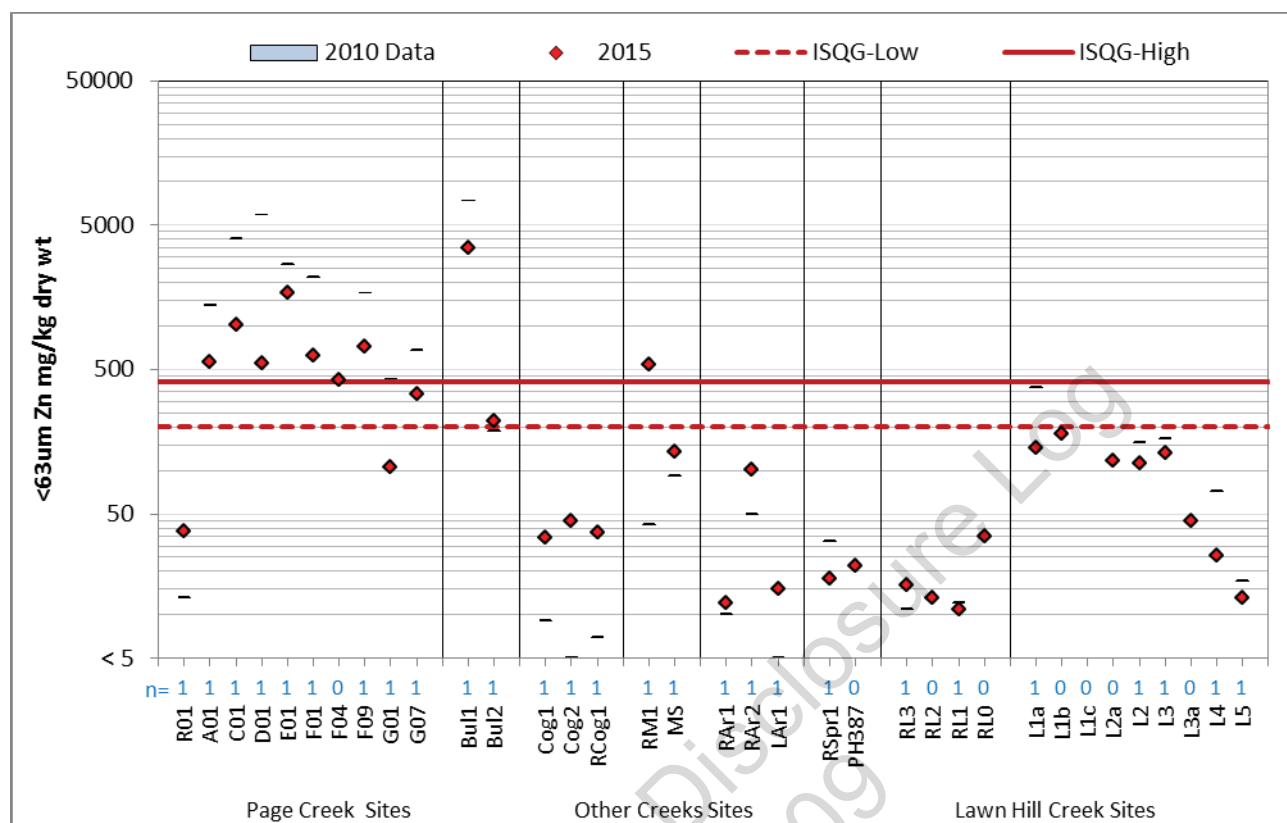
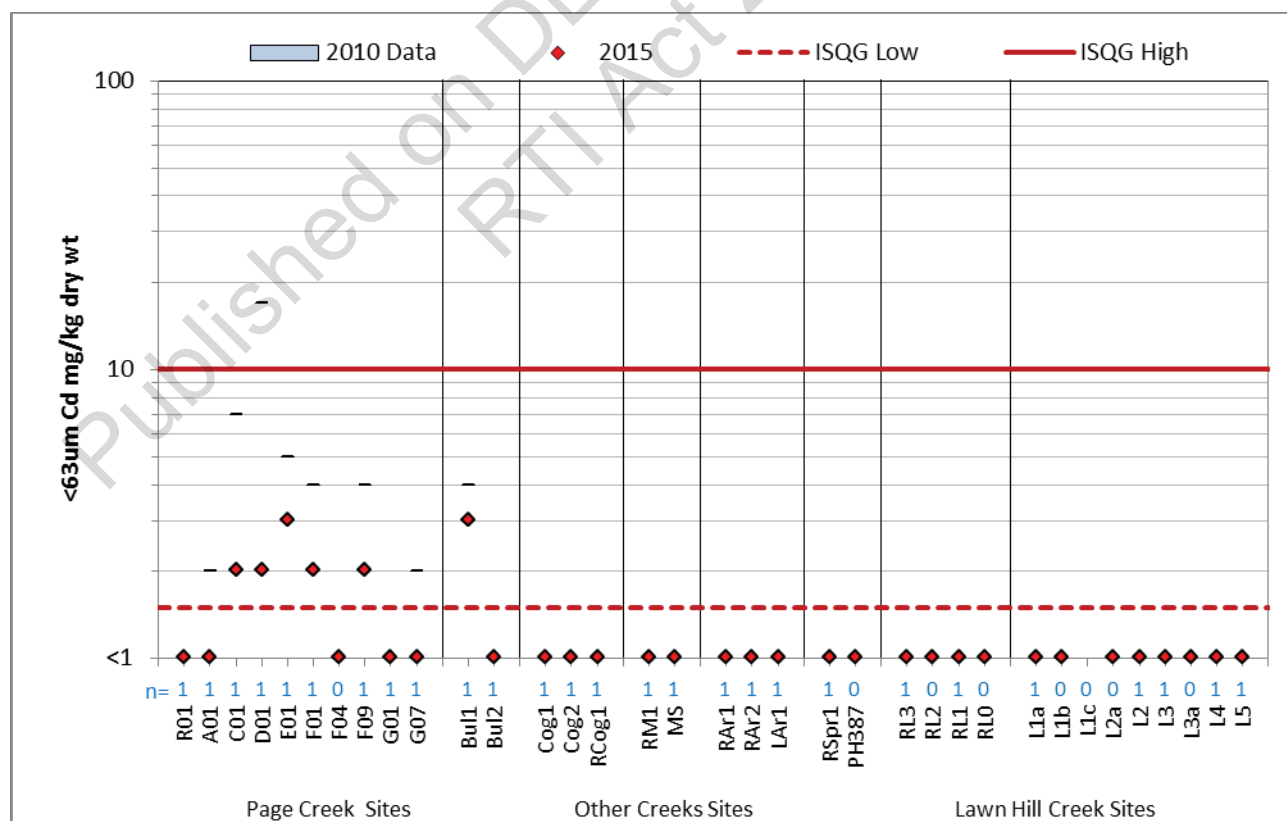


Figure 5.18: Plot of <63µm WAE sediment cadmium results (mg/kg) for 2015 compared to 2010 data.

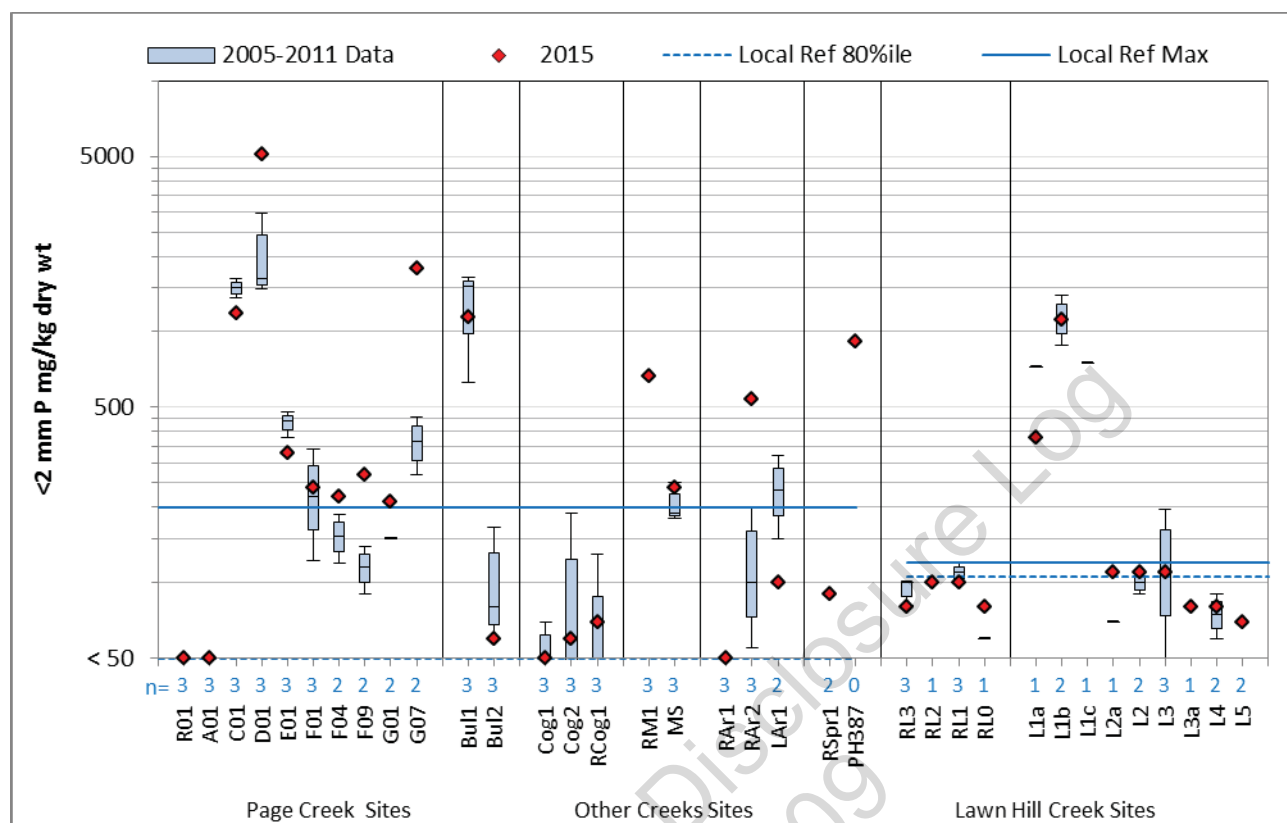


The WAE <2mm sediment metals results in Table 5.6 have been obtained by analysing whole sediment (i.e. the <2 mm fraction; noting that for the purposes of this kind of assessment, stone and gravel greater than 2 mm in size are not generally considered to be part of the sediment). However, it should be noted that the limnological monitoring site network is necessarily constrained to those places within the creeks that retain water long enough to allow assessment of ambient water quality and the integrity of the aquatic ecosystem. These sites do not provide the optimum basis for evaluating the distribution of stream sediments throughout the watercourse as a whole. Moreover, in this survey samples have only been collected near the sediment surface in order to determine the quality of the sediment to which benthic and demersal biota will be most exposed, so the quality of deeper sediments has not been determined. It must therefore be stressed that the results presented here are primarily intended to assess the potential ecological relevance of existing contaminant accumulations at the surface of the benthos within each waterhole and only yield preliminary indications of contaminant distribution patterns; the depth profiling results presented in the annual dry season sediment monitoring report provide a much more quantitative basis for assessing variations in sedimentary contaminant distributions.

Phosphorus results in 2015 are more consistent with historical data (and 2013 results) and almost all sites (both reference and impact) reported results that were within the expected order of magnitude (Figure 5.19). However, the 2015 phosphorus level at one of the four the Lawn Hill reference sites, is still slightly above the pre-2012 reference values. The margin involved is conceivably within the realms of natural variability and/or normal analytical and sampling errors; however, the new data will not be incorporated into the long term reference dataset until the sources of interlaboratory biases have been thoroughly investigated (which is currently being done as part of the process of certifying the locally derived QC standards).

The phosphorus results for the impact sites do not appear to have been subject to the substantial biases and/or errors that have been observed at the reference sites. All of the impact sites reported results with spatial distribution patterns largely mirroring the historical trends indicated by the boxplots; i.e. the highest values occurred in close proximity to previously identified phosphorus sources (the Phantom Hills phosphate deposit adjacent to site D01 on Page Ck, the Mt Jennifer deposit adjacent to G07 on Page Ck, and the Page Ck confluence immediately upstream of L1a, L1b and L1c on Lawn Hill Ck), and there was clear evidence of attenuation with distance downstream of those points. This simple distribution has been maintained in Page Ck since 2009 (when monitoring was first extended into the lower reaches of the creek), however, each year there have been one or two minor discontinuities in the attenuation gradients caused by slugs of sediment deposited on the tail of large-scale flow events. It must be noted that for Figures 5.19 to 5.21 the points displayed for sites L1a to L3 on Lawn Hill Ck are median values obtained from multiple samples collected along transects across the creek.

Figure 5.19: WAE (<2 mm) sediment phosphorus results (mg/kg) for 2015, compared 2005-2011 historical data.



The elevated phosphorus levels at C01 and D01 indicate that some of the phosphorus residues in the creek originate from the mine, but further downstream at G07, the effects of this are confounded by inputs from the natural phosphate deposits. It is pertinent to note that, even though the phosphorus levels adjacent to input sources throughout this study area are generally quite elevated, most of the phosphorus occurs in forms that are neither water soluble nor bioavailable, and hence to date there has been no indication at any monitoring site of elevated concentrations in the water column or of any eutrophication effects that could be attributable to uptake of benthic phosphorus (eutrophication being the most likely impact of bioavailable phosphorus). Algal blooms have occasionally been observed at some sites (including reference sites) but their occurrence has not been correlated to the sediment phosphorus levels and appears to have mainly been linked to other more available nutrient sources such as livestock excrement.

The <2 mm WAE zinc results for 2015 (Figure 5.20) largely recapitulate the spatio-temporal patterns observed for <63 μm WAE zinc. There are clear indications of attenuation gradients in the middle reaches of Page Creek and downstream of the Page Creek confluence on Lawn Hill Creek (note that the Lawn Hill Ck data are examined more closely later in this section of the report). The lower reaches (F01 & F04) of Page Creek have the lowest <2 mm WAE zinc values compared to pre-2012 data.

The 2015 zinc concentrations at the Cogan Creek sites (Cog1, Cog2, RCog1) were generally elevated compared to historical data although still below ISQG-Low (Figure 5.20). This effect was similar across most sites with <2mm WAE results higher than historic results for all “Other Creek” sites and likely reflects natural accumulation of material over time.

As is normally the case in this study area, the <2 mm WAE cadmium results (Figure 5.21) exhibited the same general spatio-temporal trends as zinc. From an ecological perspective the main difference is that none of the Page Creek sites exceeded the ISQG-high.

Figure 5.20: WAE (<2 mm) sediment zinc results from 2005 – 2011 compared to 2015 results

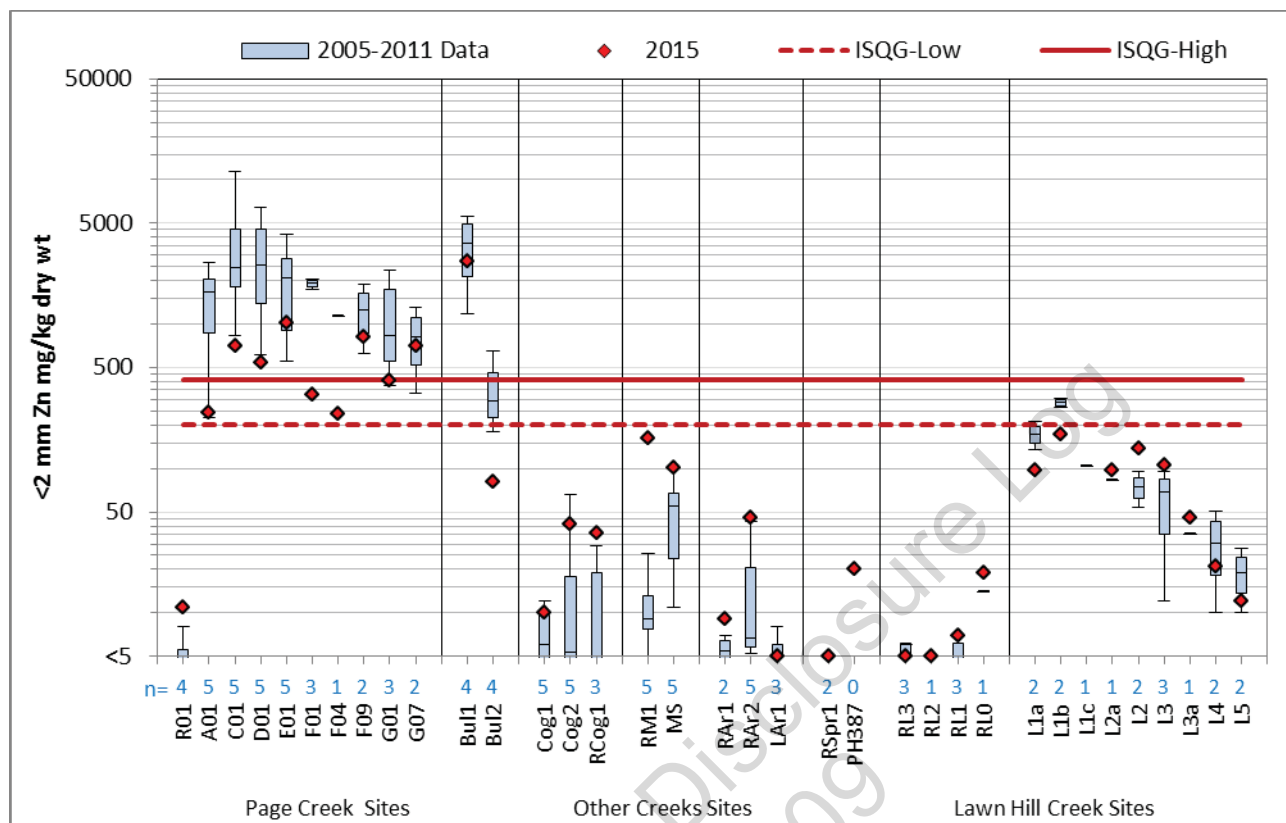
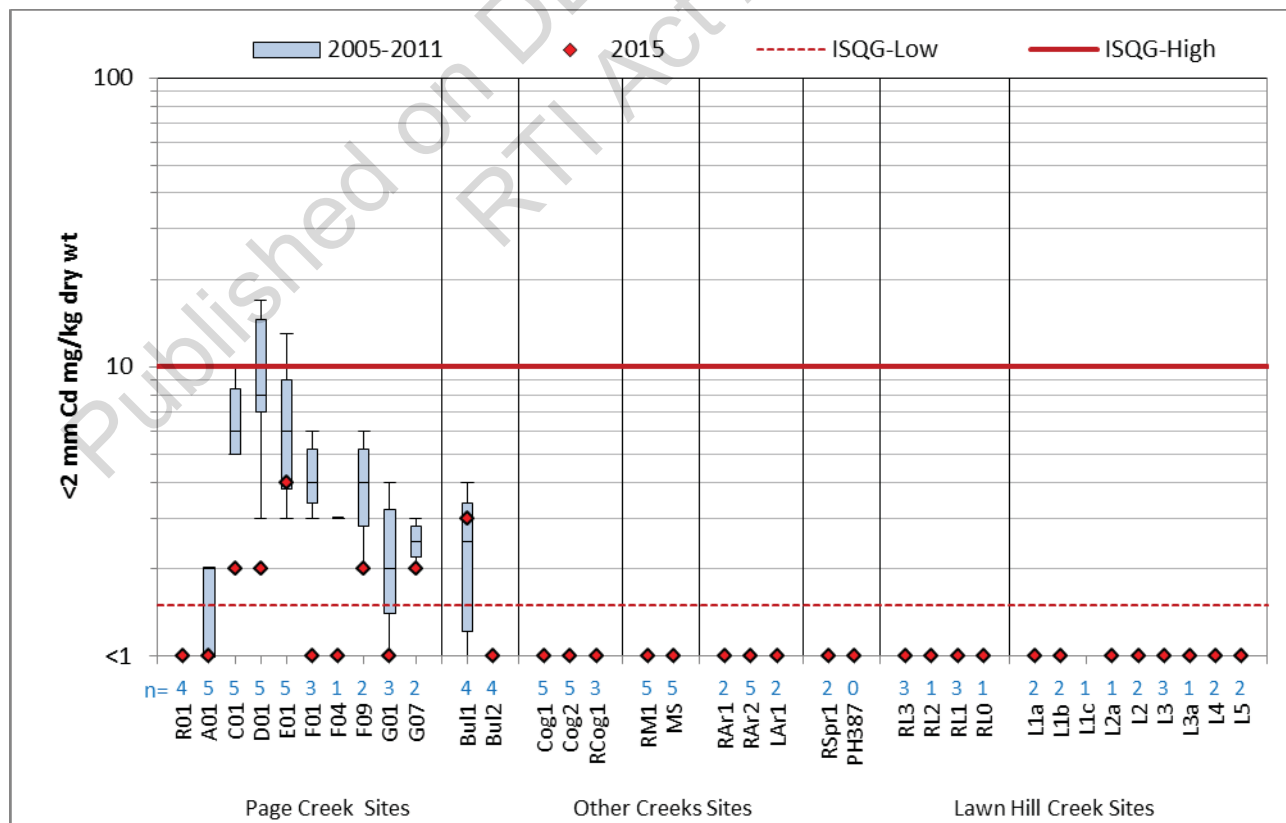


Figure 5.21: WAE (<2 mm) sediment cadmium results from 2005 – 2011 compared to 2015 results



An assessment of the relative fractional concentrations show the WAE concentrations of zinc and lead, and to a lesser extent phosphorus in the WAE <63µm sediment fraction are generally higher than the levels in the whole (<2mm) sediment sample Table 5.6, Figures 5.22, Figure 5.23). However, the fine fraction

typically represents less than 30% of the whole sediment sample and generally makes a low contribution to the <2mm contaminant concentration at most sites (Table 5.6). The proportion of fines in the sediment was similar to 2014.

For the reference sites, the percent contribution of the <63µm fraction to the whole sediment zinc concentration ranged from 4% at RAr2 to 28% at RM1 (Table 5.6). Cog1 had a very high fines contribution of <63µm zinc fraction to the whole sediment. All other sites were much lower, ranging from 3% (G01) to 40% (A01). This supports the hypothesis that the zinc residues at Cog1 have resulted from sorption and/or precipitation of dissolved zinc rather than having been introduced in particulate form (as appears to be the case at most other impact sites).

This is also true for phosphorus which in some cases occurs at higher levels in the sand (<2mm) sediment fraction than in the fine fraction (>63µm). This suggests that those sites are located close enough to the phosphorus source for low mobility coarse-grained mineral particles to regularly reach them. This effect is evident in Page Creek at D01 (immediately adjacent to the Phantom Hills phosphate deposit) and at G04 (adjacent to the Mt Jennifer phosphate deposit), but it is most obvious at site L1 on Lawn Hill Creek (also immediately adjacent to the Mt Jennifer deposit).

Accordingly, <2 mm WAE results are considered to provide the most meaningful basis for assessing existing zinc, cadmium and phosphorus levels, and it is the method that has been adopted for most of the detailed sediment monitoring that has been carried out in connection with the Century Mine project.

Figure 5.22: Contribution of <63 µm WAE zinc to the <2mm WAE zinc concentration.

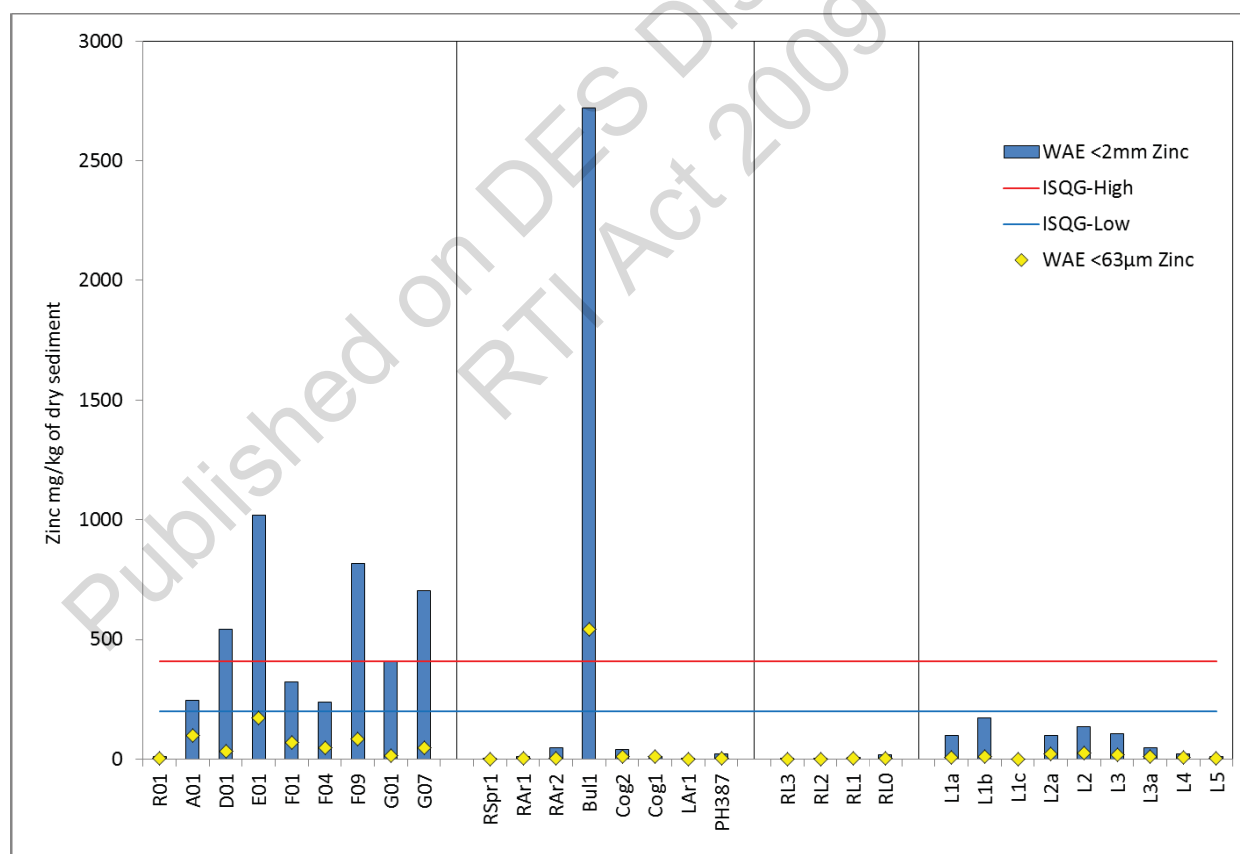
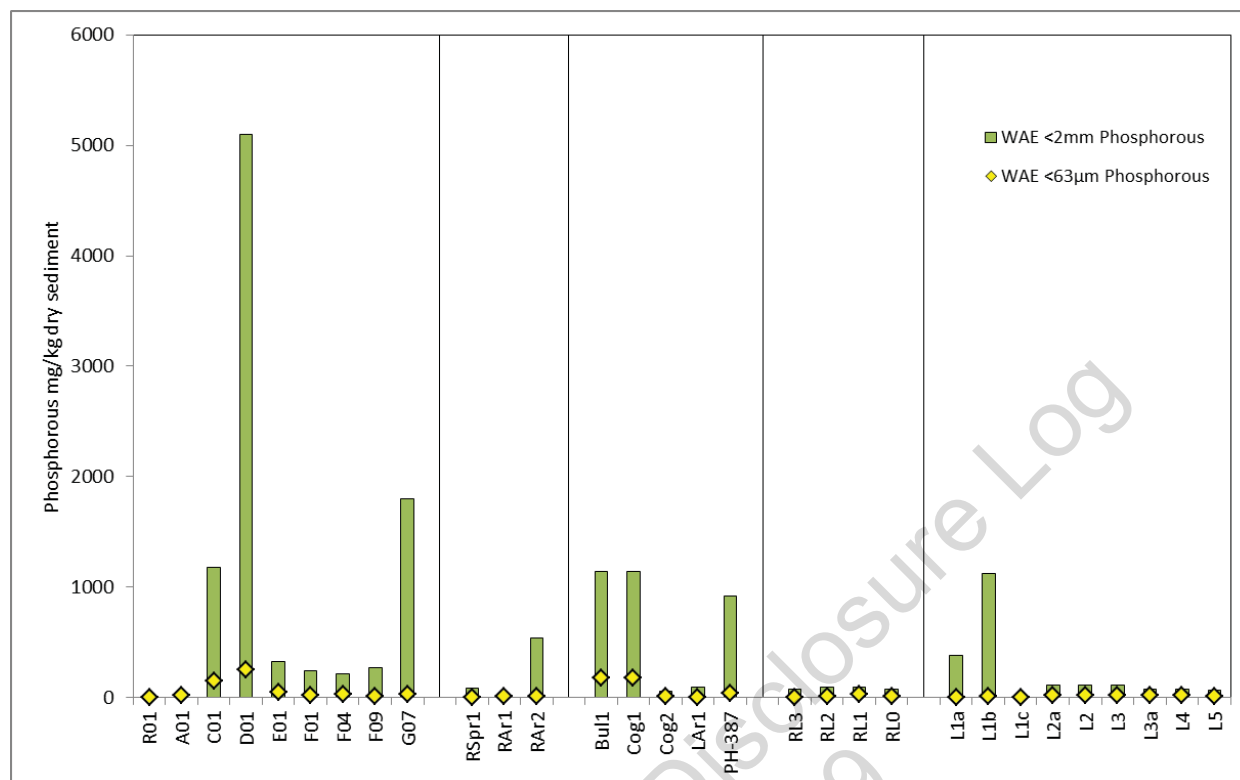


Figure 5.23: Contribution of <63 µm WAE phosphorus to the <2mm WAE phosphorus concentration.



As a consequence of the metals being principally associated with the coarse particle fraction, the sediments at some Lawn Hill Creek sites have exhibited extreme heterogeneity. This has necessitated the implementation of quite intensive sampling at sites L1a, L1b, L1c, L2a, L2 and L3a (additional to the routine composite sample that is taken at all sites). For the past 4 sampling programs, a total of eight composite samples have been collected along transects across the creek at each site. Summary statistics for the <2mm WAE zinc and phosphorus results obtained in 2015 are listed in Table 5.7 and the raw data for each of the metals that were analysed are presented in Table 5.8.

Table 5.7 Summary statistics for the <2 mm WAE Zinc and Phosphorus results obtained at transect sampling sites on Lawn Hill Creek in 2015. Data in blue exceeds ANZECC (2000) ISQG-Low

<2mm WAE Zinc (mg/kg)						
Site	Random Composite	Site Mean ($\pm$ 95% C.I.)	Upper limit of mean	Min	Median	Max
L1a	97	69 $\pm$ 48	117	14	51	194
L1b	171	226 $\pm$ 31	257	186	218	278
L1c	-	77 $\pm$ 42	119	18	59	147
L2a	97	80 $\pm$ 19	99	47	82	115
L02	137	81 $\pm$ 41	122	19	63	164
L03	106	60 $\pm$ 27	87	7	71	96
L3a	46	-	-	-	-	-
L04	21	-	-	-	-	-
L05	12	-	-	-	-	-
<2mm WAE Phosphorus (mg/kg)						
Site	Random Composite	Site Mean ($\pm$ 95% C.I.)	Upper limit of mean	Min	Median	Max
L1a	380	341 $\pm$ 219	560	100	250	880
L1b	1120	1914 $\pm$ 715	2629	950	1570	3080
L1c	-	398 $\pm$ 224	622	160	310	1000
L2a	110	110 $\pm$ 17	127	80	120	140
L02	110	128 $\pm$ 22	149	90	140	150
L03	110	114 $\pm$ 42	156	60	125	210
L3a	80	-	-	-	-	-
L04	80	-	-	-	-	-
L05	70	-	-	-	-	-

Table 5.8 <2 mm WAE analysis results (mg/kg) for replicate surface samples & composite sample collected at selected impact sites on Lawn Hill Creek in April 2015.

Sample	Phosphorus	Cadmium	Zinc	Lead
L1a (composite)	380	<1	97	9
L1a-1	100	<1	76	8
L1a-2	170	<1	100	6
L1a-3	200	<1	14	6
L1a-4	360	<1	35	6
L1a-5	880	<1	43	5
L1a-6	300	<1	33	4
L1a-7	560	<1	194	9
L1a-8	160	<1	58	10
Mean (Transect)	341	<1	69	7
L1b (composite)	1120	<1	171	12
L1b-1	1130	1	271	15
L1b-2	1550	<1	250	11
L1b-3	1370	<1	188	8
L1b-4	2670	1	207	12
L1b-5	2970	<1	228	12
L1b-6	3080	<1	199	12
L1b-7	1590	1	278	14
L1b-8	950	<1	186	8
Mean (Transect)	1914	N.D.	226	12
L1c (composite)				
L1c-1	540	<1	141	10
L1c-2	1000	<1	147	10
L1c-3	310	<1	59	10
L1c-4	310	<1	58	8
L1c-5	290	<1	116	10
L1c-6	360	<1	46	9
L1c-7	160	<1	29	6
L1c-8	210	<1	18	5
Mean (Transect)	398	<1	77	9
L2a (composite)	110	<1	97	10
L2a-1	120	<1	86	12
L2a-2	120	<1	98	12
L2a-3	120	<1	115	16
L2a-4	140	<1	97	13
L2a-5	90	<1	47	10
L2a-6	120	<1	77	13
L2a-7	80	<1	59	8
L2a-8	90	<1	62	7
Mean (Transect)	110	<1	80	11

Table 5.8 (cont.) <2 mm WAE analysis results (mg/kg) for replicate surface samples & composite sample collected at selected impact sites on Lawn Hill Creek. Refer to main text for explanation of sample ID codes.

Sample	Phosphorus	Cadmium	Zinc	Lead
L02 (composite)	110	<1	137	11
L02-1	90	<1	40	8
L02-2	100	<1	61	6
L02-3	100	<1	19	5
L02-4	140	<1	65	15
L02-5	150	<1	127	18
L02-6	150	<1	164	14
L02-7	140	<1	58	14
L02-8	150	<1	116	13
Mean (Transect)	128	<1	81	12
L03 (composite)	110	<1	106	9
L03-1	130	<1	96	9
L03-2	120	<1	90	9
L03-3	130	<1	76	4
L03-4	70	<1	65	5
L03-5	60	<1	33	3
L03-6	60	<1	32	3
L03-7	130	<1	83	7
L03-8	210	<1	7	7
Mean (Replicates)	114	<1	60	6
L3a (composite)	80	<1	46	8
L04 (composite)	80	<1	21	7
L05 (composite)	70	<1	12	7
RL3 (composite)	80	<1	4	3
RL2 (composite)	100	<1	4	3
RL1 (composite)	100	<1	7	8
RL0 (composite)	80	<1	19	8

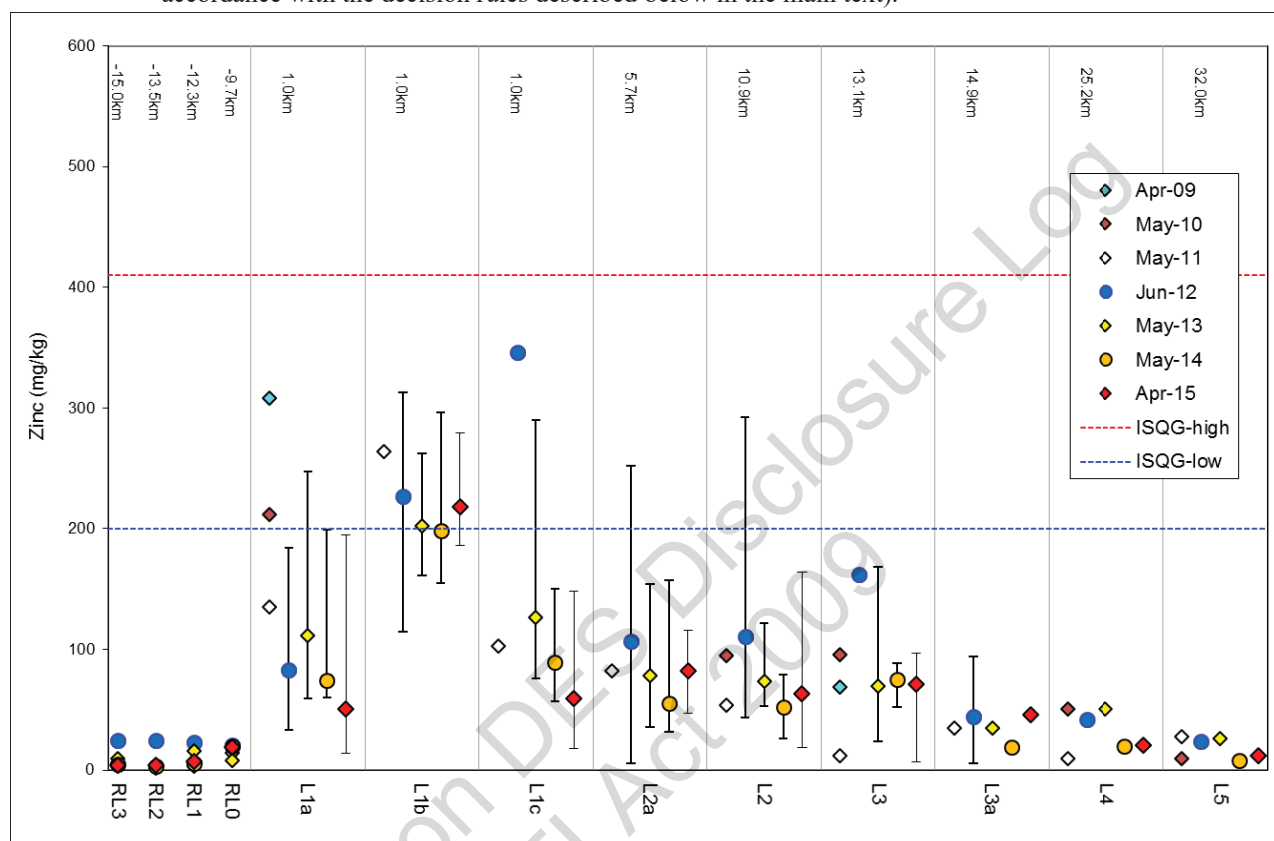
As has been the case in the past, the phosphorus variations recorded at L1a, b and c (the Lawn Hill Creek sites closest to Page Creek) were large with the confidence intervals of the mean ranging from 291 to 715 mg/kg. This level of spatial variability makes it very difficult to resolve temporal variations and/or isolate the effects of analytical errors and inconsistencies. Nevertheless, it is apparent that the phosphorus enrichment is largely confined to within close proximity of Page Creek and the Mt Jennifer phosphate deposit, with the concentrations at Lawn Hill Creek sites downstream of L1 being substantially lower and less variable.

Zinc results were not as variable as phosphorus but were still large enough to suggest that in order to assess future spatio-temporal trends in this section of Lawn Hill Creek, it will be necessary to maintain the high spatial sampling replication employed this year, especially given that the levels at some sites currently span the ISQG-Low.

Despite the variability, it is clear that zinc levels in Lawn Hill Creek decline with distance downstream from Page Creek (Figure 5.24) with levels at the most downstream sites (L4 and L5) trending towards reference. In 2015 L1b (median 218 mg/kg) was the only site to report any values above the ISQG-Low (of 200 mg/kg). It is salient to note that the highest result at that site (278 mg/kg) was more than 100 mg/kg below the ISQG-High (of 400 mg/kg). Sites L1a and L1c (situated in separate braids of the creek adjacent to L1b) were the only other sites that reported any individual results that approached the ISQG-Low but the median

values at those sites were substantially lower than the ISQG suggesting that the sediments in those braids of the creek currently present minimal risk to aquatic biota.

Figure 5.24 <2 mm WAE zinc results obtained from surface sediment samples collected on Lawn Hill Creek in 2015 compared to historical monitoring results. Points without error bars are individual values obtained from random composite samples. Error bars denote the range of values obtained from replicate samples collected along transverse transects. Points with error bars are either mean or median values (in accordance with the decision rules described below in the main text).



There is a suggestion in Figure 5.24 that zinc levels may have decreased slightly at some sites over the past few years but none of the apparent interannual differences are statistically significant.

The high levels of variability at these sites raise the question of which statistical measures provide the best basis for assessment. That issue was addressed in the 2012 dry season sediment report; the following text is an edited excerpt from that document.

TropWATER believe that the following principles should apply: Non-metric statistics (such as medians and percentiles) lack the statistical power of metric statistics (such as means and confidence intervals) so whenever the number of samples (n) is less than six, the mean is the preferred measure of central tendency. However, if $n \geq 6$, medians and percentiles should be used to assess the risks to benthic organisms that inhabit the monitoring site, and mean values should be used to assess potential risks to downstream environments. That is because unlike means, the non-metric measures provide a direct (though admittedly somewhat notional) indication of the probability that organisms inhabiting the site will become exposed to a certain contaminant concentration (e.g. we know that there is a 50% chance that organisms will encounter sediment concentrations higher or lower than the median value).

Mean values provide less realistic indications of the exposure risks presented to biota that inhabit highly heterogeneous sediments. Nevertheless means are important because they provide a direct indication of the total quantity of contaminant that is present in the streambed (i.e. the mean zinc value multiplied by the mass of sediment present, yields an estimate of the total zinc load in the streambed), and hence an indication of potential risks to downstream receiving environments. For means it is also theoretically possible to gain

more quantitative indications of certainty, for example by calculating 95% confidence intervals and limits. However, it must be stressed that the data at most of these sites are not normally distributed, and that will undermine the accuracy of these statistical measures.

5.5 Sediment Pore Water

Pore water filterable metals were collected at sites holding water. The pore water results have been compared with the WAE sediment results for the host sediment (Table 5.9). Cadmium was below the detection limit at all sites, while lead was only detected at one site (RAr1) and was only just above the reporting limit (Table 5.9).

The zinc results for the Lawn Hill sites in 2015 were lower compared to 2014 results. The highest pore water concentration in Lawn Hill in 2015 was 18 µg/L at L3a compared to the 82 µg/L reported at RL2 in 2014. In 2015, both R01 and A01 on Page Creek exceeded the HMTV for zinc (Table 5.9), the higher value being recorded at the reference site. It is important to note that both these sites had received isolated rain in the week prior to sampling although it is unlikely there were any sustained flows in the system. It is possible that the results for this more likely reflect the results of “first flush” events than ambient flows. Both Archie Creek reference sites also exceeded the HMTV for zinc which may be a combination of restricted flows that did not flush the system and evapo-concentration of elements (Table 5.9).

Table 5.9: Pore water filterable metals results for 2015. Pore water values are compared to the WAE concentrations obtained from the host sediment. ANZECC (2000) HMTVs for lead, cadmium and zinc have been included and pore water results that exceed the HMTV are highlighted in red. The zinc results have also been expressed as a percentage of the WAE metal values reported in the preceding section. “-” indicates one analyte less than reported detection limit. NA indicates no pore water sample

Site	Ca mg/L	Mg mg/L	Calculated Hardness mg/L	Pb µg/L	Pb HMTV µg/L	WAE <2mm Pb mg/kg	Cd µg/L	Cd HMTV µg/L	WAE <2mm Cd mg/kg	Porewater Zn µg/L	Zn HMTV µg/L	WAE <2mm Zn mg/kg	% of WAE <2mm zinc in pore water
Lawn Hill Ck													
RL3	56	49	341	<1	74.5	3	<0.1	1.74	<1	8	63.1	4	0.200
RL2	60	56	380	<1	85.4	3	<0.1	1.91	<1	<5	69.2	4	-
RL1	54	47	328	<1	70.8	8	<0.1	1.68	<1	<5	61.1	7	-
RL0	56	52	353	<1	77.9	8	<0.1	1.80	<1	<5	65.1	19	-
L1a	51	48	324	<1	69.9	9	<0.1	1.66	<1	9	60.5	97	0.009
L1b	48	48	317	<1	67.8	12	<0.1	1.63	<1	8	59.3	171	0.005
L1c	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
L2a	60	46	339	<1	73.8	10	<0.1	1.73	<1	16	62.8	97	0.016
L2	47	44	298	<1	62.7	11	<0.1	1.54	<1	6	56.3	137	0.004
L3	49	46	311	<1	66.3	9	<0.1	1.60	<1	8	58.4	106	0.008
L3a	31	42	250	<1	50.1	8	<0.1	1.32	<1	18	48.5	46	0.039
L5	89	45	407	<1	91.2	7	<0.1	2.01	<1	6	72.3	21	0.029
Page Ck													
R01	26	14	122	<1	20.3	12	<0.1	0.70	<1	64	26.4	11	0.582
A01	28	9	107	<1	17.1	37	<0.1	0.62	<1	39	23.6	246	0.016
C01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
D01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
E01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
F09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
G01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
G07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other Creeks													
BUL2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RCog1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cog1	634	1330	7038	<1	91.2	2	<0.1	2.01	<1	28	72.3	10	0.280
Cog2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RM1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RAr1	2	1	9	1	0.7	6	<0.1	0.07	<1	52	2.9	9	0.578
RAr2	32	11	125	<1	20.8	50	0.1	0.71	<1	67	26.9	46	0.146
LAr1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PH-387	126	132	856	<1	91.2	13	<0.1	2.01	<1	31	72.3	20	0.155
RSpr1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

5.6 Aquatic Macroinvertebrates

5.6.1 Routine indicators

Due to lower than average rainfall, opportunities for macroinvertebrate collections were very limited in 2015 except at the Lawn Hill Creek sites. The raw macroinvertebrate results have been summarised by calculating total abundance, taxonomic richness, SIGNAL Index, Shannon Diversity index, H' max and evenness scores for non-Lawn Hill Creek sites (Table 5.10) and Lawn Hill Creek sites (Table 5.11). The Queensland Water Quality Guidelines - QWQG (DERM 2009) recommend using the 20th percentile value from a suitable local reference dataset as a benchmark for assessing the significance of variations in number of taxa and SIGNAL score. Values in the tables that fall below the 20th percentile are highlighted in blue and those that are below the minimum reference value are shown in red. As noted earlier in this report, though it can help put results into context, the procedure of comparing individual results to the 20th percentile reference value is not strictly valid and it is important to remember that, on average over long time frames, 20% of test samples will fall below the 20th percentile reference even if impacts are absent.

There are currently insufficient data to be able to propose individual reference values for ephemeral sites (i.e. Page, Bullridge, Coglan, Mitton and Spring Creek) and sites with intermittent flow that hold permanent water (such as Mitton Springs, Archie Creek and Little Archie Creek). It may be possible to segregate these site groups in the future if regular monitoring continues, but at this stage it has been necessary to derive the reference values from pooled data obtained from both types of site (Table 5.10). The reference values for Lawn Hill Creek have been obtained by pooling all data from upstream control sites on Lawn Hill Creek since monitoring began there in 2009 (Table 5.11).

Pool bottom habitats were able to be sampled at four non-Lawn Hill Creek sites (Table 5.10), while edge and riffle habitats were able to be sampled at most Lawn Hill Creek sites (Table 5.11).

Data collected in 2015 are compared to historical data as boxplots with boxes displaying the 20th, 50th and 80th percentiles, and whiskers denoting the minimum and maximum value (Figure 5.25a-c). The 20th percentile and minimum values derived from the reference datasets are also plotted as reference lines for comparative purposes. Taxonomic richness in pool bottom were below the 20th percentile reference at a number of non-Lawn Hill Creek sites (Figure 5.25a).

As seen in previous years there was low abundance and richness at Cog1 (pool bottom), the latter being particularly low with only 48 individuals from 4 taxa having been recorded although this was higher than the 26 individuals in 2014 (Table 5.10). These relatively depauperate conditions can almost certainly be attributed to the combined effects of very high filterable metals (4440 µg/L Mn), conductivity (12190 µS/cm) and sulphate (8420 mg/L) levels, all of which are diagnostic of seepage from the adjacent evaporation dam. The bottom richness at RAr1 was also below previous results, however, the higher filterable pore water zinc and low dissolved oxygen levels (Table 5.9, Figure 5.9) may be indicative of some local impairment at this site. As there is no previous data for PH-387 it is not known how characteristic the low taxonomic richness is of this site, although it was highly disturbed from cattle and pig activity at the time of sampling. There were also some indications of eutrophication at this location which was also associated with the livestock activity.

Due to the dry conditions no edge habitats were available for sampling at the non-Lawn Hill Creek sites in 2015. For the Lawn Hill Creek sites, the reference sites exhibited reduced richness in the riffle habitat (Figures 5.25b). Some of the sites downstream of the Page Creek confluence typically had higher edge habitat richness and for a number of sites this exceeded the reference 80th percentile (Figure 5.25b). In contrast, richness in riffle habitat at Lawn Hill Creek reference sites was similar to historic data with the impact sites exhibiting greater variability in richness (Figure 5.25c).

Table 5.10: Taxa counts and index values for macroinvertebrate communities at non-Lawn Hill Creek sites in 2015. Results in blue indicate values that are below the historic 20th percentile for the local reference data and values in red are below the historic reference data minimum.

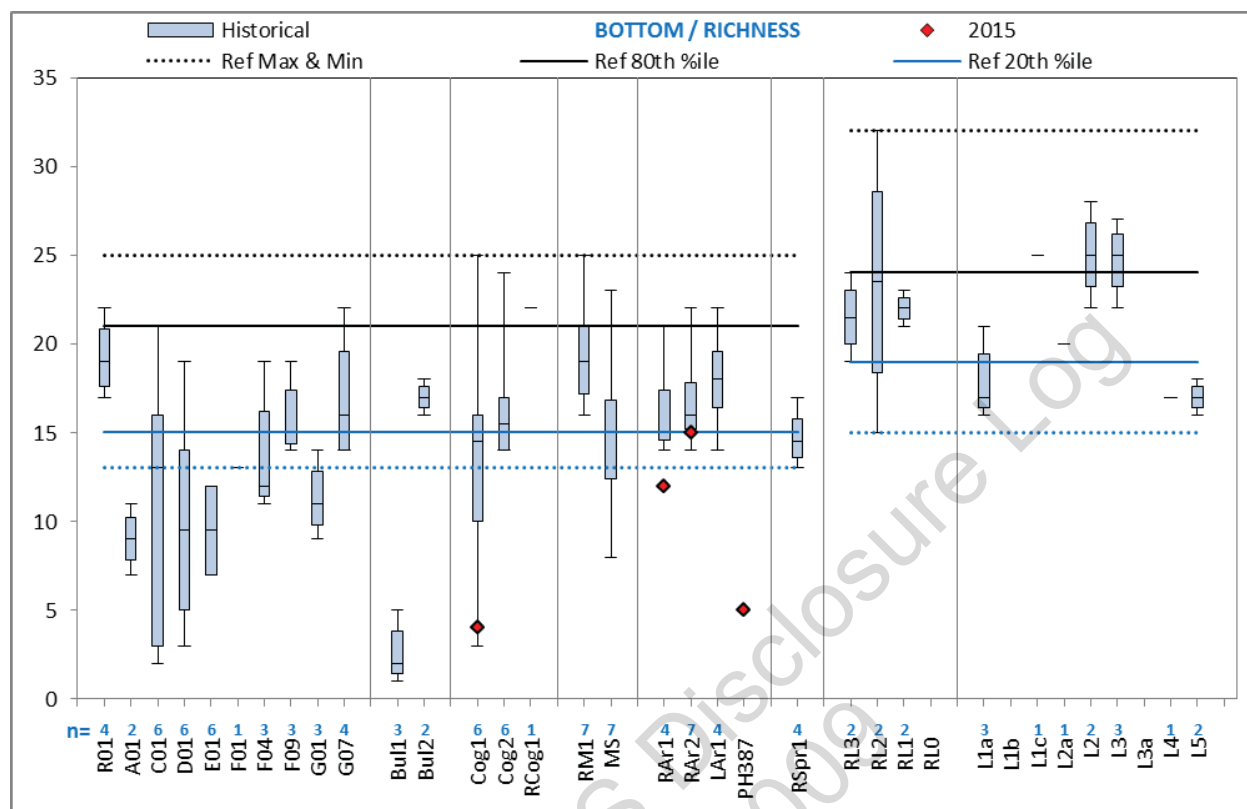
	Total Abundance	Taxonomic Richness	SIGNAL	Shannon Diversity (H')	H'max	Evenness (J')
Pool Habitat						
<i>Other Creeks</i>						
Cog1	48	4	3.00	0.64	1.39	0.47
RAr1	627	12	3.00	1.55	2.48	0.62
RAr2	771	15	3.36	1.43	2.71	0.53
PH387	233	5	3.50	1.24	1.61	0.77
<i>Local Reference Values n=33</i>						
20 th percentile	160	15	3.29	1.72	2.71	0.64
Minimum	126	13	2.94	1.06	2.56	0.39

Table 5.11: Taxa counts and index values for the macroinvertebrate communities at Lawn Hill Creek sites in 2015.

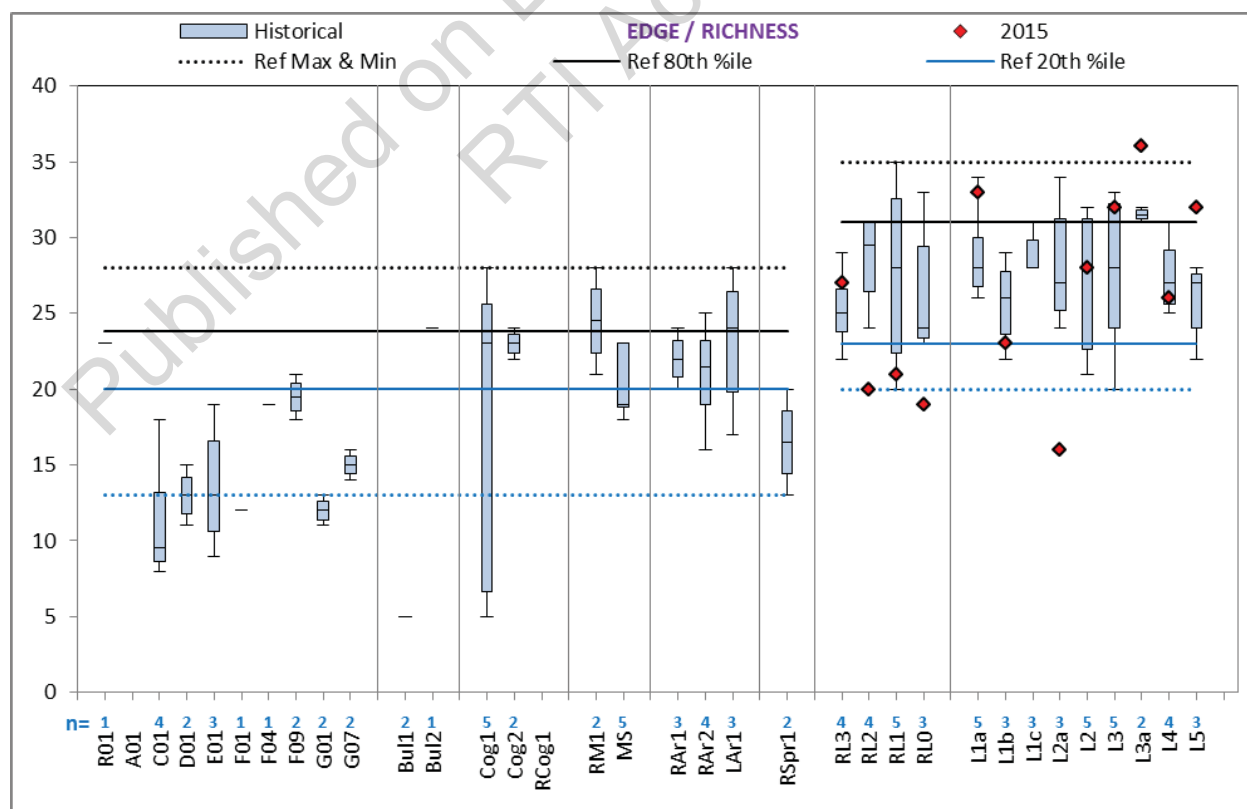
Site	Total Abundance	Taxonomic Richness	SIGNAL	Shannon Diversity (H')	H'max	Evenness (J')
Edge Habitat						
<i>Upstream of Page Ck</i>						
RL3	153	27	3.92	2.37	3.30	0.72
RL2	140	20	3.70	2.53	3.00	0.84
RL1	81	21	3.89	2.68	3.04	0.88
RL0	145	19	4.19	2.21	2.94	0.75
<i>Downstream of Page Ck</i>						
L1a	213	33	3.90	2.82	3.50	0.81
L1b	146	23	3.95	2.75	3.14	0.88
L1c	NA	NA	NA	NA	NA	NA
L2a	102	16	3.81	2.31	2.77	0.83
L2	120	28	4.12	2.90	3.33	0.87
L3	183	32	3.48	3.00	3.47	0.87
L3a	281	36	3.50	3.09	3.58	0.86
L4	544	26	3.30	1.08	3.26	0.33
L5	189	32	3.87	2.97	3.47	0.86
<i>Local Reference Values n= 20</i>						
20 th percentile	120	24	3.58	2.32	3.14	0.73
Minimum	56	20	3.34	1.42	3.00	0.42
Riffle Habitat						
<i>Upstream of Page Ck</i>						
RL3	193	21	4.47	2.63	3.04	0.86
RL2	139	21	4.05	2.16	3.04	0.71
RL1	150	22	4.33	2.72	3.09	0.88
RL0	NA	NA	NA	NA	NA	NA
<i>Downstream of Page Ck</i>						
L1a	161	16	4.31	2.03	2.77	0.73
L1b	183	19	4.28	2.29	2.94	0.78
L1c	NA	NA	NA	NA	NA	NA
L3a	220	21	4.10	2.07	3.04	0.68
L2a	233	22	4.43	2.66	3.09	0.86
L2	210	17	4.41	2.24	2.83	0.79
L3	177	27	4.24	2.78	3.30	0.84
L4	202	23	4.10	2.42	3.14	0.77
L5	NA	NA	NA	NA	NA	NA
<i>Local Reference Values n=21</i>						
20 th percentile	91	20	4.10	2.13	2.91	0.69
Minimum	61	15	4.00	1.83	2.71	0.60

Figure 5.25: Taxonomic richness results for 2015 compared to historical data collected since 2005.

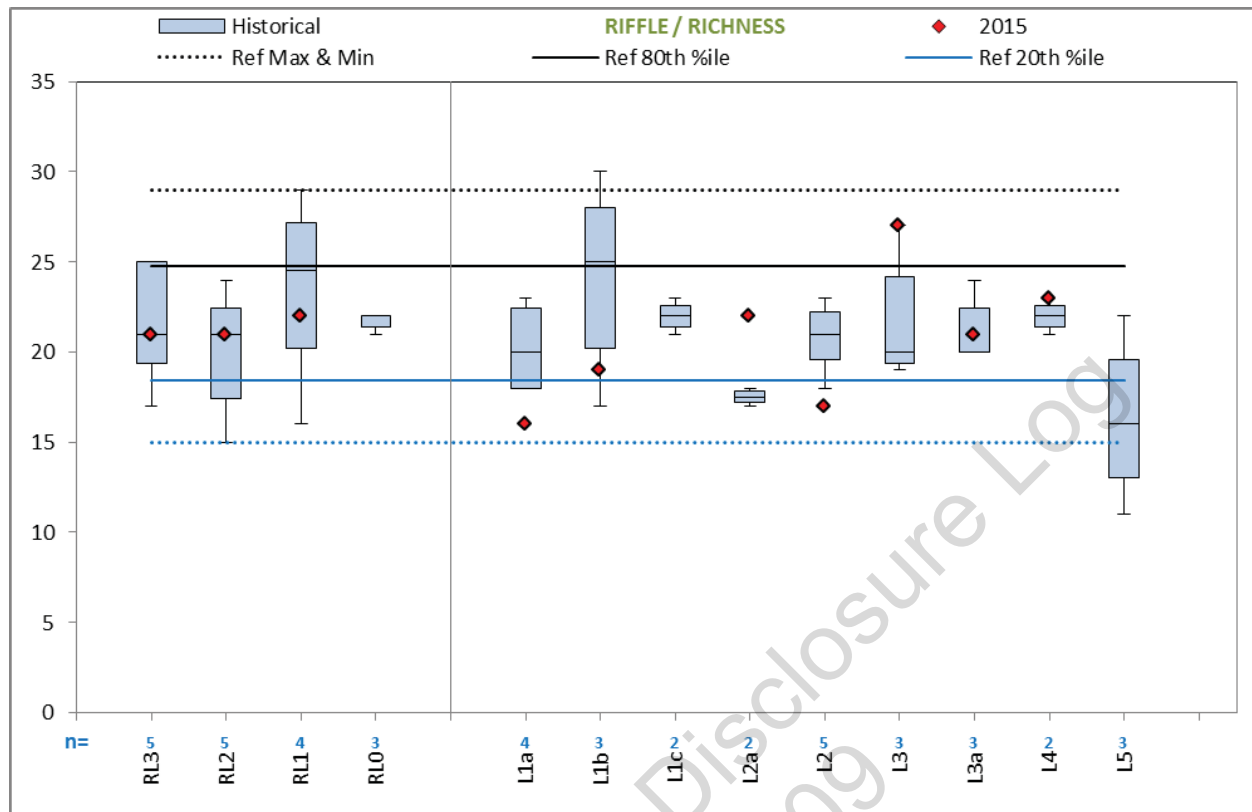
a) Pool bottom habitat



b) Edge habitat



c) Riffle habitat

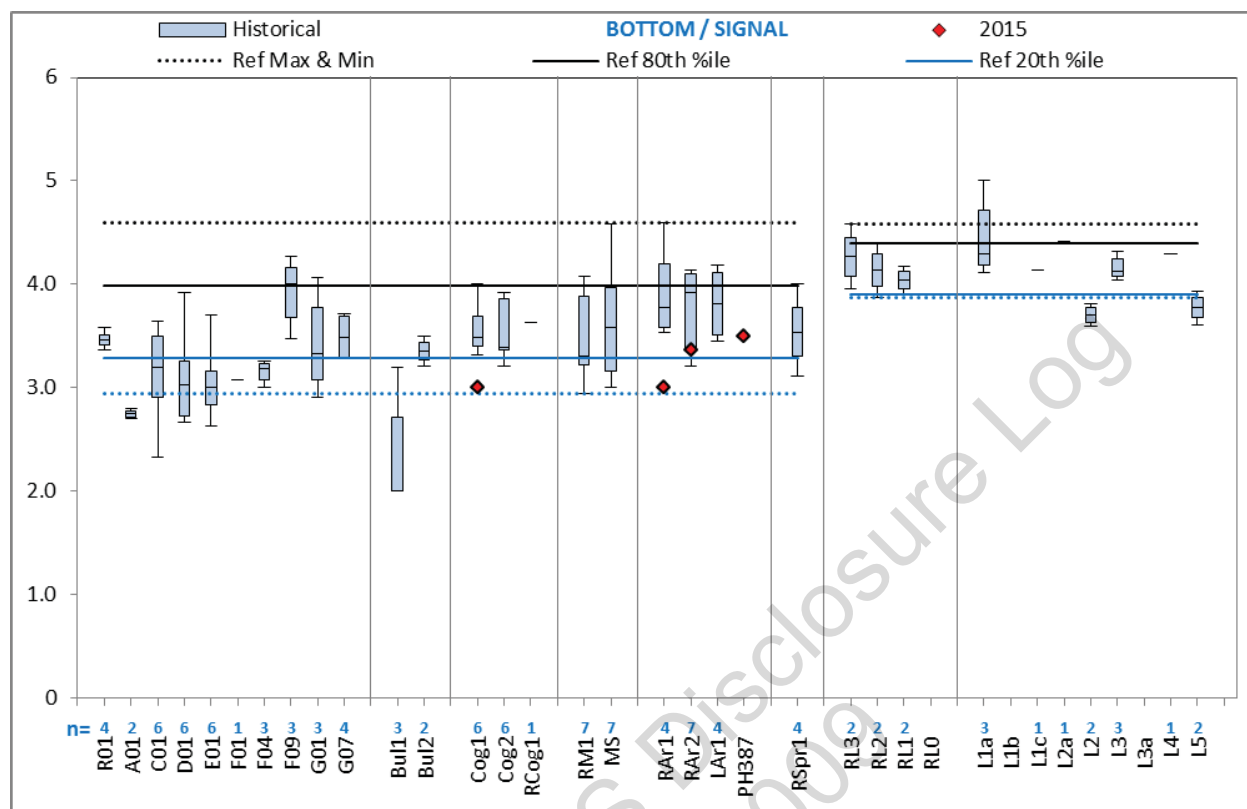


Although the taxonomic richness scores were typically low for non-Lawn Hill Creek sites, the pool bottom habitat SIGNAL scores were at or above the minimum percentile reference for all sites (Figure 5.26). Note that SIGNAL scores provide a numeric estimate of the average sensitivity of the invertebrates taxa that are present, expressed on a scale of one to ten - one being the most tolerant taxa and ten being the most sensitive (Refer to the methods section for a more detailed explanation).

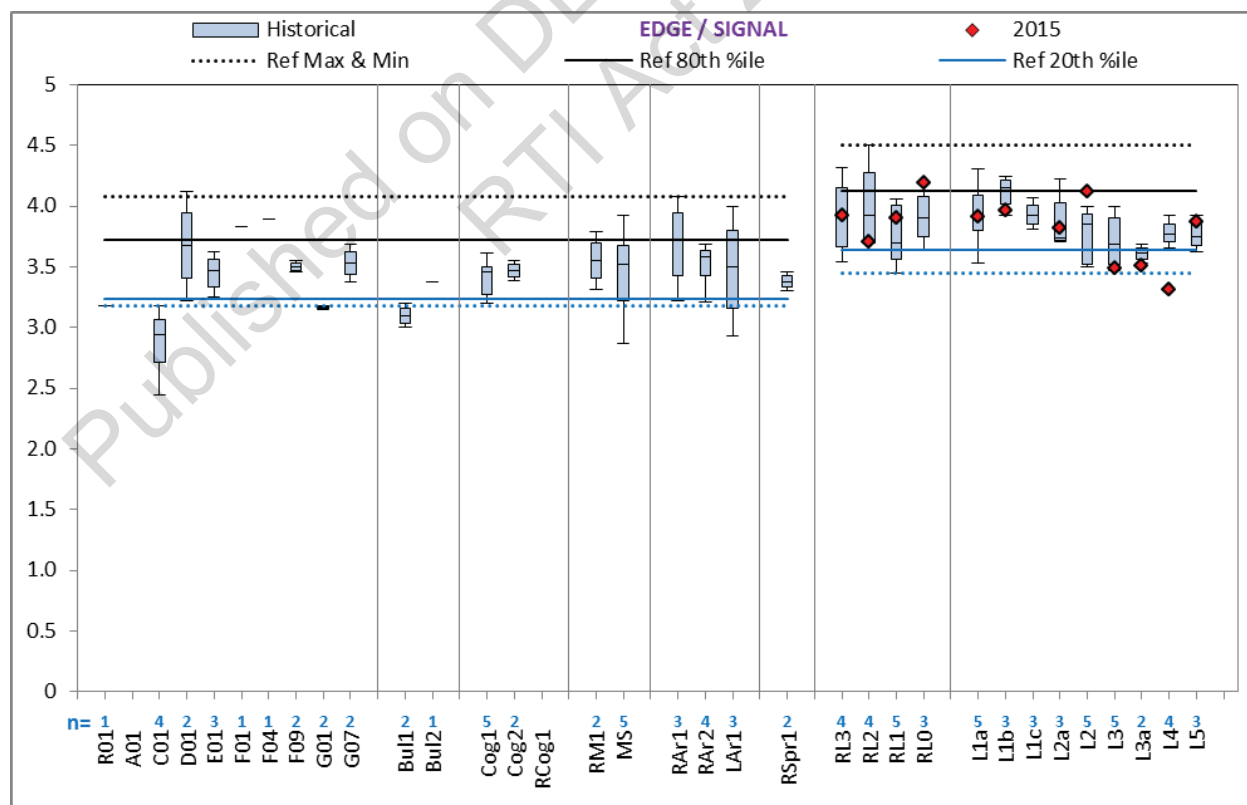
There was no evidence of any significant differences between the upstream controls and the impact sites on Lawn Hill Creek that might be indicative of effects from mine-related contaminants. The SIGNAL scores for edge and riffle habitats for the Lawn Hill Creek reference sites were generally between the 20th and 80th percentiles. The downstream impact sites generally reported SIGNAL scores that were above 20th percentile reference for both edge and riffle habitat indicating they were potentially in as good condition as the reference sites. The lower Lawn Hill Creek sites (L3 – L5) exhibited low riffle SIGNAL (Figure 5.26 c).

Figure 5.26: SIGNAL scores for 2015 compared to historical data collected since 2005.

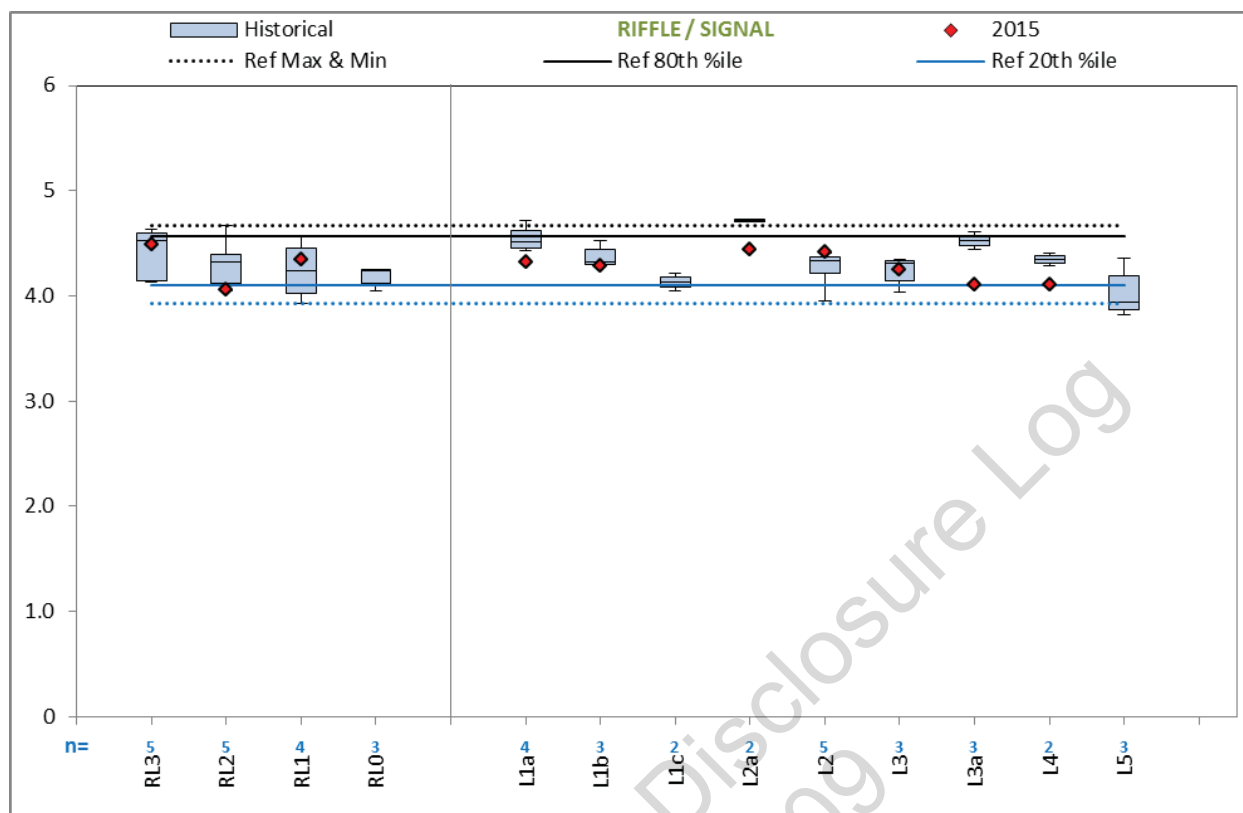
a) Pool bottom habitat



b) Edge habitat



c) Riffle habitat



5.6.2 Multivariate analyses

Non-metric multidimensional scaling (NMDS) is a multivariate method that demonstrates the extent of similarity or difference between samples based on consideration of all the different taxa that make up the biological communities represented. Samples that contain similar numbers and types of taxa tend to cluster together on the plots, and those which contain different combinations and numbers of taxa separate out – i.e. the distance of separation between samples is indicative of the relative differences between communities. In this case, samples from each particular habitat type (which would normally be expected to contain similar communities) have been arbitrarily allocated to data groups which are discriminated on plots using distinctive markers. These groups have been further broken into subgroups based on whether the samples were taken at reference or impact sites. The resulting plots allow convenient visualisation of relative differences within and between groups. Any differences which appear potentially significant can then be tested to determine their statistical significance.

Such tests calculate the probability that there is no difference between the samples being tested; hence a probability (p) of less than 0.05 (i.e. <5%) would indicate that we can be more than 95% confident that the observed difference is statistically significant. Note though, that this does not necessarily mean that the difference is significant in practical terms or that an impact is implied, because there are many potential sources of unresolved background variability, both within and between groups. For example natural localised variations in factors including streambed morphology, sediment texture, bed slope, riparian vegetation, leaf litter, fish communities, instream debris, plankton communities and underwater light climate have been shown to potentially lead to substantial variations in invertebrate community structure. Quantifying the effects of such variables would require prohibitive levels of sampling replication and is not feasible in routine monitoring programs. Accordingly, the results obtained from statistical analyses presented in these kinds of reports must be interpreted heuristically, using professional judgement to identify and account for unquantified sources of variability.

Habitat conditions (i.e. morphology, substratum composition, riparian vegetation, etc) vary among the Lawn Hill Creek impact sites and differ significantly from reference sites. Specifically, some of the expected differences between Lawn Hill Creek sites stem from the fact that the upstream control sites are all situated in the high gradient upper reaches of the creek where the stream channel is bedrock constrained, water flows are swift and turbulent, and the riparian vegetation canopy is dense. Conversely the impact sites are located on a lower gradient section of the creek within a floodplain where the stream channel is frequently anastomosed, flows are less turbulent and the riparian vegetation canopy is more open. Also, as noted previously, the Lawn Hill Creek impact sites are subject to significantly greater pressure from livestock than the controls.

Figure 5.28 Two dimensional MDS ordination plots of the macroinvertebrate community in Lawn Hill Creek. 2D Stress=0.18



5.6.3 AUSRIVAS modelling

AUSRIVAS predictive modelling produces a variety of output information and levels of technical reporting regarding the condition of a test site including; taxa probabilities; predicted, expected and observed taxa; and predicted, expected and observed SIGNAL scores. Modelling also produces an ultimate designation for a site by integrating all technical information into a 'band' representing different levels of biological impairment. Band X represents a richer invertebrate community than reference; band A is equivalent to reference; band B represents a site below reference condition; band C represents sites well below reference; and band D represents impoverished sites (see Table 5.12 below for more detail).

Table 5.12: AUSRIVAS Band Descriptions

Band Label	Band Name	Band description
Band X	More biologically diverse than reference sites	More taxa found than expected. Potential Biodiversity hotspot. Possible mild organic enrichment
Band A	Reference Condition	Most/all of the expected taxa found. Water quality and/or habitat condition roughly equivalent to reference sites. Impact on water quality and habitat condition does not result in a loss of macroinvertebrate diversity
Band B	Significantly impaired	Fewer taxa than expected. Potential impact on water quality or habitat quality or both resulting in loss of taxa
Band C	Severely impaired	Many fewer taxa than expected. Loss of macroinvertebrate biodiversity due to substantial impacts of water and/or habitat quality
Band D	Extremely impaired	Few of the expected taxa remain. Extremely poor water quality and/or habitat quality. Highly degraded.

Similar to 2013 there was a very restricted AUSRIVAS model run in 2015 (Table 5.13). The outcome from the pool bottom habitat model run support the other results in this year's survey with indications of some impairment (Band B) identified at sites RAr1 and PH-387, and more significant impairment at Cog1 (Band C).

Among the Lawn Hill Creek riffle habitats, there were three X-band scores indicating that taxa diversity was greater than expected. As was seen in 2014, only site L03 reported higher than historic taxa richness with the other two sites reporting riffle richness below the 80th percentile (Figure 5.25). A number of sites including three of the four reference sites on Lawn Hill Creek showed some indication of impairment among edge habitats (Table 5.13). Otherwise, the outcomes of the model suggest that invertebrate communities within Lawn Hill Creek were similar to previous years and generally indicative of good health. There is an indication of localised impairment (Band B) at site L04 which aligns with the other results reported in this year's survey. Site RL1 also reported indications of some impairment (Band B). Similar to the more ephemeral systems, lower flows and poor wet season conditions are potential contributors to impairment.

Table 5.13: AUSRIVAS modelling band scores for different aquatic habitats in 2015 compared to previous years. W= Wet season, PW= Post-wet season

Habitat	Pool Bottom							Pool Edge							Riffle							
Site	2009	2010	2010	2011	2012	2014	2015	2009	2010	2010	2011	2012	2013	2014	2015	2009	2010	2011	2012	2013	2014	2015
Season	PW	W	PW	PW	PW	PW	PW	PW	W	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW	PW
Page Ck																						
R01			A	A	A	A			A	A												
A01		C	C			B																
C01	D	B	C	B	A	A		C	B	B	C											
D01	D	B	C	C	A	A				B												
E01	C		C	D	A	A		C		B	B											
F01			C							B												
F04			B	C	A						B											
F09			B	B	X	B				B	B											
G01		C	C	B	B				B	C	C											
G07	B		B	B	X	B				B	B			A								
Other Cks																						
Bul1	D		D					C														
Bul2		A	B		A	A			A	A												
Cog1	A		A	X	C	B	C			A	A	C										
Cog2	A		B	A	A	A				A												
RCog1		A	A			A																
RM1	A		A	A	X	A				A												
MS	A		B	A	A	A		B		B		A										
RAr1	A		B	B	X	B	B			B	B			B								
RAr2	B		B	A	X	A	A			B	B						A					
LAr1			B	A	X	A				A	B			A			A					
PH387							B															
RSpr1			B	A	A	A				B												
Lawn Hill																						
RL3	A		B					A		A	B	B		A	A	A	A	A	A	A	A	A
RL2	B		B					B		A	B	A		A	B	A	A	A	B	A	X	A
RL1	A		B					B		B	B	A	A	A	B	A	A	A		B	X	
RL0										B	B	B	A	A	B			A	A	A		
L1a										A	A	A	A	A	A			A	A		X	A
L1b	A		A					B		A	B	A	B	B	B	A	A	A	X	A	A	A
L1c										B	A	A	A	A				A	A		A	
L2a										A	A	A	A	B	B			A	A		A	X
L2	A		A					B		A	A	A	A	A	B	A	A	A	A	A	A	A
L3	A		A					B		A	A	A	A	A	A	A		A	A		X	X
L3a										B	A			A	A			A	A	A	A	A
L4			A							A	B	A	A	A	A			A	A		B	A
L5			A							B	A	A		B	A		A	A	A		A	

4.5 Fish and Crabs

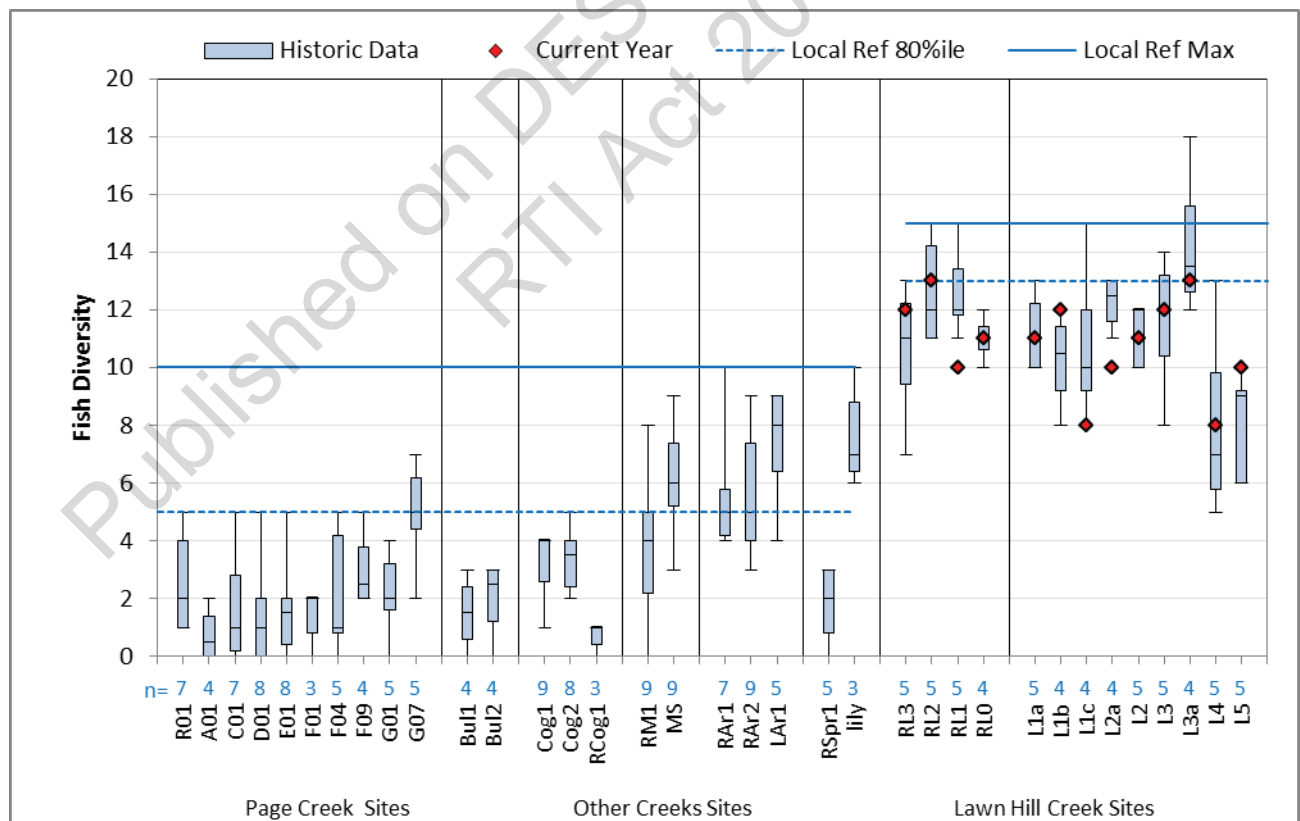
In terms of size, morphology, water quality and hydraulics, sites surveyed in this program vary substantially both temporally and spatially. Accordingly, the efficiency of different fishing techniques can differ enormously between sites and between sampling trips, making it necessary to vary methods on a case by

case basis to suit the prevailing conditions. In many cases visual underwater observation has proven to be an effective survey method although this has always been done in conjunction with other techniques such as electrofishing, netting and/or baited traps. The range and varying efficiency of the methods used precludes the possibility of employing catch per unit effort as a metric for data analyses in this study. Nevertheless, the level of effort invested at each site is considered to have been sufficient to ensure that the fish counts recorded during this survey provide semi-quantitative indications of the relative abundances of each species.

The 2015 fish survey is reported as relative abundance (Table 5.14) from the raw data (Appendix C, Volume 2). There was no data collected from the non-Lawn Hill sites for 2015 due to lack of water at most sites. Note that since the abundance data are semi-quantitative estimates, an ordinal ranking scheme has been employed to express counts in terms of a relative abundance score (Table 5.14). The boundary conditions for the categories used are defined in the table.

Fish diversity among sites is shown in Figure 5.27. The reference lines shown in the Lawn Hill Creek section of Figure 5.27 are derived from analysis of the historical data available for the upstream control sites on Lawn Hill Creek, while the reference lines on the other section of the graph are obtained from those ephemeral reference sites that are considered to be reasonably comparable to the ephemeral impact sites (i.e. reference sites RSpr1, R01, Rcog1 and Lily Ck). Note that Mitton Springs (MS), Archie Ck (RAR1 and RAR2) and Little Archie Ck (LAR1) all differ from the ephemeral sites in that they often retain water all year, but they are also unlike Lawn Hill because they do not flow perennially. Accordingly none of the reference lines is applicable to that site group and, not surprisingly, the species richness at those sites is generally intermediate between the two other groups.

Figure 5.27: Fish species richness for 2015 compared to historical data collected between 2005 and 2014.



Since 2009 fish diversity in Lawn Hill Creek has varied randomly at each site but there are suggestions of some consistent between-site differences with L3a tending to support higher species richness and sites L4 and L5 tending to report lower values. However, there are no indications of potential correlations between fish diversity and contaminant residues. In fact, the sites with the lowest fish diversities are the most distant

sites from the mine and contain considerably lower contaminant residues than the impact sites further upstream. The lower diversity at these sites appears to be due mainly to inherently less desirable fish habitat conditions. Impacts from livestock and associated degradation of riparian vegetation may also have a bearing, but it is salient to note that reference site RL3 has reported similarly low species numbers on two occasions and that site is not subject to significant pressures of that kind.

The Mouth Almighty (*Glossamia aprion*), Banded Grunter (*Amniataba percooides*), Seven Spot Archer Fish (*Toxotes chatareus*) and the Eastern Rainbowfish (*Melanotaenia splendida*) were the most common species, being recorded at all Lawn Hill Creek sites (Table 5.14). The Eastern Rainbowfish (*Melanotaenia splendida*) was also the most abundant species across the entire survey area. Note that crabs have never been observed in Lawn Hill Creek even though they are ubiquitous inhabitants of most the ephemeral creeks in the surrounding region.

Table 5.14: Relative fish abundance in 2015 & total crabs reported. Fish abundance “-“ = 0, 1 = 1, 2 = 2 - 9, 3 = 10 - 49, 4 = 50 - 99, 5 = 100 - 500, 6 >500 animals caught.

Site	Fish																							Crustaceans				
	Glass fish	Banded grunter	Freshwater sole	Flyspeckeled hardyhead	Strawman hardyhead	Mouth almighty	Gloden goby	Coal grunter	Sooty grunter	Barramundi	Spangled perch	Eastern rainbowfish	Bony bream	Black catfish	Hyrtl's tandan	One gilled eel	Sleepy cod	Giant gudgeon	Saratoga	Gulf grunter	Freshwater longtom	Seven spot archerfish	Freshwater prawn	Freshwater crab	Redclaw crayfish	Fish	Crustaceans	Total
R01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
A01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
C01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
D01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
E01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
F01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
F09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
F09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
G07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
RSPR1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Bul1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Bul2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
RCOG1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
COG1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
COG2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
PH387	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
LAR1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
RAR1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
RAR2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
RM1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
MS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	0	0
L5	-	1	-	2	-	2	2	-	2	-	-	3	1	-	-	-	1	1	-	-	-	2	-	-	-	10	0	10
L4	-	2	-	2	-	3	2	-	-	-	3	5	-	-	-	-	2	-	-	-	-	1	-	-	-	8	0	8
L3A	-	3	-	2	-	3	2	2	3	-	3	5	-	-	2	-	3	2	-	-	2	3	-	-	-	13	0	13
L3	2	2	-	3	-	3	2	2	2	-	2	3	-	-	-	-	3	1	-	-	-	2	-	-	-	12	0	12
L2A	-	3	-	3	-	3	2	2	-	-	2	4	-	-	-	-	2	-	-	-	1	2	-	-	-	10	0	10
L2	-	3	-	3	-	3	3	2	2	-	2	4	-	-	-	-	3	-	-	1	-	3	-	-	-	11	0	11
L1C	2	2	-	-	-	2	-	1	-	-	3	2	-	-	-	-	1	-	-	-	-	2	-	-	-	8	0	8
L1B	1	3	-	3	-	2	2	2	2	-	2	4	-	-	-	-	1	-	-	-	-	2	-	-	1	11	1	12
L1A	-	3	-	3	2	3	2	2	-	1	2	3	-	-	-	-	2	-	-	-	-	1	-	-	-	11	0	11
RL3	-	3	-	1	-	1	1	2	3	-	2	3	-	-	1	-	-	1	-	-	2	3	-	-	-	12	0	12
RL2	2	4	-	-	-	2	2	3	1	-	1	5	-	-	-	-	2	2	2	-	1	3	-	-	-	13	0	13
RL1	-	3	-	3	-	2	-	2	3	-	3	4	-	1	-	-	2	-	-	-	-	3	-	-	-	10	0	10
RL0	2	3	-	3	-	2	-	3	3	1	-	4	-	-	-	-	2	-	-	-	2	3	-	-	-	11	0	11

6. CONCLUSIONS

6.1 Analytical Issues

As discussed in the previous reports, the certainty of the conclusions that this report can draw regarding the current status of zinc and phosphorus residues in this study area have been somewhat constrained by the development of a number of issues relating to the reliability and accuracy of the results. The constraints were primarily associated with analytical problems arising with the 2012 sediment program and an aqueous zinc sample-contamination problem that was identified in 2014. In response to the analytical issues raised in the 2012 sediment program, local reference standards have been collected and prepared to be used for QC purposes into the future and resolve discrepancies between laboratories and/or methods. At time of writing the QC standards are undergoing certification analyses and are expected to be available for use in the 2016 program.

The development of a potential aqueous zinc sample contamination issue in 2014 constrained the conclusions that can be drawn from this study. Many water quality practitioners throughout the region have reported similar difficulties, leading us to suspect that a batch of contaminated sampling consumables (such as filters or syringes) has found its way into the marketplace. A detailed assessment of sampling consumables identified some brands of consumables may be partly responsible for the sample contamination reported. Changes to brands of consumables have resulted in only one sample reporting a filterable result higher than the total result in the 2015 program.

The Lawn Hill Creek sites continue to exhibit high degrees of spatial heterogeneity in the sediments. It is recommended that the intensive sediment sampling program initiated in 2011 at Lawn Hill Creek be continued as a routine monitoring protocol for those sites until existing uncertainties have been resolved and existing risks can be confidently assessed. The current receiving environment monitoring program is subject to regular review to ensure it meets key environmental monitoring requirements while ensuring cost effectiveness.

6.2 Current Status of the Receiving Environment

6.2.1 Page Creek

Due to the low wet season rainfall almost all ephemeral stream sites were dry at the time of sampling. Water was able to be collected at a few sites (i.e. R01, A01) on Page Creek but these sites had received an isolated rain event in the previous week which was sufficient to fill the temporary pools but not sufficient to trigger flow. Consequently, although water samples were collected at these sites, the water quality was considered to be reflective of pre-flush conditions rather than ambient conditions. For all other Page Creek sites, only surface sediments were collected and analysed.

The 2015 sediment results indicate that zinc concentrations in the surface layer of bottom sediment have been gradually decreasing over the course of the dry spell which has persisted for the past few years, presumably due to surface deposition of sediment from localised runoff generated by small scale rain events (i.e. a predominance of runoff derived mainly from uncontaminated soils proximal to each waterhole). However, sedimentary zinc levels at all Page Creek sites except A01, F01, F04 and G01 are still above the ISQG-High.

6.2.2 Lawn Hill Creek

The intensive sediment sampling regime implemented since 2011 indicates that there have been no statistically significant changes in zinc distribution over the past three years. This is not an unexpected result given that during that period there have been no flows large enough to mobilise coarse-grained sediment. Zinc concentrations in Lawn Hill Creek sediments decline with distance downstream from Page Creek, with levels trending towards background at sites L4 and L5. The highest concentrations are

currently located at site L1b where median levels are above the ISQG-Low, though significantly below the ISQG-High. None of the other Lawn Hill Creek sites reported any values that exceed the ISQG-Low.

The status of sedimentary phosphorus in Lawn Hill is currently poorly understood due to its extreme spatial heterogeneity and also because of the analytical issues discussed previously. Nevertheless, it is still possible to draw a few conclusions: 1) phosphorus residues in the bottom sediment are largely insoluble in Lawn Hill Creek waters and do not appear to be readily bioavailable; 2) Page Creek is obviously a significant source of phosphorus inputs to Lawn Hill Creek, and; 3) a large, and possibly predominant, proportion of the phosphorus exported from Page Creek originates from natural phosphate deposits.

The 2015 water quality results provided no indication of differences between the upper reference/control sites and lower impact sites that could be attributable to mine influences. There are indications of impacts from grazing (erosion, loss of riparian vegetation, weeds, trampling/pugging) but overall water quality was consistent with previous years and typical of this type of perennial system. Macroinvertebrate and fish survey results were also generally consistent with previous years and provided no indication of potential influences from the mine.

In summary, it can be stated that zinc and phosphorus residues in the benthic sediments of Lawn Hill Creek provide the only evidence of potential mine-related influences and there are no indications that these have adversely affected the environmental values of the creek.

6.2.3 Other Creeks

Site Cog1, a small pool at the head of Coglan Creek receives seepage water from an adjacent evaporation pond. This site has historically reported high concentrations of mine-sourced salts (especially sulphate), and has generally exceeded the drinking water guideline for beef cattle as it did again this year. However this site falls within the fenced lease area and as such is not accessible to livestock. Available data indicate that these effects have historically been confined to that one site, with Cog2 located further downstream on Coglan Creek having typically been well within reference with respect to all mine-sourced contaminants.

Similar to Page Creek, one week prior to the sampling trip RCog1 and RM1 received an isolated rain event which was sufficient to fill the temporary pools but not sufficient to trigger flow. Consequently, although water samples were collected at these sites, the water quality was considered to be reflective of pre-flush conditions and the transient effects of localised runoff and the results are not therefore considered to be indicative of ambient conditions.

Site Cog1, RAr1, RAr2 and PH-387, where full limnology was able to be conducted, showed some level of impairment, particularly in the macroinvertebrate community. These results are similar to 2013 and reinforce the conclusions that reduced indices are likely a consequence of lower than average rainfall and associated evapo-concentration effects rather than direct mining impacts.

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TropWATER

Centre for Tropical Water and Aquatic Ecosystem Research

CENTURY MINE RECEIVING ENVIRONMENT MONITORING PROGRAM (REMP) 2015

VOLUME TWO

A Report for MMG Century Mine

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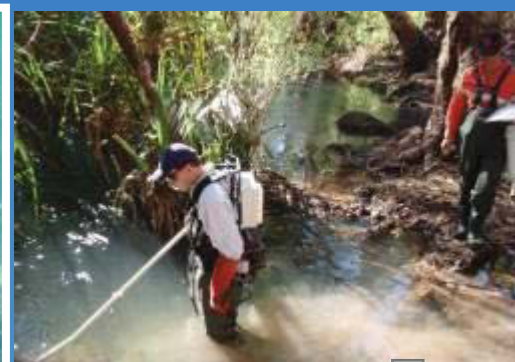


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A.1 FIELD NOTES

Table A.1.1 Site observations and field notes recorded during the limnological survey of the Lawn Hill creek system within the vicinity of the Century-MMG Mine, March - April 2015

Site	Date	Time	water colour	flow m/s	algae	%	substrate	%	habitat in 100m	%	secchi m
Upstream Lawn Hill Creek											
RL3	23-Apr-15	11:43	clear	0.1-0.3	epiphytic	1-10	pebble	10	riffle	10	BV
					epilithic	10-50	gravel	10	run	40	
					filamentous	1-10	silt/clay	50	Pool - sandy	25	
					floating	1-10	cobble	10	Pool - silty	25	
							sand	20			
RL2	23-Apr-15	14:00	clear	nil	floating	1-10	clay	90	riffle	40	
					filamentous	10-50	sand	10	run	10	
							pool-silty	50			
RL1	24-Apr-15	11:00	clear	0.1-0.3	filamentous	10-50	silt	20	riffle	20	
									Pool- rocky	40	
									Pool-sandy	30	
									Pool - silty	10	
RL0	24-Apr-15	12:45	clear	0.1-0.3	filamentous	1-10	pebble	5	pool-sandy	80	1.6
					epiphytic	10-50	gravel	5	pool-silty	20	
					floating	10-50	sand	40			
							cobble	10			
							silt	20			
							clay	20			
Downstream Lawn Hill Creek											
L1a	22-Apr-15	9:30	clear	0.05-0.2	epiphytic	10-50	pebble	20	riffle	30	
					epilithic	10-50	gravel	20	pool-rocky	10	
					filamentous	1-10	sand	20	pool-sandy	30	
							silt	30	pool-silty	30	
							cobble	10			
L1b	22-Apr-15	14:30	clear	0.05-0.2	epiphytic	10-50	pebble	30	riffle	30	
					filamentous	1-10	gravel	20	pool-sandy	50	
							sand	30	pool-silty	10	
							silt	5	pool-rocky	10	
							clay	5			
		cobble	10								
L2a	27-Apr-15	13:30	clear		epilithic	10-50	gravel	20	riffle	10	1.45
					epiphytic	10-50	pebble	10	pool-rocky	30	
					filamentous	10-50	cobble	20	pool-sandy	30	
					planktonic	10-50	sand	20	pool-silty	30	
							silt/clay	30			
L2	27-Apr-15	9:00	clear green		epilithic	50-75	sand	10	riffle	20	1.15
					filamentous	1-10	cobble	30	pool-rocky	40	
					floating	10-50	pebble	20	pool-silty	40	
					planktonic	10-50	gravel	20			
							silt	20			

Table A.1.1 cont.

Site	Date	Time	water colour	flow m/s	algae	%	substrate	%	habitat in 100m	%	secchi m
Downstream Lawn Hill Creek											
L3a	26-Apr-15	15:50	clear	0.1-0.3	epiphytic epilithic planktonic filamentous	10-50 10-50 10-50 10-50	pebble gravel sand cobble clay silt	10 10 30 10 20 10			0.78
L3	26-Apr-15	8:00	clear green	0.05-0.3	epiphytic epilithic filamentous	10-50 10-50 10-50	pebble gravel sand silt clay	20 10 10 30 30	riffle pool-silty pool-sandy pool-rocky pool-rocky	10 40 35 15	>1.0
L4	25-Apr-15	13:00	clear green	<0.1	epiphytic epilithic filamentous	10-50 10-50 10-50	silt pebble gravel clay sand	25 10 10 25 30	riffle dry pool-silty Pool-sandy	2 8 30 60	0.25
L5	25-Apr-15	9:10	clear brown	0.1-1	epibenthic filamentous	1-10 1-10	sand clay pebble cobble gravel	25 30 20 5 20	run dry pool-rocky Pool-sandy	20 10 40 30	

Table A.1.2 Site observations and field notes recorded during the limnological survey of the Page creek system within the vicinity of the Century-MMG Mine, March - April 2015

Site	Date	Time	water colour	flow m/s	algae	%	substrate	%	habitat in 100m	%	secchi m
Upstream Page Creek											
R01	2-Apr-15	7:15:00	grey turbid	nil	epibenthic	10-50%	cobble pebble gravel sand clay silt	10 10 10 20 30 20	pool-silty	100	
Downstream Page Creek											
A01	29-Mar-15	0:00:00									
C01	29-Mar-15	14:35:00	dry						dry	100	
D01	29-Mar-15	14:15:00	dry				boulder cobble pebble gravel sand clay	20 30 20 10 10 10	dry	100	

Table A.1.2 cont.

Site	Date	Time	water colour	flow m/s	algae	%	substrate	%	habitat in 100m	%	secchi m
Downstream Page Creek											
E01	15-Apr-15	16:35:00	dry				gravel sand silt	5 20 75	dry	100	
F01	1-Apr-15	9:15:00	dry						dry	100	
F04	1-Apr-15	10:35:00	dry						dry	100	
F09	1-Apr-15	12:00:00	dry						dry	100	
G01	1-Apr-15	12:40:00	dry						dry	100	
G07	14-Apr-15	8:41:00	dry				sand silt	70 30	dry	100	

Table A.1.3 Site observations and field notes recorded during the limnological survey of other creek systems within the vicinity of the Century-MMG Mine, March - April 2015

Site	Date	Time	water colour	flow m/s	algae	%	substrate	%	habitat in 100m	%	secchi m
Other Creeks Control											
RM1	29-Mar-15	15:45	dry				cobble pebble gravel sand clay silt	40 20 10 10 10 10	dry	100	
RAR1	28-Mar-15	0:00	tannins	nil		1-10%	cobble boulder gravel bedrock	20 20 10 50	pool-rocky	100	
RAR2	28-Mar-15	0:00	Clear brown green	nil		1-10%	cobble boulder silt constructed	20 30 10 40	pool-rocky dry	20 80	
RSpr1	29-Mar-15	11:45	dry				cobble gravel sand clay silt	60 20 10 5 5	dry	100	
RCog1	30-Mar-15	11:45	dry				cobble pebble gravel sand clay silt	10 10 10 20 30 20	dry	100	

Table A.1.3 cont.

Site	Date	Time	water colour	flow m/s	algae	%	substrate	%	habitat in 100m	%	secchi m
<i>Other Creeks Impact</i>											
BUL1	22-Mar-14	13:00	dry						dry		
BUL2	29-Mar-15	13:00	dry				sand clay	50 50	dry		
Cog1	30-Mar-15	7:45	turbid green brown	nil			silt clay	30 70	pool-silty	100	
Cog2	30-Mar-15	15:00	dry				boulder cobble pebble gravel sand clay silt	20 30 10 10 10 10 10	dry		
MS	28-Mar-15	16:00	dry				bedrock boulder silt	5 15 80	dry	100	

A.2 PHYSICO-CHEMICAL DEPTH PROFILING DATA

Table A.2 Vertical profiles of water quality at MMG Century REMP sites, 2015

Site	Date	Start Time	Depth	pH	Temp	EC	DO	DO Sat
<i>Upstream Lawn Hill Creek</i>								
RL0	24-Apr-15	16:10	0.1	7.87	25.20	603	6.67	81.4
			0.25	7.87	25.20	603	6.67	81.5
			0.5	7.86	25.21	602	6.69	81.2
			0.75	7.86	25.21	603	6.54	79.8
			1	7.86	25.20	603	6.6	80.3
		16:15	1.25	7.86	25.21	602	6.57	78.2
			0.1	7.86	25.19	603	6.85	82.4
			0.25	7.85	25.20	603	6.75	81.8
			0.5	7.85	25.20	603	6.75	82.3
			0.75	7.85	25.20	603	6.7	82.5
		16:20	1	7.85	25.20	603	6.69	81.8
			0.1	7.84	25.16	602	7.02	84.2
			0.25	7.84	25.18	602	6.76	82.2
			0.5	7.84	25.18	603	6.67	80.8
			0.75	7.84	25.18	603	6.65	80.9
			1	7.84	25.19	603	6.62	80.9
			1.25	7.83	25.20	602	6.59	80.5
			1.5	7.83	25.20	602	6.65	81
			1.75	7.83	25.20	603	6.67	81.2
			2	7.82	25.20	603	6.67	82.4
			2.25	7.83	25.20	602	6.55	78.3
			2.5	7.82	25.20	603	6.61	81.3
			2.75	7.81	25.20	602	6.42	76.1
RL1	24-Apr-15	11:40	0.1	7.84	24.34	610	7.04	83.7
			0.25	7.86	24.35	609	6.98	84.6
			0.5	7.85	24.37	609	6.99	83.3
			0.75	7.85	24.36	609	6.9	83
			1	7.84	24.35	609	6.9	82.9
			1.25	7.84	24.36	609	6.89	82.8
			1.5	7.84	24.36	609	6.86	82.8
			0.1	7.84	24.35	610	6.84	82.3
			0.25	7.84	24.35	609	6.83	82.2
			0.5	7.84	24.34	609	6.86	82.3
			0.75	7.84	24.37	609	6.84	82
			1	7.83	24.34	609	6.8	81.4
			1.25	7.82	24.35	609	6.79	81.3
			1.5	7.83	24.34	609	6.76	81.1
			1.75	7.83	24.33	610	6.78	81.4
		11:55	2	7.82	24.34	609	6.79	81.4
			2.25	7.82	24.34	610	6.76	81.2
			2.5	7.83	24.34	609	6.78	81.1
			3	7.81	24.33	609	6.8	81.1
			0.1	7.84	24.36	609	7.7	91.5
			0.25	7.83	24.38	609	7.47	89.6
			0.5	7.84	24.38	609	7.41	89
			0.75	7.84	24.39	610	7.38	88.7
			1	7.84	24.39	609	7.36	87
			1.25	7.83	24.40	609	6.81	80.2
			1.5	7.83	24.39	608	6.71	79.3

Table A.2 (Cont.)

Site	Date	Start Time	Depth	pH	Temp	EC	DO	DO Sat
RL2	23-Apr-15	16:40	0.1	7.84	26.39	619	7.91	95.2
			0.25	7.83	26.29	620	7.65	94.2
			0.5	7.82	26.21	620	7.46	91.2
			0.75	7.81	26.17	619	7.83	92.3
			1	7.81	26.21	619	7.83	97.6
		16:45	0.1	7.80	26.13	622	7.48	92.6
			0.25	7.97	26.10	622	7.35	90.8
			0.5	7.78	26.08	621	7.1	89.7
			0.7	7.76	26.08	621	7.13	88.4
			16:50	0.1	7.77	26.05	622	7.51
		0.25		7.76	26.02	621	7.41	92
		0.5		7.76	26.06	621	7.41	91.9
		0.75		7.76	26.07	621	7.41	91.7
		1		7.74	26.02	620	7.45	91.8
			1.15	7.74	26.01	621	7.36	91
RL3	23-Apr-15	11:43	0.1	7.75	26.12	629	8.05	99.4
			0.25	7.75	26.11	629	7.93	98.5
			0.5	7.75	26.11	629	7.94	98.7
			0.75	7.75	26.11	629	7.93	98.5
			1	7.75	26.12	629	7.91	98
		11:47	0.1	7.75	26.14	629	7.91	98.4
			0.25	7.75	26.13	629	7.92	98.5
			0.5	7.75	26.13	629	7.89	98.1
			0.75	7.75	26.12	630	7.86	97.7
			1	7.75	26.13	629	7.88	96.8
		11:54	1.25	7.76	26.12	630	7.72	96.3
			1.5	7.75	26.13	629	7.61	94.3
			1.75	7.76	26.13	629	7.65	94.4
			1.85	7.76	26.13	629	7.56	93.4
			0.1	7.76	26.13	628	7.76	94.7
			0.25	7.75	26.14	628	7.75	95.1
			0.5	7.75	26.08	629	7.75	94.8
			0.75	7.75	26.02	630	7.75	92.4
			0.8	7.77	25.96	628	7.77	101
Downstream Lawn Hill Creek								
L1a	22-Apr-15	9:40	0.1	7.98	25.54	586	6.04	73.2
			0.25	7.98	25.55	585	5.91	72.4
			0.5	7.98	25.55	585	5.87	72.1
			0.65	7.97	25.55	585	5.83	71.5
		9:43	0.1	7.95	25.59	585	5.84	71.5
			0.25	7.93	25.62	585	5.8	71.3
			0.5	7.93	25.62	585	5.8	71.3
			0.75	7.93	25.62	585	5.79	71.3
			0.95	7.93	25.62	585	5.77	70.9
		9:45	0.1	7.92	25.61	586	5.82	71.4
			0.25	7.93	25.63	587	5.79	71.3
			0.5	7.94	25.63	585	5.79	71.3
			0.75	7.94	25.63	585	5.81	71.5
			1	7.94	25.62	585	5.78	71
			1.15	7.93	25.63	585	5.76	70.9

Table A.2 (Cont.)

Site	Date	Start Time	Depth	pH	Temp	EC	DO	DO Sat
L1b	22-Apr-15	14:55	0.1	7.91	26.50	585	6.16	77.3
			0.25	7.91	26.50	585	6.15	76.7
			0.5	7.91	26.49	585	6.15	76.5
			0.75	7.91	26.49	585	6.15	76.7
			1	7.91	26.49	585	6.11	76.3
			1.1	7.90	26.50	585	6.07	75.7
		15:00	0.1	7.90	26.48	586	6.61	82.3
			0.25	7.90	26.49	586	6.54	81.6
			0.5	7.90	26.49	586	6.5	81.3
		15:05	0.1	7.89	26.48	586	6.87	82.6
			0.25	7.91	26.48	586	6.48	81
			0.3	7.91	26.49	585	6.43	80.4
L1c			0.1					
L02	27-Apr-15	12:45	0.1	8.02	23.84	572	7.53	88.8
			0.25	8.01	23.81	573	7.3	86.9
			0.5	8.01	23.83	573	7.26	86.4
			0.75	8.00	23.83	573	7.25	86
			1	8.00	23.83	573	7.27	86.5
			1.2	7.99	23.84	573	7.3	86.9
		12:50	0.1	8.03	24.10	571	8.2	98
			0.25	8.04	24.11	570	8.15	97.6
			0.5	8.06	24.12	567	8.27	105.9
		13:00	0.1	7.98	23.95	573	7.69	90.1
			0.25	7.97	23.92	574	7.37	87.5
			0.5	7.96	23.68	574	7.34	87
			0.75	7.96	23.59	573	7.32	86.6
			1	7.95	23.54	574	7.31	86.4
			1.2	7.96	23.55	573	7.21	85.8
L2a	27-Apr-15	10:55	0.1	8.20	21.93	580	6.93	79.7
			0.25	8.20	21.93	582	6.81	78.1
			0.5	8.19	21.94	582	6.83	78.6
			0.55	8.19	21.94	582	7.05	80
		11:00	0.1	8.18	21.92	583	7.07	81.1
			0.25	8.17	21.92	583	7.05	81
			0.5	8.17	21.92	582	7.08	81.3
		11:05	0.75	8.17	21.94	583	7.06	80.9
			0.1	8.17	21.93	582	7.44	83.6
			0.25	8.17	21.93	582	7.21	82.6
			0.5	8.16	21.92	582	7.24	83
			0.75	8.16	21.91	582	7.21	82.7
			1	8.16	21.92	582	7.23	82.9
			1.25	8.16	21.92	582	7.23	82.9
L03	26-Apr-15	11:40	0.1	8.00	23.88	569	6.55	78.8
			0.25	8.00	23.85	569	6.47	77
			0.5	7.99	23.77	569	6.46	76.5
			0.75	7.99	23.76	569	6.45	76.8
			1	7.97	23.66	568	6.41	75.8
		11:45	0.1	7.98	23.96	570	6.57	78
			0.25	7.98	23.80	568	6.49	77.1
			0.5	7.98	23.76	568	6.48	77.1
			0.75	7.98	23.74	568	6.52	77.6
			0.9	7.98	23.76	568	6.55	77.9

Table A.2 (Cont.)

Site	Date	Start Time	Depth	pH	Temp	EC	DO	DO Sat
L03 cont.		11:50	0.1	7.99	23.87	569	7	83.9
			0.25	7.98	23.88	569	6.77	80.5
			0.5	7.98	23.88	569	6.72	80
			0.75	7.98	23.83	568	6.68	79.5
			1	7.97	23.80	568	6.64	79
			1.25	7.97	23.77	568	6.62	78.7
			1.5	7.96	23.74	568	6.56	77.8
			1.75	7.95	23.72	568	6.49	77
			2	7.95	23.72	569	6.44	76.5
			2.25	7.94	23.71	568	6.43	76.4
			2.5	7.94	23.71	568	6.44	76.5
			2.75	7.93	23.71	568	6.42	76.1
L3a	26-Apr-15	16:30	0.1	8.05	23.36	566	6.83	80
			0.25	8.04	23.35	568	6.68	78.1
			0.5	8.02	23.34	568	6.53	76.8
		16:35	0.6	7.98	23.31	568	6.34	74
			0.1	7.99	23.38	567	7.34	83.5
			0.25	7.98	23.40	568	6.89	81.1
		16:40	0.5	7.97	23.39	568	6.84	80.7
			0.75	7.95	23.17	569	6.68	77.6
			1	7.94	22.68	568	6.53	74.6
		16:45	1.25	7.92	22.39	568	6.1	69
			1.5	7.92	22.29	568	5.82	66.8
			1.75	7.91	22.25	568	5.7	65.4
		16:50	1.95	7.86	22.24	568	4.99	58.5
			0.1	8.05	23.66	565	8.08	95.3
			0.2	7.99	23.68	565	6.37	71.9
		16:55	0.25	7.87	23.74	568	5.26	60
L04	25-Apr-15	14:40	0.1	8.21	24.32	539	8.86	107.1
			0.25	8.21	24.33	539	8.9	106.4
			0.45	8.19	24.11	539	8.82	105.3
		14:43	0.1	8.22	24.33	538	9.16	109.3
			0.25	8.22	24.26	538	9.08	108.4
			0.5	8.21	24.18	537	9.18	109.5
		14:45	0.7	8.20	24.31	538	9.23	109.2
			0.1	8.22	24.35	538	9.18	109.8
			0.25	8.22	24.39	538	9.13	109.8
		14:50	0.5	8.22	24.28	538	9.16	109.9
			0.55	8.19	24.34	538	9.19	111.5
L05	25-Apr-15	9:15	0.1	8.16	21.98	555	7.72	88.1
			0.25	8.16	21.99	554	7.59	87.3
			0.4	8.16	21.99	555	7.59	87.3
		9:18	0.1	8.16	21.99	555	7.65	87.7
			0.25	8.16	21.99	555	7.6	87.3
			0.5	8.15	21.99	555	7.6	87.4
		9:25	0.1	8.15	21.97	555	7.7	88.2
			0.25	8.15	21.98	555	7.63	87.6
			0.5	8.16	21.99	554	7.6	87.5
		9:30	0.75	8.15	21.99	554	7.6	87.2

Table A.2 (Cont.)

Site	Date	Start Time	Depth	pH	Temp	EC	DO	DO Sat
Upstream Page Creek								
R01	02-Apr-15	7:45	0.1	6.78	27.97	128	0.4	3.9
		7:50	0.1	6.78	27.45	129	0.2	2.2
Downstream Page Creek								
A01	29-Mar-15	7:35						
C01	29-Mar-15	14:35						
D01	29-Mar-15	14:15						
E01	15-Apr-15	16:35						
F01	01-Apr-15	9:15						
F04	01-Apr-15	10:35						
F09	01-Apr-15	12:00						
G01	01-Apr-15	12:40						
G07	14-Apr-15	8:41						
Other Creeks Control								
RM1	29-Mar-15	15:45						
RAR1	28-Mar-15	12:05	0.1	7	28.65	58	4.88	67.2
			0.25	6.93	28.16	59	4.53	59.5
			0.5	6.89	27.88	59	4.4	55.3
			0.1	6.87	28.78	58	4.88	64
			0.25	6.86	28.54	58	4.78	61.5
		12:15	0.5	6.84	28.08	58	4.47	57.6
			0.1	6.84	29.2	58	5.17	67.5
			0.25	6.87	28.83	58	5.62	71.2
			0.5	6.86	28.07	59	4.67	58.8
			0.75	6.83	27.56	59	4.12	52.2
RAR2	28-Mar-15	8:20	0.1	8.63	23.17	214	4.15	47.6
		8:25	0.1	8.66	24.18	216	4.51	53.9
		8:30	0.1	8.65	24.79	214	3.99	47.3
RSpr1	29-Mar-15	11:45						
RCog1	30-Mar-15	11:45						
Other Creeks Impact								
BUL2	29-Mar-15	13:00						
Cog1	30-Mar-15	8:20	0.1	7.53	27.82	11230	0.91	12
			0.25	7.52	27.8	11230	0.89	11.7
			0.5	7.53	27.82	11210	0.79	10.2
			0.1	7.53	27.75	11200	1	13.2
			0.25	7.53	27.76	11230	0.91	12.2
		8:30	0.5	7.53	27.78	11220	0.84	11.1
			0.1	7.54	27.75	11200	1.05	14
			0.25	7.54	27.76	11210	1.04	13.9
			0.5	7.54	27.75	11210	0.99	13.1
Cog2	30-Mar-15	15:00						
PH-387	31-Mar-15	11:20	0.1	8.80	31.30	781	12.53	170
			0.25	8.76	29.95	785	12.11	157
		11:25	0.1	8.52	32.60	863	12.28	169
			11:30	0.1	8.31	30.40	904	8.31
		0.25		8.22	29.67	911	8.22	80.6
		0.45	8.17	29.30	915	8.17	60.0	
MS	28-Mar-15	16:00						

Figure A.2 (a) Dissolved oxygen profile plots, Century Mine March – April 2015

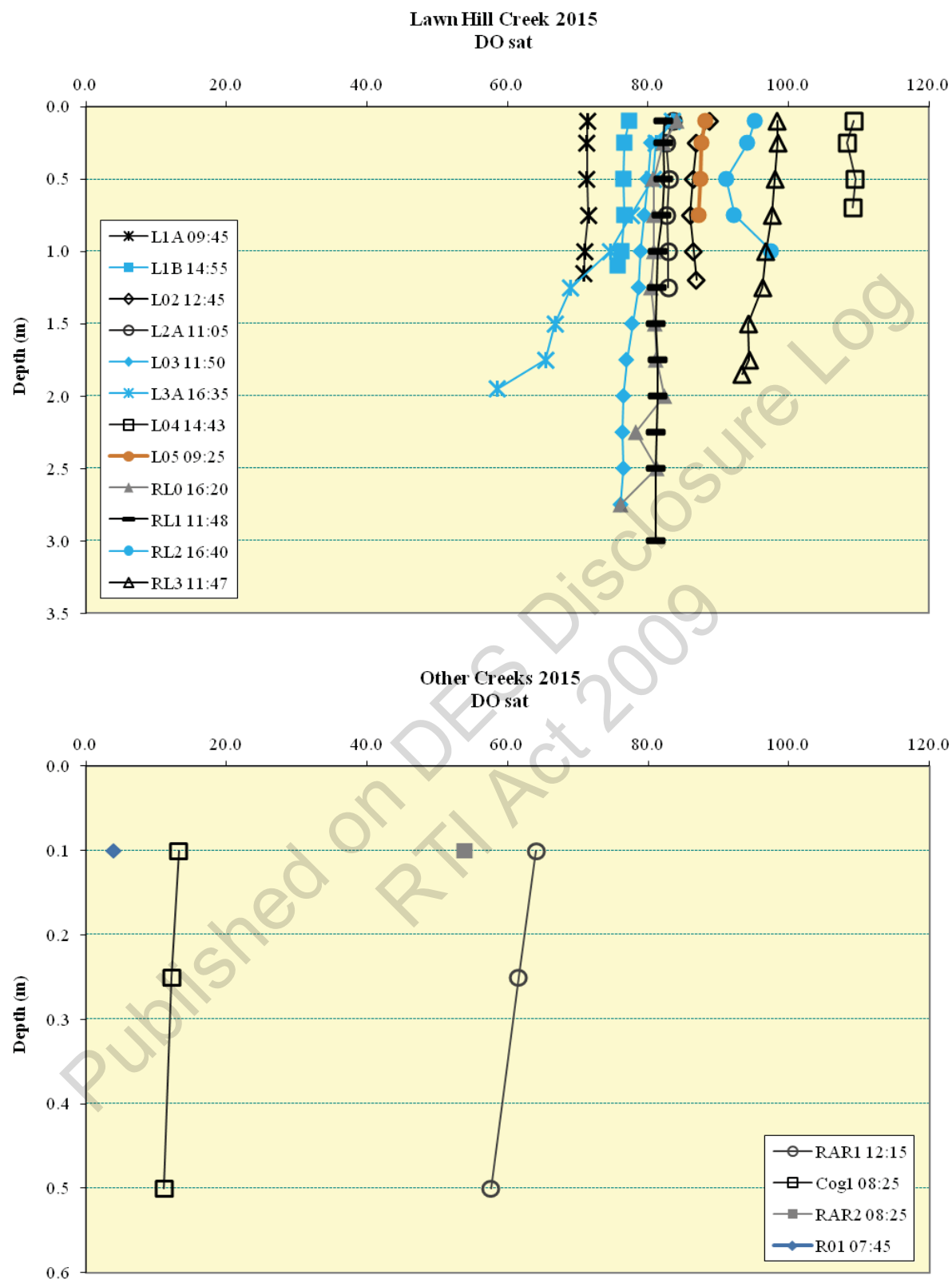


Figure A.2 (b) Temperature Profile plots, Century Mine March – April 2015

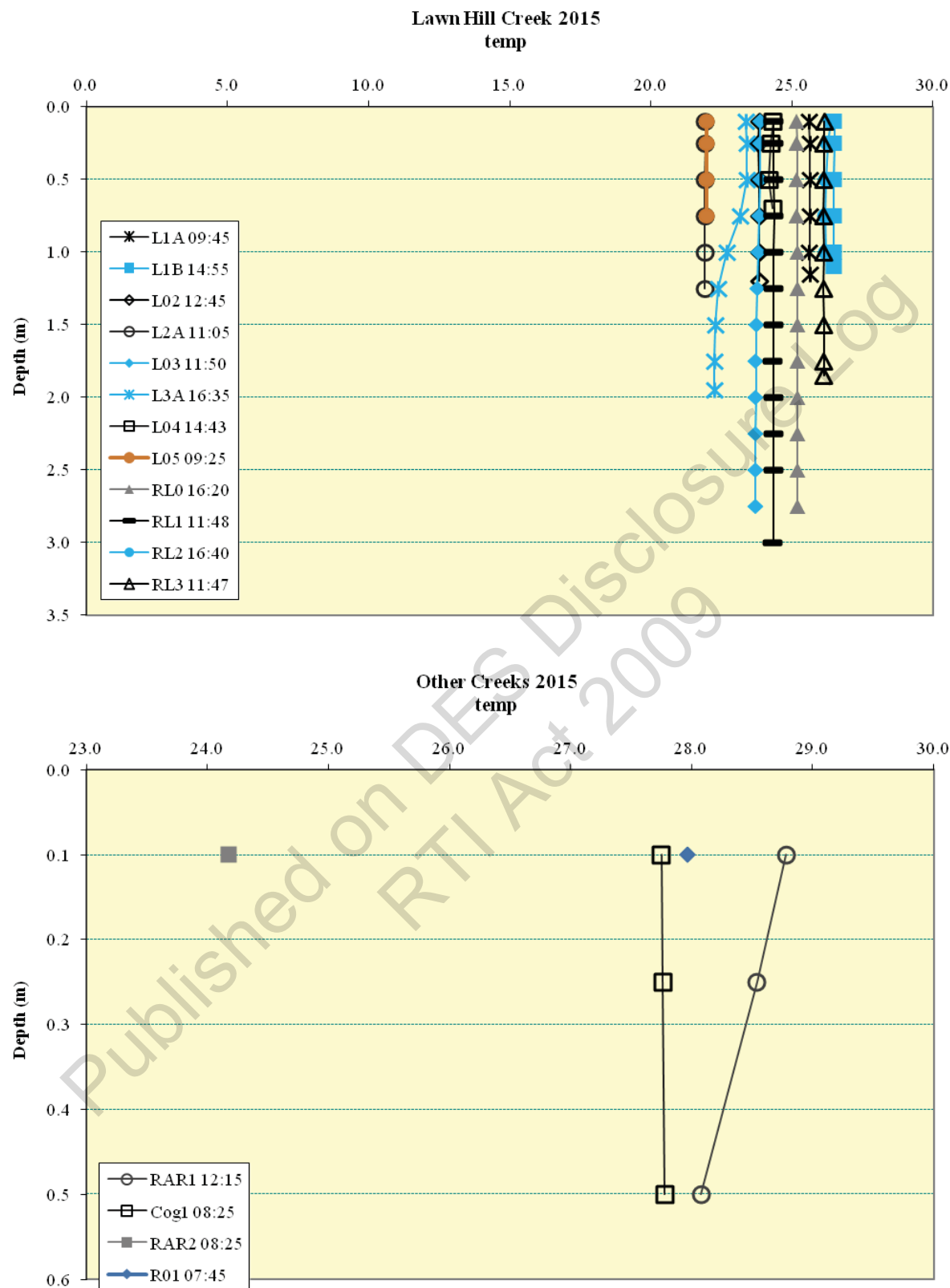


Figure A.2 (c) pH profile plots, Century Mine March – April 2015

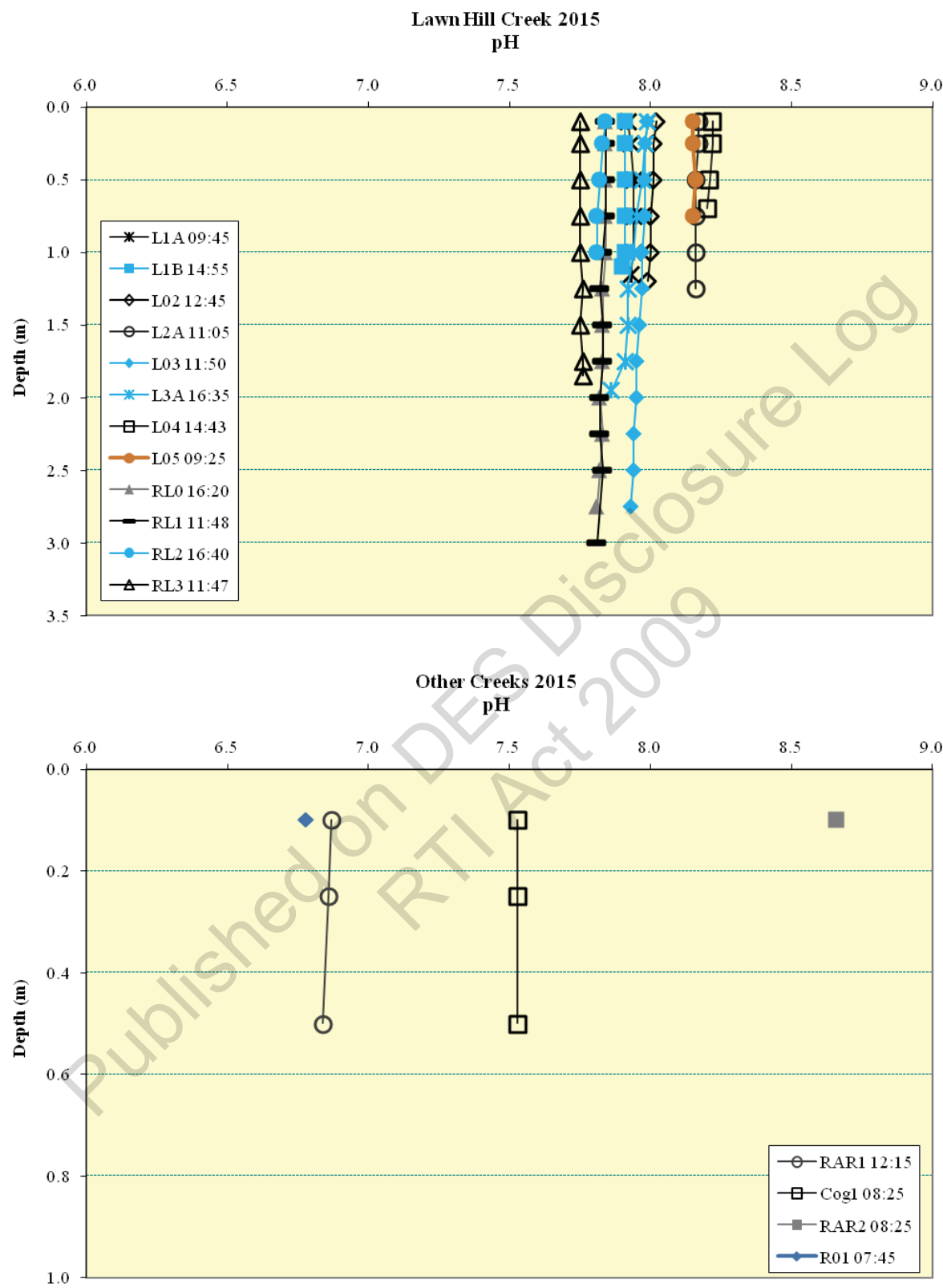
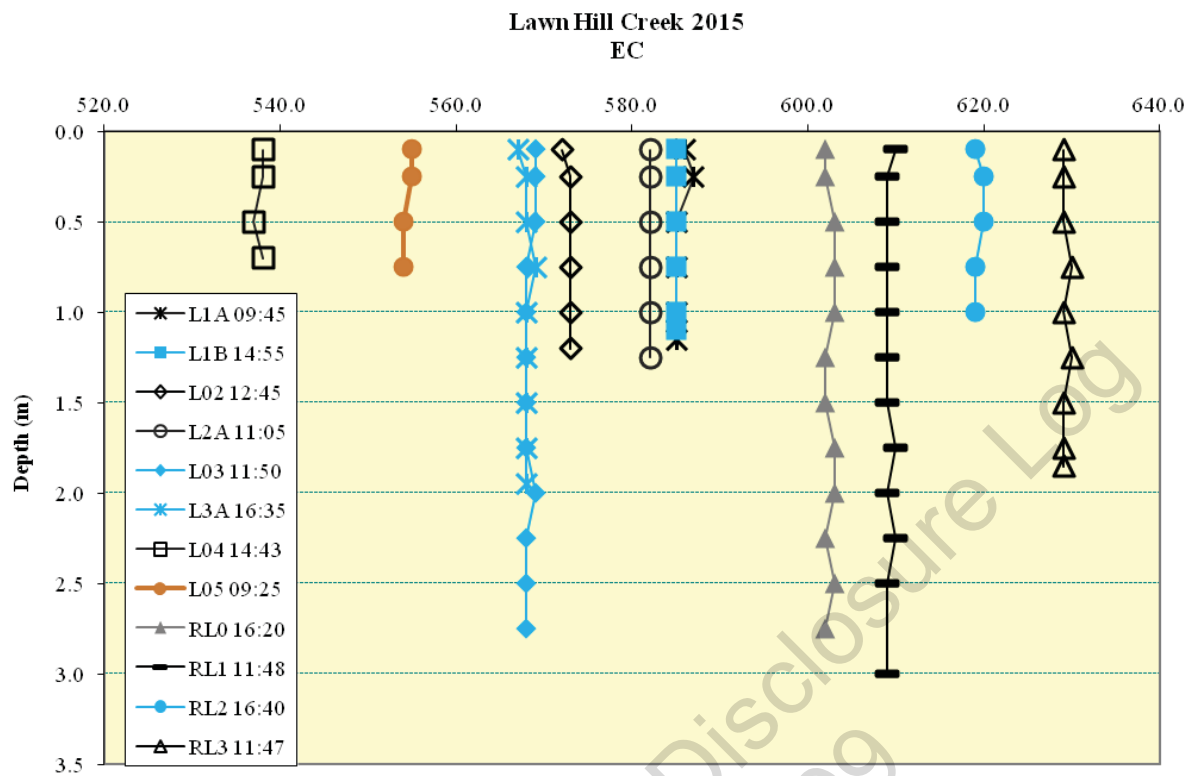
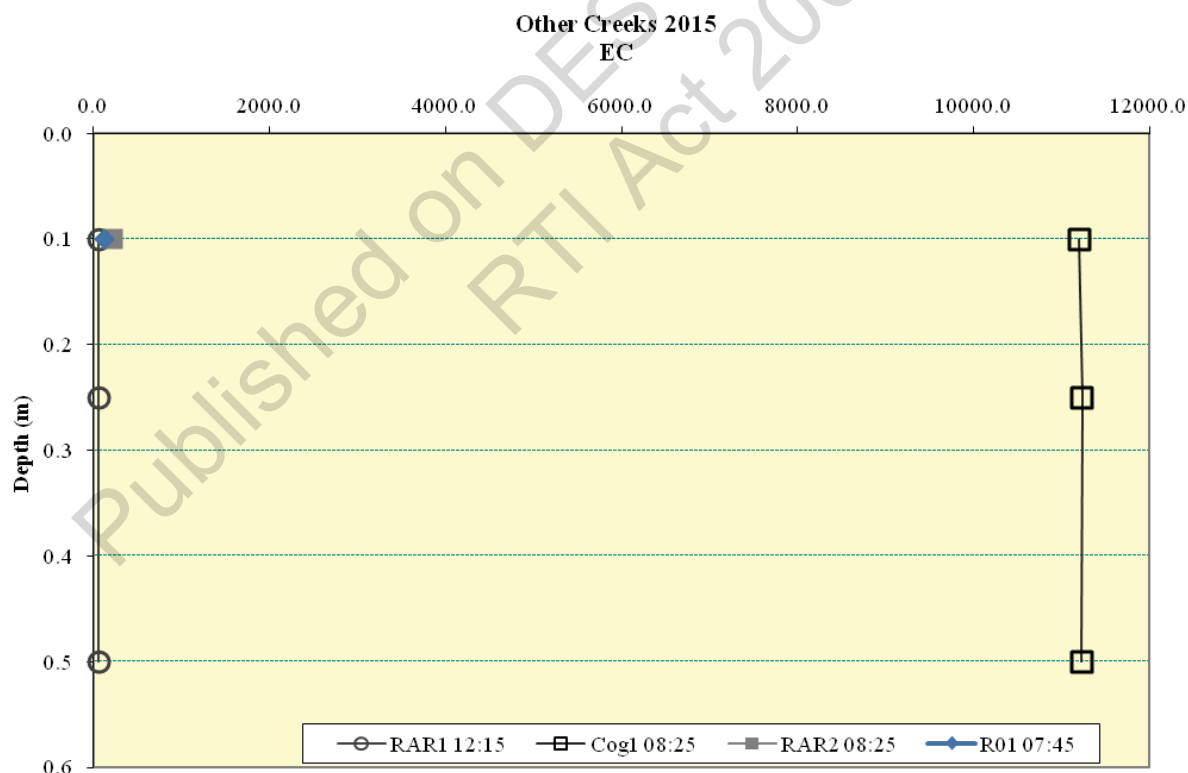


Figure A.2 (d) Electrical conductivity profile plots, Century Mine March – April 2015



A.3 CONDITION ASSESSMENTS

Table A.3.1 Condition assessment criteria

PAHV Rating (1-10):		
10	Large Perrenial River (eg. Burdekin)	
9	Perennial tributary stream (regionally rare) and/or intermittent hydraulic habitat in a large perennial river (eg. Lawn Hill)	
8	Large permanent waterhole (reliable oases/drought refugia and/or potential focal point for wetland vegetation	
7	Small permanent waterhole in an intermittent stream	
6	Seasonally intermittent waterhole with potentially persistent wet sub-surface habitat	
5	seasonally intermittent waterhole with no potentially persistent wet sub-surface habitat	
4	Ephemeral wet habitats supporting distinctive riparian vegetation & potentially persisting wet sub-surface habitat	
3	Ephemeral wet habitats supporting distinctive riparian vegetation but no potentially persisting wet sub-surface habitat	
2	Highly ephemeral waterway with no specialised riparian vegetation but denser riparian "type" vegetation	
1	Highly ephemeral watercourses or constructed drainage with no riparian vegetation	
U/S PAHV (1-5)		
1	no high value habitat upstream	
2	moderate value upstream habitats with alternative paths	
3	moderate value upstream habitats with no alternative path	
4	high value upstream habitats with alternative paths	
5	high value upstream habitats with no alternative path	
Geomorph Condition (1-5): How natural is the site & what is the complexity of structure (eg. Pools, riffles etc.)		
1	Very Poor	eg. Culvert or constructed channel
2	Low	eg. Very straight stream with no instream structures
3	Average	eg. Typical sandy stream
4	Good	eg. Creek with pools and riffles
5	Excellent	eg. Pools, riffles and logjams etc.
Ecological Condition (1-5):		
1	Very Poor	eg. extensive damage from grazing, weeds, erosion etc.
2	Low	eg. Significant damage or impacts
3	Average	eg. Slight-moderate damage
4	Good	eg. Minimal damage
5	Excellent	eg. No obvious damage
Bed Obstruction (1-5):		
1	Very Poor	eg. None
2	Low	eg. A few
3	Average	eg. 1 or 2 types of obstruction
4	Good	eg. A number of different types
5	Excellent	eg. Very complex
Bed Sediment Description		
5	Loose fines (mud & sand) or salt scale	
4	packed fines (mud & sand)	
3	Loose fines with gravel & cobble	
2	Packed fines, gravel and cobble	
1	Poorly sorted coarse materials including cobble and rock	

Table A.3.1 cont.

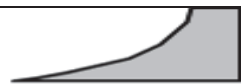
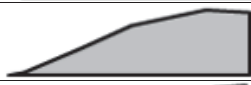
Bank Shape			
CC	concave		
CV	convex		
ST	stepped		
WB	wide base		
UC	undercut		
Bank O'hang			
Vegetation	Length % of bank covered or bare		
Roots			
Bare			
Bank Slope		Bank Stability	
V	Vertical - 80-90°	E	eroding
S	Steep - 60-80°	A	aggrading
M	Moderate - 30-60°	S	stable
L	Low - 10-30°		
F	Flat - <10°		
Native Fauna/ Exotic Fauna/ Weeds/ Other Damage / Impacts			
1	Single Observation	(<10%)	
2	Occasional	(10-25%)	
3	Moderate	(26-50%)	
4	High	(51-75%)	
5	Very High	(76-100%)	

Table A.3.2 Condition assessments recorded during the limnological survey of other creek systems within the vicinity of the Century-MMG Mine, March - April 2015

		RAR2	28/03/2015	RAR1	28/03/2015	A01	29/03/2015	Bul1	29/03/2015	RSpr1	29/03/2015	Bul2	29/03/2015	RM1	29/03/2015	Cog1	30/03/2015	RCog1	30/03/2015	Cog2	30/03/2015	PH387	31/03/2015	LAr1	31/03/2015	D01	1/04/2015	E01	1/04/2015	F01	1/04/2015	F04	1/04/2015	F09	1/04/2015	G01	1/04/2015	R01	2/04/2015	C01	2/04/2015
Site Length (m)		50	-	50	50	50	40	50	40	40	40	80	100	30	200	100	30	200	100	30	30	100	20	40	50																
Site Width (m)		23	23	25	5	7	3	9	20	21	27	20	8	15	6	7	8	8	7	5	11																				
PAHV		7	7	1	1	6	3	3	8	3	5	8	5	5	5	5	4	4	3	4	4																				
U/S PAHV		1	2	1	1	1	1	1	2	1	2	5	5	1	1	1	1	1	1	1	1																				
Geomorph Cond.		1	4	2	1	3	2	2	1	3	4	4	4	3	3	4	2	2	2	2	3																				
Ecol. Cond.		1	4	2	1	2	3	3	3	2	3	3	3	3	2	2	3	3	3	2	3																				
Bed Obsn.		3	3	1	1	2	2	2	2	2	2	3	3	2	2	3	2	1	2	2	2																				
Bed Sed.		-	1	-	-	3	4	2	5	3	2	2	2	3	4	3	4	4	3	3	3																				
Creek Bed Sediment (%)	Fines	5	0	60	50	10	50	20	100	50	20	40	20	20	40	40	30	30	30	50	25																				
	Sand	5	0	30	40	10	50	10	0	20	10	10	30	20	60	40	40	50	40	20	25																				
	Gravel	20	10	10	10	20	0	30	0	20	20	10	20	20	0	15	20	10	30	20	10																				
	Cobble	20	60	0	0	60	0	40	0	10	30	40	30	20	0	5	10	10	0	10	40																				
	Boulder/Bed	0	30	0	0	0	0	0	0	0	20	0	0	20	0	0	0	0	0	0	0																				

Table A.3.3 Condition assessments of creek banks recorded during the limnological survey of other creek reference systems within the vicinity of the Century-MMG Mine, March - April 2015

Site Name		RAR2		RAR1		RCog1		RSpr1		RM1	
Bank (L/B)		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Bank Height (m)		3	1.5	3	5.5	0.8		1.5	1.3	1	1.2
Sediment (%)	Fines	10	10	60	0	50	70	20	40	70	50
	Sand	0	10	15	0	20	10	15	30	10	10
	Gravel	0	10	10	0	10	10	60	30	10	20
	Cobble	0	0	10	0	10	10	5	0	10	20
	Boulder /Bed	90	0	5	100	10	0	0	0	0	0
	Concrete		70								
Canopy Cover	Bank length (%)	0	0	80	60	20	40	50	60	20	10
	Av. Width (m)			8	10	2	2	<5	<5	5	5
	% Shade of Bed			20	30	<1	<1	10	10	10	10
O'hang (%)	Vegetation	25	10	20	20	90	60	20	20	100	90
	Bare	75	90	80	80	10	20	80	80	0	10
Slope		M	L	S	S	M	M	V	M	M	S
Shape		CV	CV	UC	ST	CV	CV	UC	ST	CV	CC
Stability		S	S	E	S	S	S	E	E	A	E
Riparian Zone (m)											

Table A.3.4 Creek bank observations from condition assessments undertaken during the limnological survey of other creek systems within the vicinity of the Century-MMG Mine, March - April 2015

Site Name		Bul2		Cog1		Cog2		PH387		LAr1	
Bank (L/B)		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Bank Height (m)		1.2	1	2	2	1	2.2	1.8	1.8	-	-
Sediment (%)	Fines	80	80	85	85	80	85	75	75	20	20
	Sand	20	20	5	5	10	10	5	5	30	30
	Gravel	0	0	10	10	10	5	10	10	20	20
	Cobble	0	0	0	0	0	0	10	10	30	30
	Boulder /Bed	0	0	0	0	0	0	0	0	0	0
Canopy Cover	Bank length (%)	50	60	60	20	60	60	90	90	80	90
	Av. Width (m)	5	5	5	2	5	5	20	20	5	5
	% Shade of Bed	50	50	10	5	10	10	30	30	40	40
O'hang (%)	Vegetation	70	80	30	70	70	70	30	40	70	50
	Bare	30	20	70	30	30	30	70	60	30	50
Slope		S	S	V	S	M	S	S	S	L	L
Shape		CC	CV	UC	CC	CC	UC	CC	CC	ST	ST
Stability		E	E	E	E	E	E	E	E	E	E
Riparian Zone (m)											

Table A.3.5 Creek bank observations from condition assessments undertaken during the limnological survey of Page creek within the vicinity of the Century-MMG Mine, March - April 2015

	Bank	Bank Height (m)	Sediment (%)					Canopy Cover			O'hang (%)		Slope	Shape	Stability	Riparian Zone (m)
			Fines	Sand	Gravel	Cobble	Boulder /Bed	Bank length (%)	Av. Width (m)	% Shade of Bed	Vegetation	Bare				
R01	Left	0.5	80	20	0	0	0	10	2	5	60	40	S	CC	E	1
	Right	0.5	70	30	0	0	0	10	2	5	70	30	S	CC	E	1
A01	Left	1.5	10	20	30	40	0	20	20	0	70	30	M	CV	S	2
	Right	1.5	-	-	-	-	-	20	2	0	70	30	M	CV	S	2
C01	Left		60	40	0	0	0	30	3	30	50	50	S	UC	E	2
	Right		60	40	0	0	0	30	3	30	60	40	S	CC	E	2
D01	Left	1.8	80	20	0	0	0	60	6	20	80	20	S	CC	E	
	Right	1.8	60	30	10	0	0	50	6	30	70	30	S	CC	E	
E01	Left	2	60	40	0	0	0	70	7	50	40	60	M	CV	E	5
	Right	2	60	40	0	0	0	70	7	30	30	70	S	CC	E	3
F01	Left	-	40	30	30	0	0	70	5	50	80	20	V	UC	E	2
	Right	-	30	50	20	0	0	70	5	50	70	30	S	CC	E	2
F04	Left	3	80	20	0	0	0	70	3	20	80	20	V	CC	E	5
	Right	2	60	20	10	0	10	60	3	30	50	50	M	CV	E	5.5
F09	Left	-	60	40	0	0	0	80	-	-	60	40	S	CC	E	2
	Right	-	80	20	0	0	0	80	-	-	60	40	S	CC	E	5
G01	Left	2.2	60	40	0	0	0	60	4	40	50	50	S	CC	E	5
	Right	2.2	60	40	0	0	0	70	2	20	70	30	S	CV	E	9

Table A.3.6 Fauna observed in Condition assessments undertaken during the limnological survey of other creek systems within the vicinity of the Century-MMG Mine, March - April 2015

Site Name	Date	Time	Native Fauna									Exotic Fauna	
			Mussel Shells	Snail Shells	Crab Holes	Crabs	Grass hoppers	Goanna	Birds	Fish	Macropod	Cattle	Pigs
RAR1	28/03/2015	13:40	2	2	5	2			3				
RAR2	28/03/2015	8:40			2					0	2	2	
RCog1	30/03/2015	12:00					3		3		2		
RM1	29/03/2015	15:45			2				2				
RSpr1	29/03/2015	11:45							2			2	
Bul1	29/03/2015	8:30							3				
Bul2	29/03/2015				1				2			1	
Cog1	30/03/2015	10:55						1	3	2	2		
Cog2	30/03/2015	15:00			2				2			1	
CogB1	30/03/2015	15:50	1		1				1				
CogC1	30/03/2015	16:25			1		3		1		1	1	
PH099	31/03/2015	7:45			2				3			3	
PH387	31/03/2015	14:10	3			3			3	3	3	3	3
LAr1	31/03/2015	15:30							2			1	
R01	2/04/2015	8:00							3				3
A01	29/03/2015	7:45											
C01	2/04/2015	10:30			2				3		1		
D01	1/04/2015	8:00			2				2				
E01	1/04/2015	8:30			2				2			3	3
F01	1/04/2015	9:15			2				2			3	2
F04	1/04/2015	10:35							2		2	2	
F09	1/04/2015	12:00			2				2			2	
G01	1/04/2015	12:40			2				3		3	2	

Table A.3.7 Vegetation observed in condition assessments undertaken during the limnological survey of other creek systems within the vicinity of the MMG Century Mine, March - April 2015

		RAR1	RAR2	RCog1	RM1	RSpr1	Bul1	Bul2	Cog1	Cog2	PH387	LAr1	R01	A01	C01	D01	E01	F01	F04	F09	G01
Canopy Species	<i>Eucalyptus camadulensis</i>	X	X	X		X		X	X	X	X	X	X	X	X		X	X	X	X	X
	<i>Terminalia canescens</i>	X	X	X		X				X			X		X		X	X	X		
	<i>Eucalyptus crebra</i>						X														
	<i>Lophostemon grandiflorus</i> subsp. <i>riparius</i>							X							X		X	X		X	X
	<i>Atalaya hemiglauc</i>												X								
	<i>Lysiphyllum cunninghamii</i>																				X
	<i>Melaleuca</i> sp.										X	X									
	Vine						X														
	Unidentified											X							X		X
Understorey Species	<i>Atalaya hemiglauc</i>																				X
	<i>Terminalia canescens</i>	X	X									X		X							
	<i>Acacia farnesiana</i>		X			X	X	X	X												X
	Legume						X														X
	<i>Carissa lanceolata</i>			X		X			X												
	<i>Eremophila longifolia</i>									X											
	<i>Flueggea virosa</i> subsp. <i>melanthesoides</i>									X									X	X	
	<i>Melaleuca bracteata</i>										X	X						X			
	<i>Parkinsonia aculeata</i>							X													
	Unidentified							X			X										X
Groundcover	Grasses	X	X	X		X		X	X	X		X	X	X	X		X	X	X	X	X
	Forbs	X		X		X		X	X	X		X	X	X	X		X	X	X	X	
	Vine		X																		
	Buffel Grass					X															
	Sedges		X					X			X										X

B - SITE PHOTOGRAPHS

B.1 LAWN HILL CREEK SITES





Left bank

Right bank

RL2



Upstream



Downstream



Left bank

Right bank

L1A



Upstream



Downstream

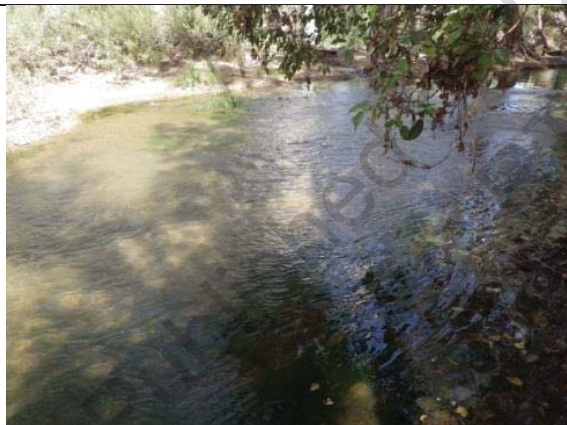


Left bank



Right bank

L1B



Upstream



Downstream



Left bank

Right bank

L1C			
			
Upstream		Downstream	
			
Blockage		Right bank	
L2			
			
Upstream		Downstream	
			
Left Bank		Right bank	

L2A



Upstream



Downstream



Left bank



Right bank

L3



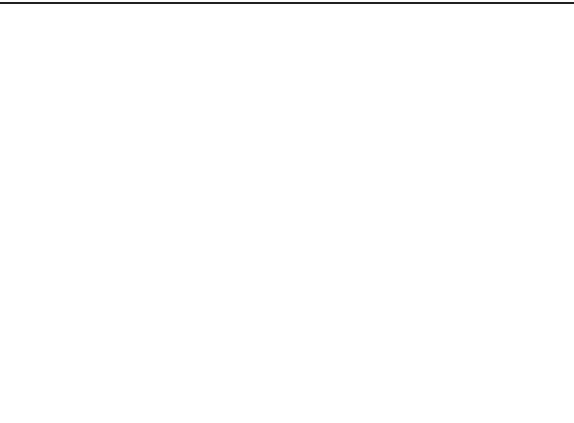
Upstream



Downstream



Left bank



Right bank

L3A



Upstream



Downstream



Left bank

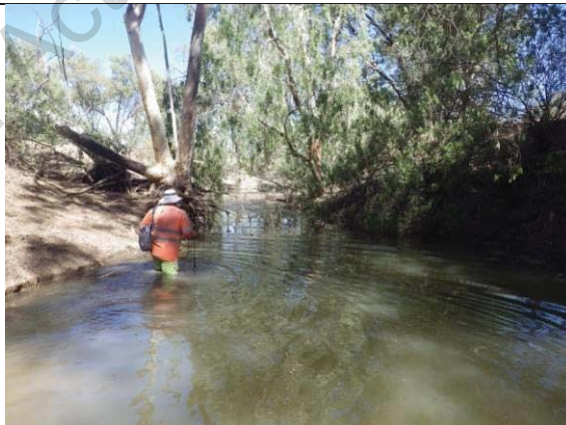


Right bank

L4



Upstream



Downstream



Left bank

Right bank

L5



Upstream



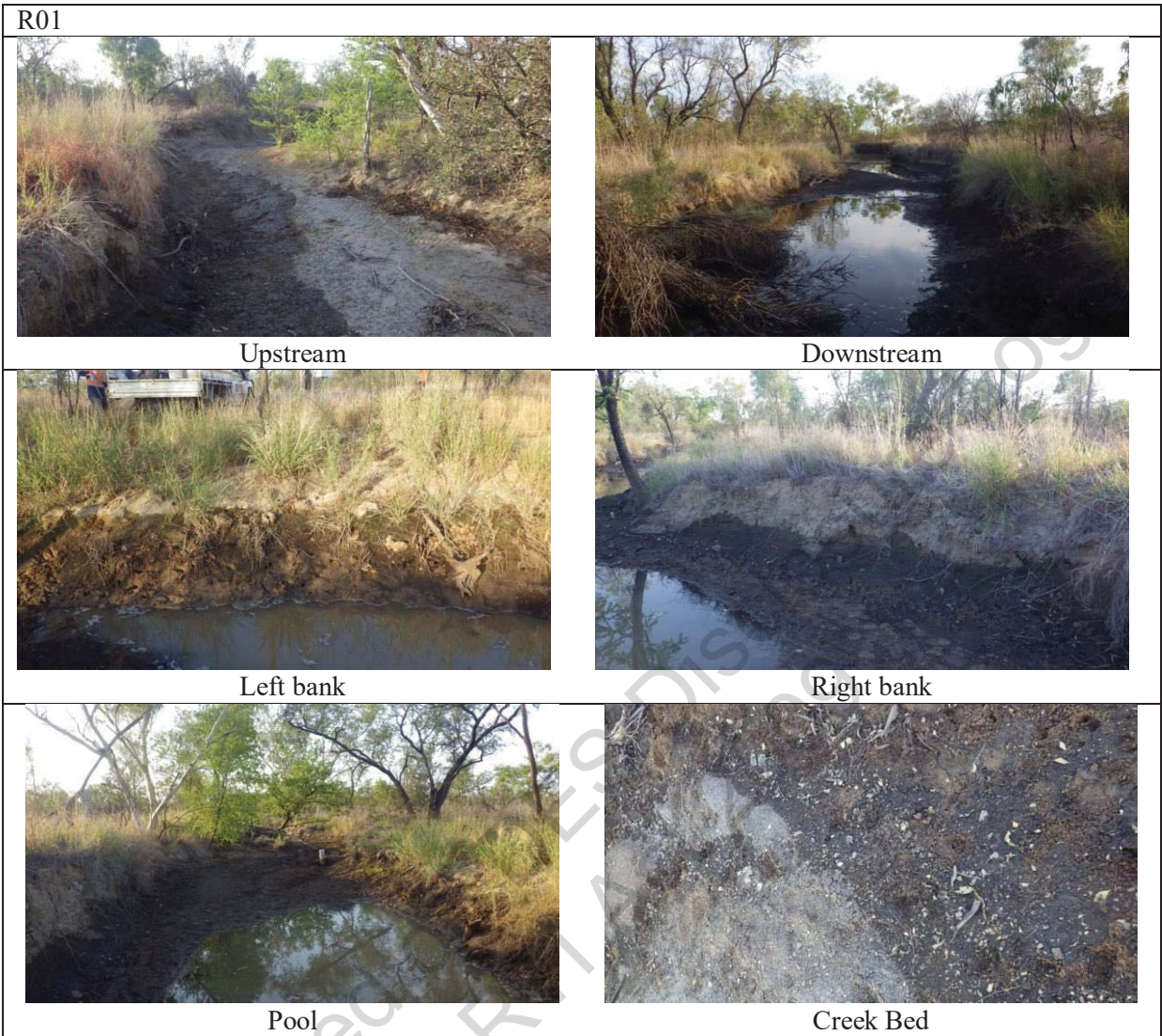
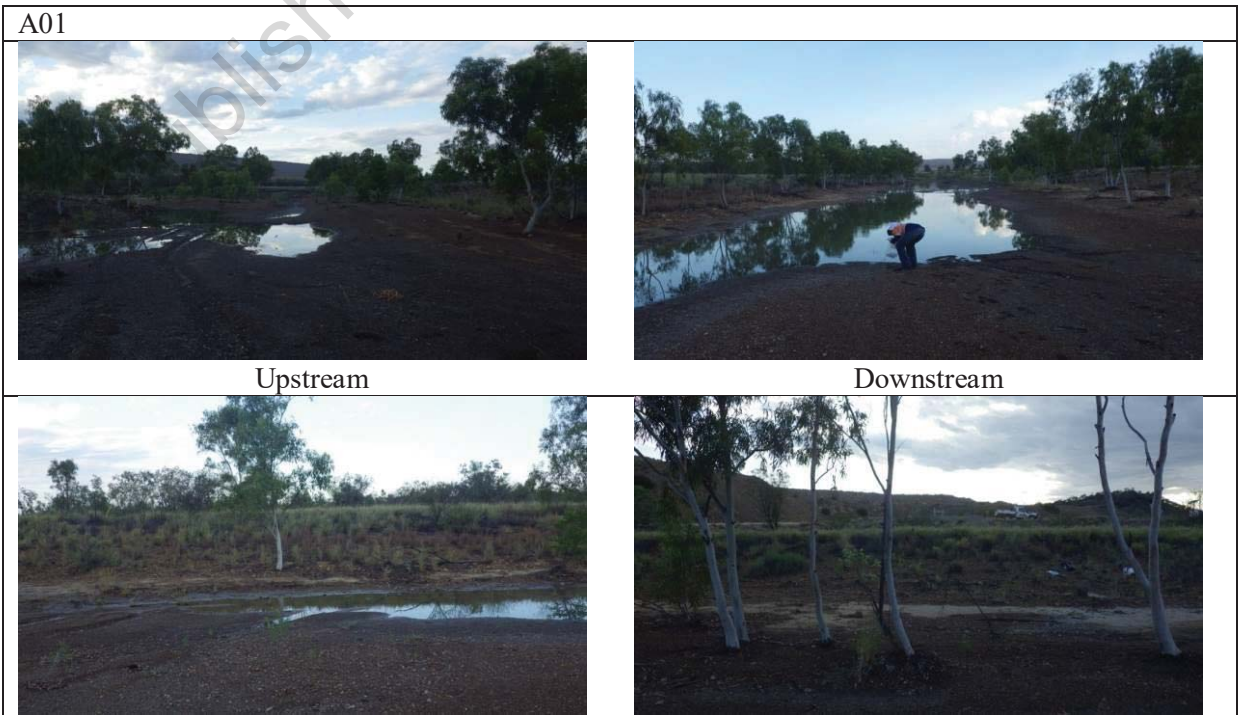
Downstream

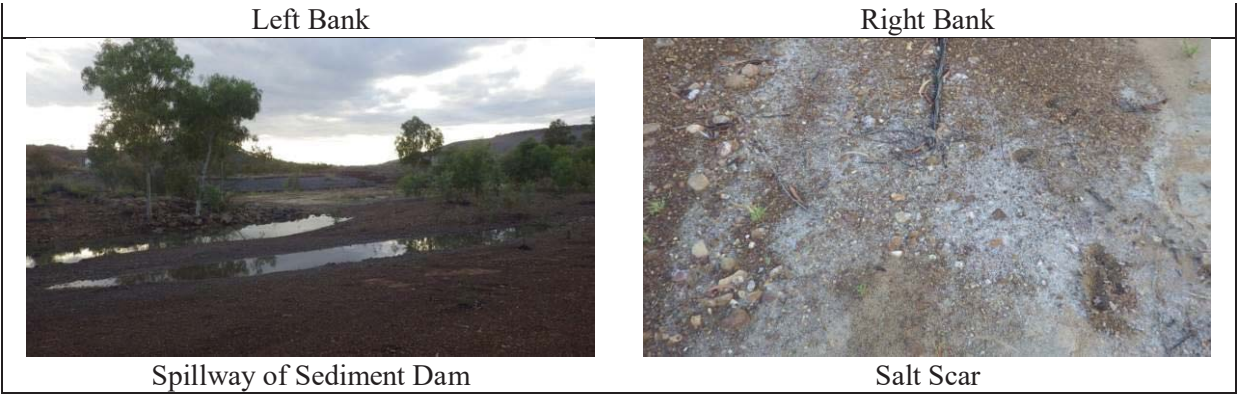


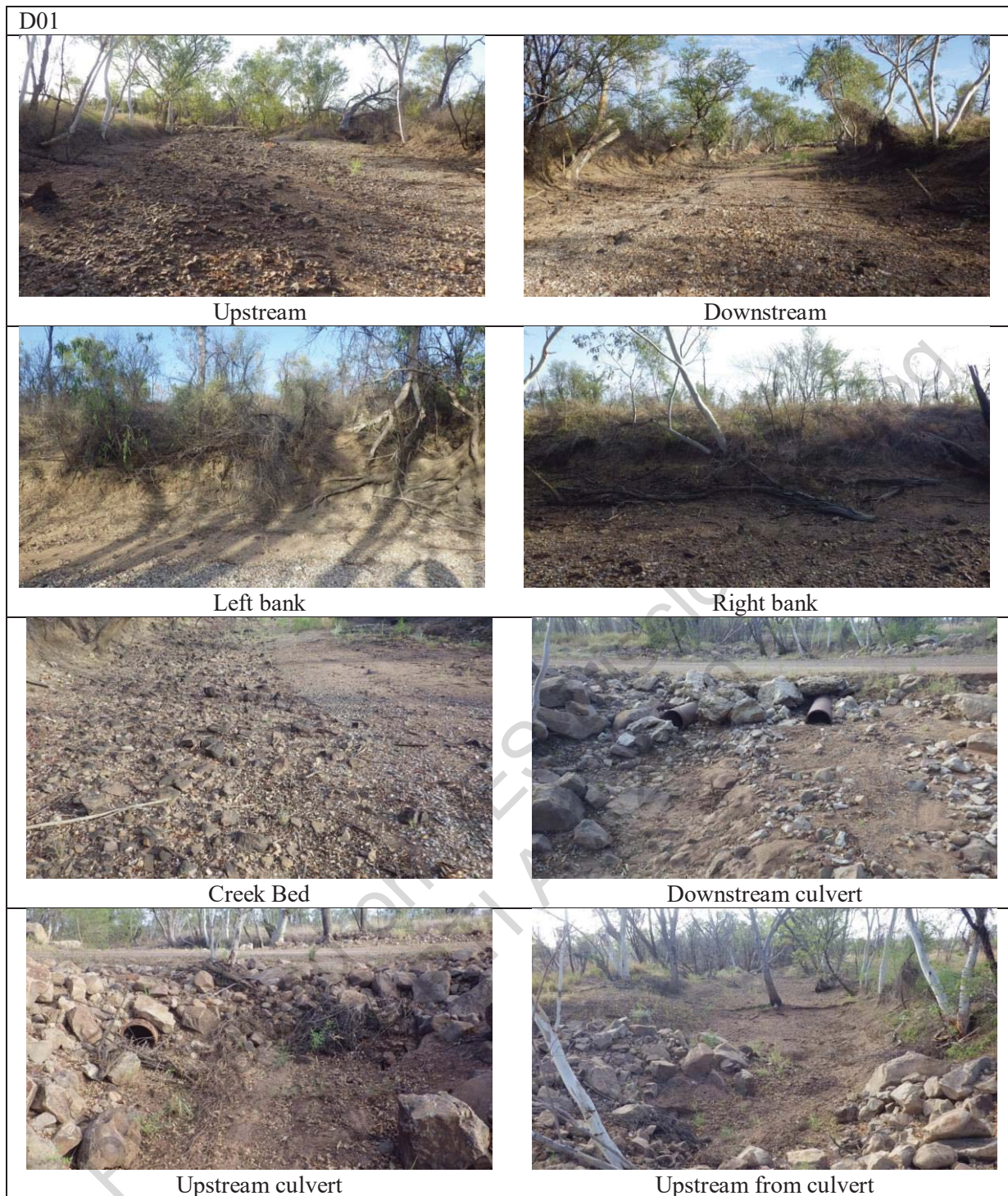
Left bank

Right bank

B.2 PAGE CREEK SITES









Left bank



Right bank



Upstream to road crossing



Upstream from road crossing



Salt Line

F01



Upstream



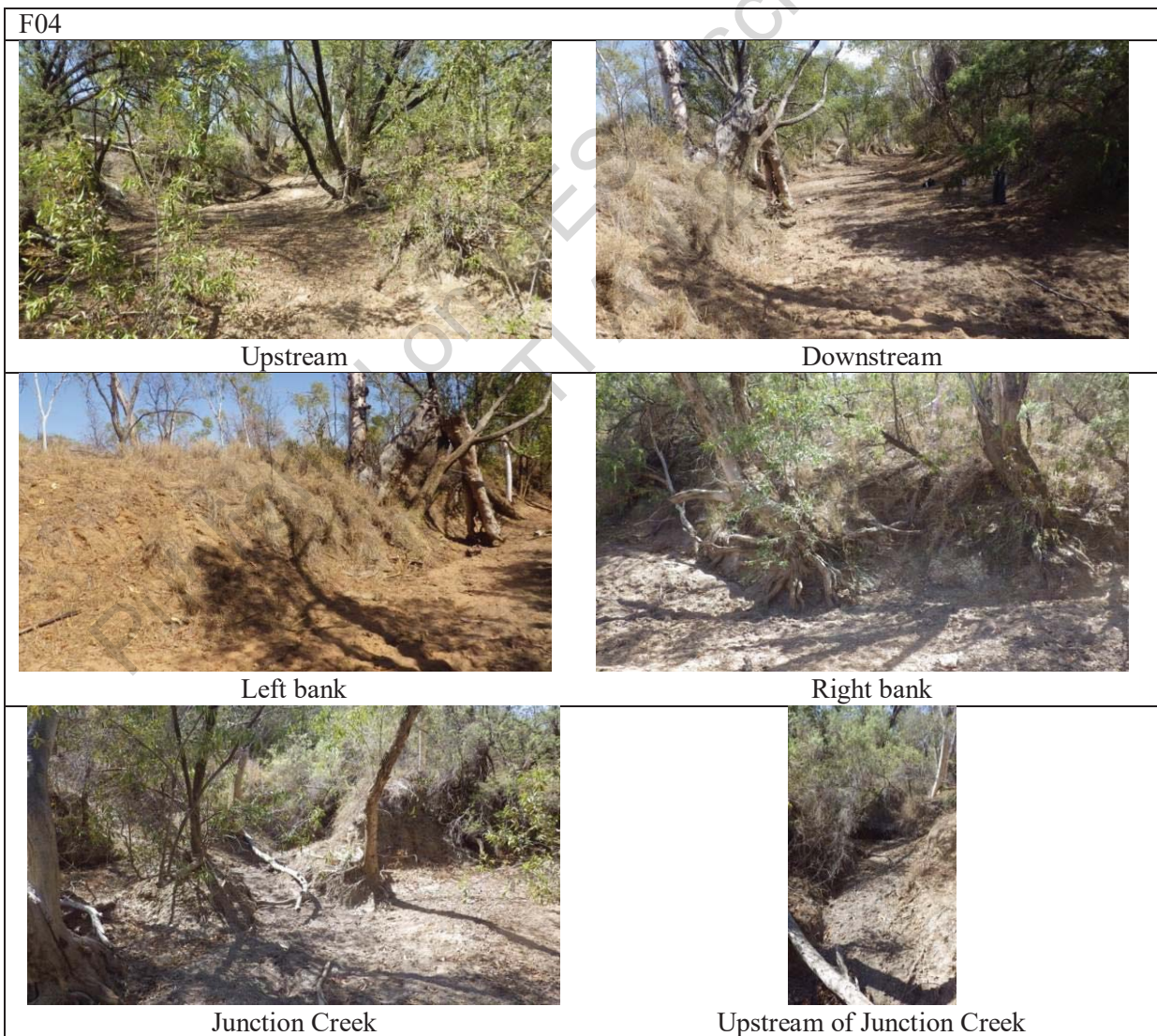
Downstream



Left bank



Right bank



F09



Upstream



Downstream



Left bank



Right bank



Creek Bed

G01



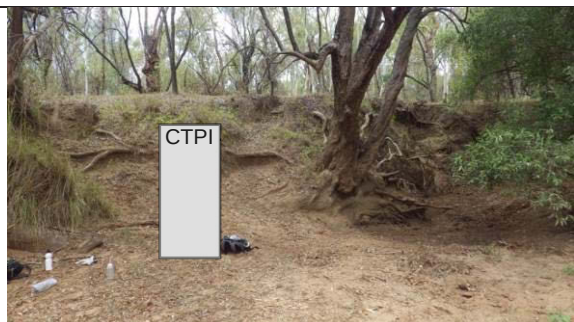
Upstream



Downstream



Left bank

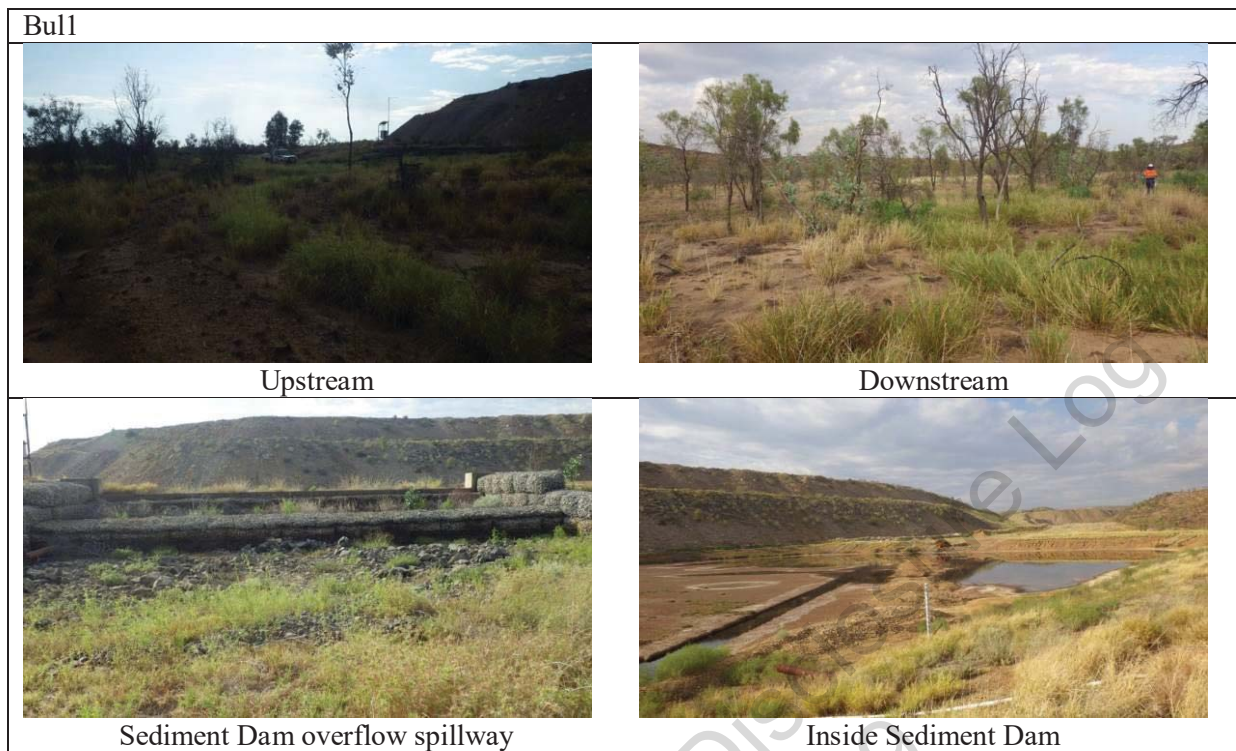
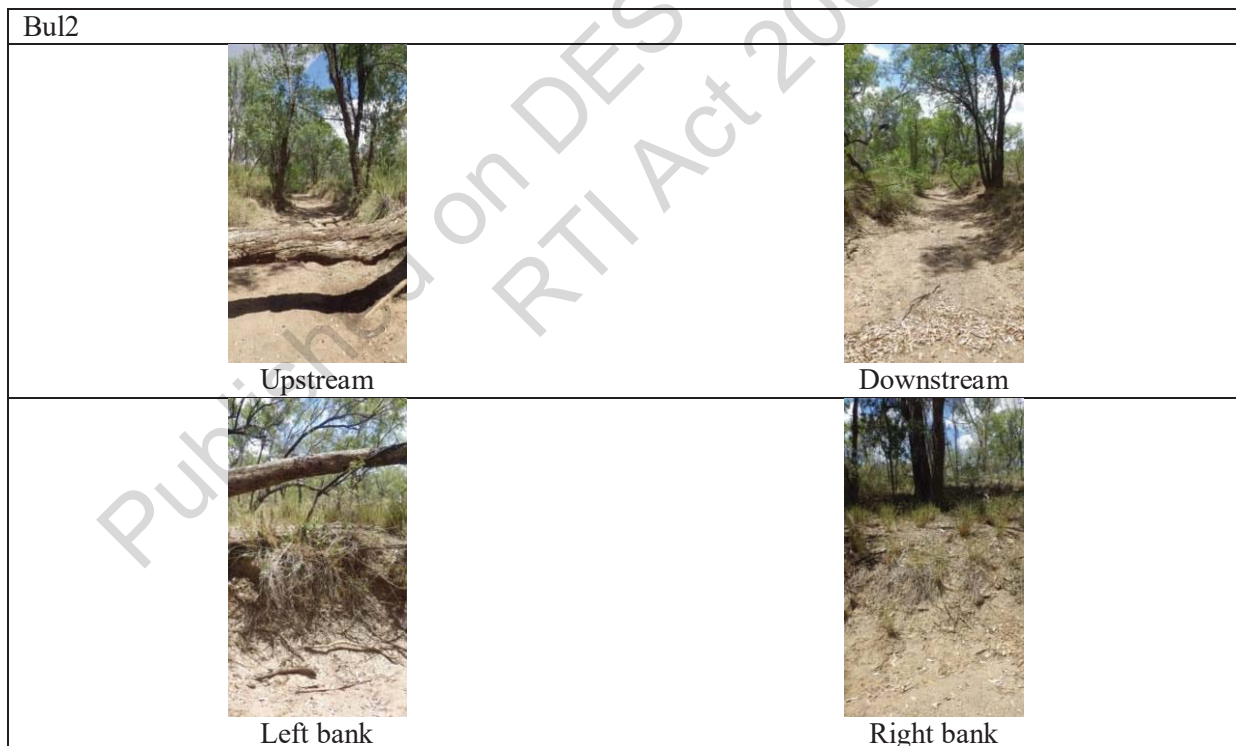


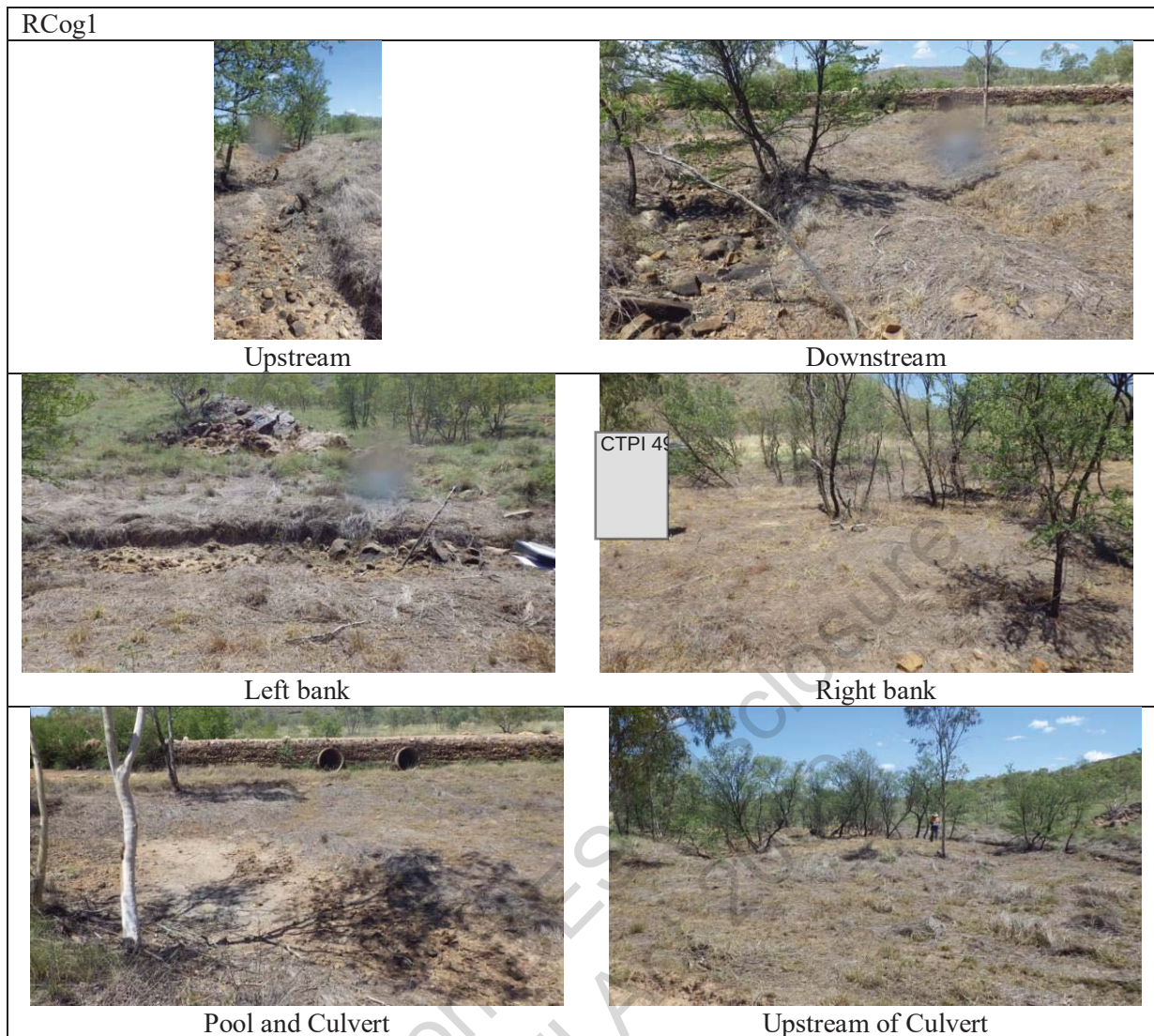
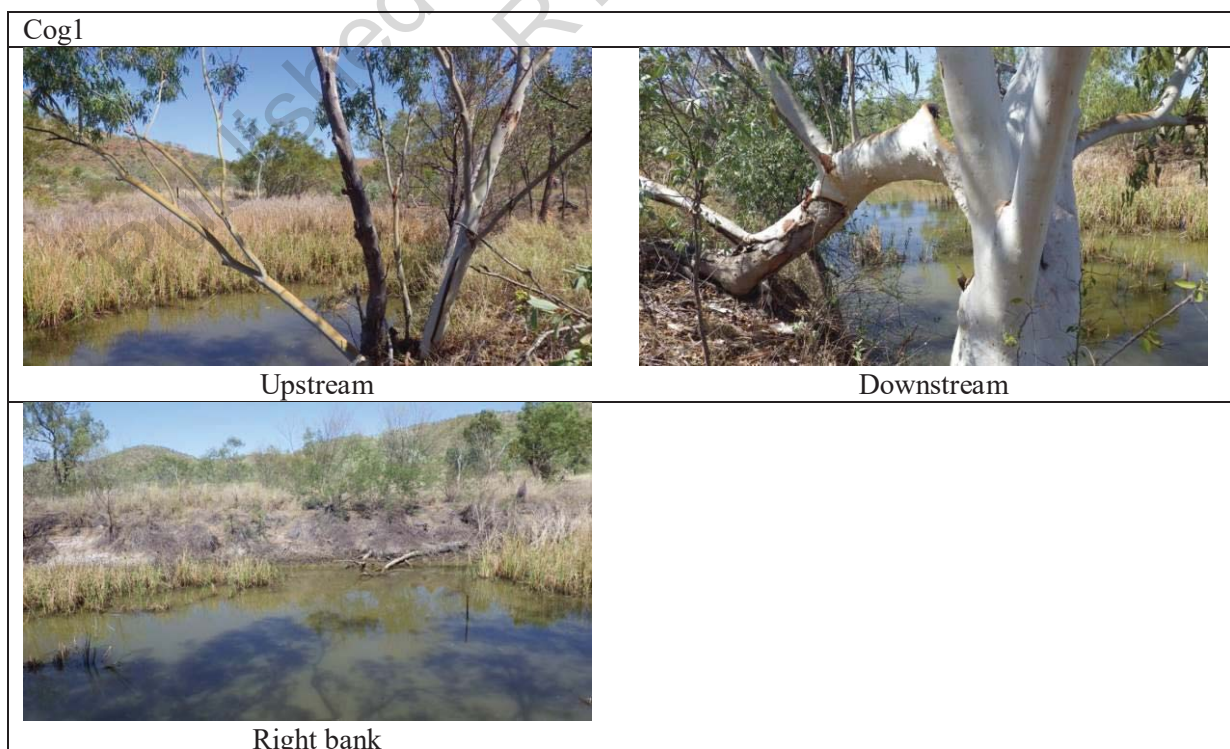
Right bank

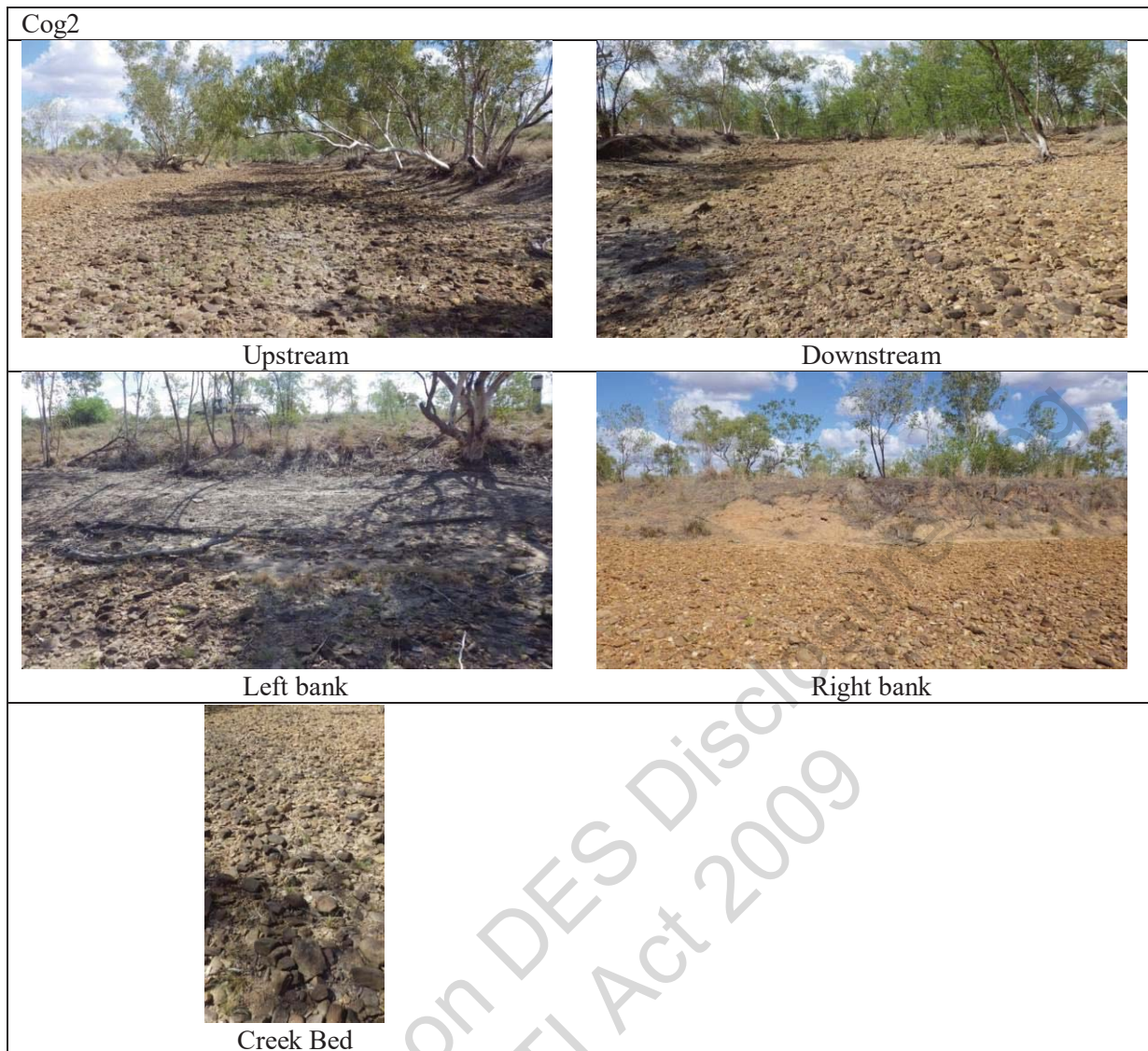
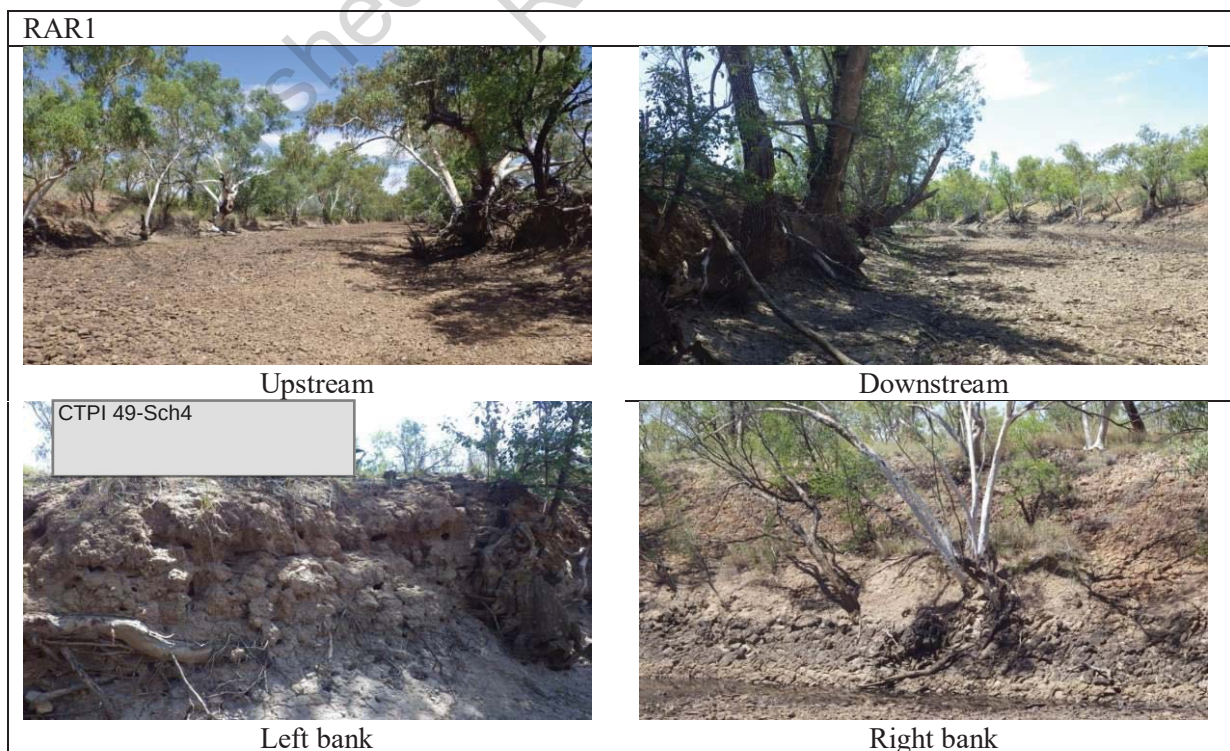
	
Pool	Creek Bed
	
Crab Holes in Pool	

G07		
No Photos	No Photos	
Upstream	Downstream	

B.3 OTHER CREEK SITES









Creek Bed

RAR2



Upstream



Downstream



Concrete Weir

LAr1

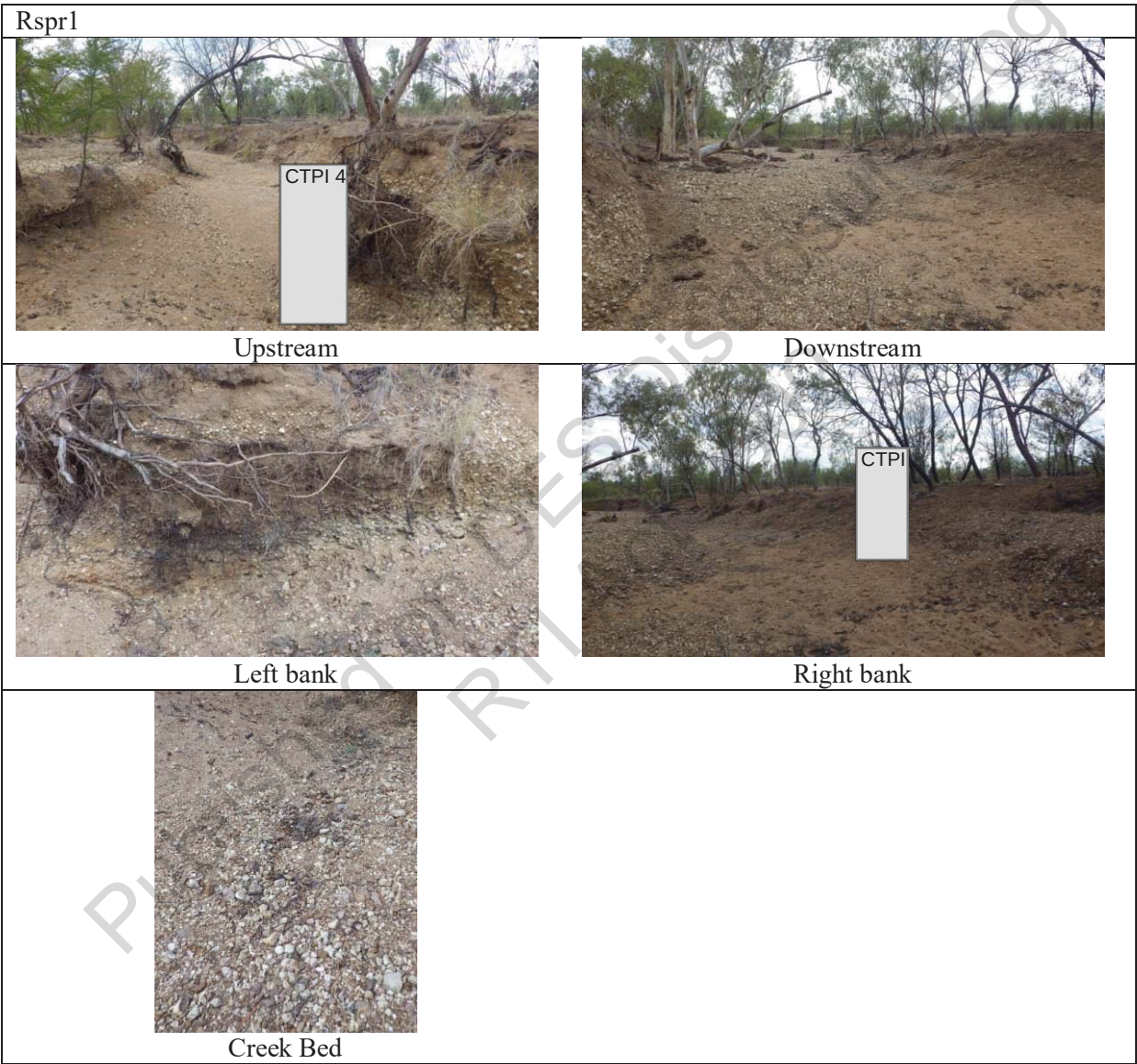
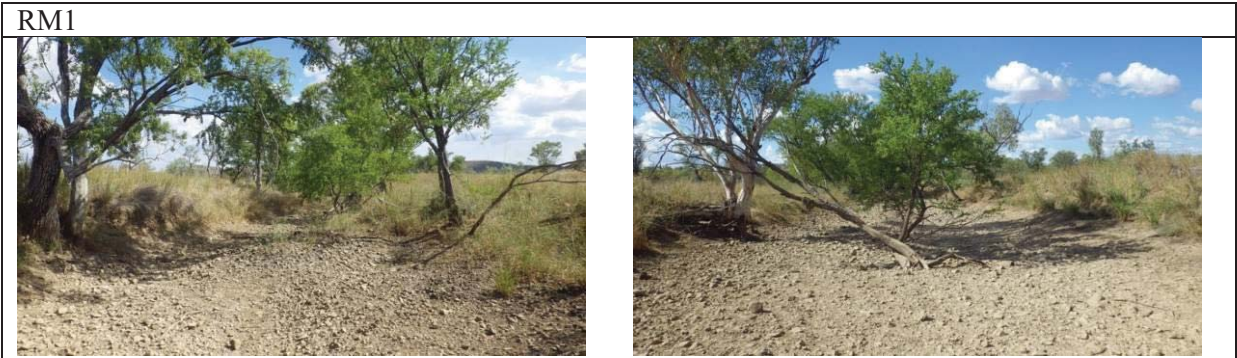


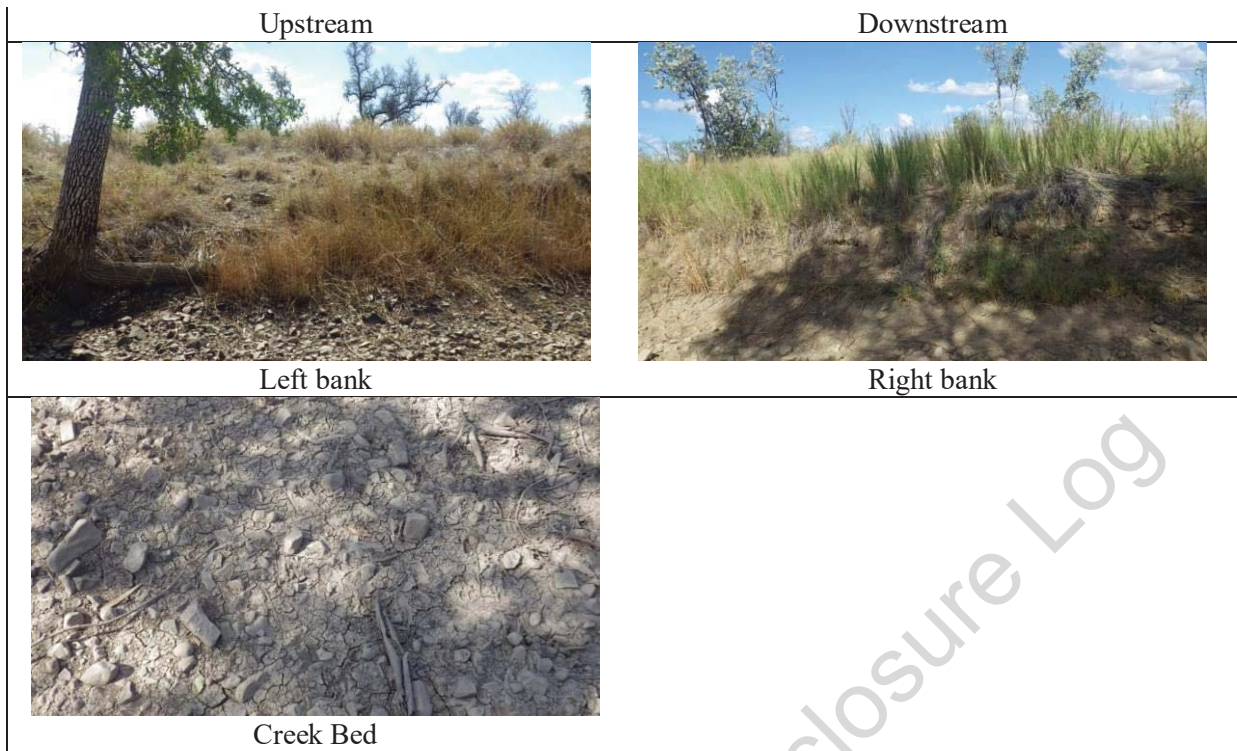
Upstream



Downstream







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C. RAW FISH AND CRUSTACEAN DATA

Table C.1 Raw Fish and Crustacean data from Lawn Hill Creek within the vicinity of the Century-MMG Mine, March - April 2015

	Fish																			Crustaceans			No. of Species/Taxa			
	Glass fish <i>Ambassis</i> spp	Banded grunter <i>Amniataba percoides</i>	Flyspeckeled hardyhead <i>Craterocephalus stercusmuscarum</i>	Strawman hardyhead <i>Craterocephalus stramineus</i>	Mouth almighty <i>Glossamia aprion</i>	Golden goby <i>Glossignius giurus</i>	Coal grunter <i>Hephaestus carbo</i>	Sooty grunter <i>Hephaestus fuliginosus</i>	Barramundi <i>Lates calcarifer</i>	Spangled perch <i>Leiopotherapon unicolor</i>	Eastern rainbowfish <i>Melanotaenia splendida</i>	Bony bream <i>Nematalosa eribi</i>	Black catfish <i>Neosilurus ater</i>	Hyrtl's tandan <i>Neosilurus hyrtlii</i>	Sleepy cod <i>Oxyeleotris lineolata</i>	Giant gudgeon <i>Oxyeleotris selheimi</i>	Saratoga <i>Scleropages jardinii</i>	Gulf grunter <i>Scortum ogilbyi</i>	Freshwater longtom <i>Strongylura krefftii</i>	Seven spot archerfish <i>Toxotes chatareus</i>	Freshwater prawn <i>Macrobrachium</i> sp.	Freshwater crab <i>Sundathelphusidae</i>	Redclaw crayfish <i>Cherax quadricarinatus</i>	Fish	Crustaceans	Total
RL3		21	1		1	1	3	15		3	38			1		1			2	12				12		12
RL2	3	59			9	2	12	1		1	108				2	2	2		1	10				13		13
RL1		25	10		8		8	10		15	67		1		2					11				10		10
RL0	3	15	14		4		23	10	1		81				4				7	30				11		11
L1A		11	10	3	17	2	4		1	8	33				3					1				11		11
L1B	1	15	12		5	4	4	3		8	53				1					3			1	11	1	12
L1C	9	8	0		5		1			15	7				1					3				8		8
L2A		12	38		20	6	3			3	89				6				1	5				10		10
L2		44	45		27	20	6	8		9	85				30			1		10				11		11
L3A		33	8		30	5	4	12		16	305			2	10	2			3	25				13		13
L3	7	4	24		11	5	2	2		4	18				12	1				3				12		12
L4		2	4		16	2				15	177				2					1				8		8
L5		1	7		5	6		2			17	1			1	1				4				10		10
Totals	23	250	173	3	158	53	70	63	2	97	1078	1	1	3	74	7	2	1	14	118	0	0	1	20	1	21

Table C.2 Fish Length Measurements from Lawn Hill Creek within the vicinity of the Century-MMG Mine, March - April 2015

		1	2	3	4	5	6	7	8	9	10
Site	Species	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
RL3	<i>Melanotaenia splendida</i>	40	43	38	28	25	20	22	28	26	
	<i>Amniataba percoides</i>	76	68	76	73	60	52				
	<i>Glossamia aprion</i>	42	33								
	<i>Oxyeleotris selheimi</i>	125									
	<i>Craterocephalus stercusmuscarum</i>	38									
	<i>Hephaestus fuliginosus</i>	80									
	<i>Glossigmius giurus</i>	80									
RL2	<i>Melanotaenia splendida</i>	36	37	39	42	46	50	50			
	<i>Amniataba percoides</i>	43	82	43	33	52					
	<i>Glossamia aprion</i>	58	75	50	74						
	<i>Hephaestus carbo</i>	130	93								
	<i>Oxyeleotris lineolata</i>	135	110								
	<i>Hephaestus fuliginosus</i>	140	38								
	<i>Glossigmius giurus</i>	105									
	<i>Strongylura krefftii</i>	310									
	<i>Leiopotherapon unicolor</i>	76									
RL1	<i>Melanotaenia splendida</i>	35	45	48	35	50	56	56	40	43	
	<i>Glossamia aprion</i>	33	70	38							
	<i>Craterocephalus stercusmuscarum</i>	40	35								
	<i>Oxyeleotris lineolata</i>	145	120								
	<i>Amniataba percoides</i>	77									
	<i>Toxotes chatareus</i>	53									
	<i>Neosilurus ater</i>	220									
	<i>Hephaestus carbo</i>	73									
RL0	<i>Oxyeleotris lineolata</i>	79	79	89	70	58					
	<i>Melanotaenia splendida</i>	35	25								
	<i>Glossamia aprion</i>	70									
	<i>Hephaestus carbo</i>	75	94								
	<i>Craterocephalus stercusmuscarum</i>	30	15	19	18	23					
L1A	<i>Glossamia aprion</i>	50	90	70	70	60	30				
	<i>Oxyeleotris lineolata</i>	140	70								
	<i>Amniataba percoides</i>	85	70								
	<i>Hephaestus carbo</i>	85									
	<i>Melanotaenia splendida</i>	30	35								
	<i>Glossigmius giurus</i>	70									
L1B	<i>Amniataba percoides</i>	90									
	<i>Oxyeleotris lineolata</i>	130									
	<i>Ambassis spp.</i>	35									
	<i>Glossigmius giurus</i>	55									
	<i>Melanotaenia splendida</i>	35	43	40	35	48	35				
	<i>Hephaestus fuliginosus</i>	55									
L1C	<i>Ambassis spp.</i>	33	40	43	40	38					
	<i>Glossamia aprion</i>	50	85	68	45	38					
	<i>Leiopotherapon unicolor</i>	97	70	87							
	<i>Amniataba percoides</i>	80	63	55	58	60	70				
	<i>Melanotaenia splendida</i>	42	45	40	35	33	31	38			

Table C.2 cont.

Site	Species	1	2	3	4	5	6	7	8	9	10
		mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
L2	<i>Oxyeleotris lineolata</i>	195	77	192	290	220	270	108	155	175	105
	<i>Glossignius giurus</i>	102	109	111	94	103					
	<i>Amniataba percoides</i>	67	60	63	56	38	35	87	86	48	
	<i>Leiopotherapon unicolor</i>	97	74	54	64	135					
	<i>Glossamia aprion</i>	89	60	71	101	52	55	49	87	30	
	<i>Hephaestus carbo</i>	86	103	85							
	<i>Melanotaenia splendida</i>	55	32	45	18	36	26				
	<i>Hephaestus fuliginosus</i>	80	72	80							
	<i>Scortum ogilbyi</i>	65									
L2A	<i>Glossamia aprion</i>	87	63	108							
	<i>Amniataba percoides</i>	76	54								
	<i>Glossignius giurus</i>	65	48								
	<i>Oxyeleotris lineolata</i>	105	140	50							
	<i>Melanotaenia splendida</i>	45	46								
	<i>Craterocephalus stercusmuscarum</i>	35	36	37	32	35					
	<i>Hephaestus carbo</i>	70									
L3	<i>Oxyeleotris lineolata</i>	200	145	160	190	205	160	320			
	<i>Melanotaenia splendida</i>	49	36	40	32	82					
	<i>Craterocephalus stercusmuscarum</i>	34	30	29							
	<i>Ambassis spp.</i>	23	35	30	32						
	<i>Glossamia aprion</i>	108	72	23	42	65					
	<i>Amniataba percoides</i>	65	55	50	53	43					
	<i>Hephaestus carbo</i>	135									
	<i>Glossignius giurus</i>	110	102								
	<i>Hephaestus fuliginosus</i>	65									
	<i>Toxotes chatareus</i>	50	52								
L3A	<i>Hephaestus carbo</i>	127	105	120	120						
	<i>Strongylura krefftii</i>	143	262	100							
	<i>Leiopotherapon unicolor</i>	84	49	105	43	58	63	74	55	62	66
	<i>Melanotaenia splendida</i>	73	42	64	43	65					
	<i>Amniataba percoides</i>	26	64	26	24	36	85	27			
	<i>Hephaestus fuliginosus</i>	47									
	<i>Glossamia aprion</i>	95	94	32	82	83					
	<i>Oxyeleotris selheimi</i>	137	275								
	<i>Oxyeleotris lineolata</i>	194	168	185	206	33					
	<i>Craterocephalus stercusmuscarum</i>	31									
	<i>Glossignius giurus</i>	95	93								
	<i>Neosilurus hyrtlui</i>	130	152								
L4	<i>Leiopotherapon unicolor</i>	72	78	117	90	73					
	<i>Melanotaenia splendida</i>	33	38	42	60	44	43	40	82	75	46
	<i>Craterocephalus stercusmuscarum</i>	58	68	55							
	<i>Glossamia aprion</i>	30	54								
	<i>Glossignius giurus</i>	28	108								
	<i>Oxyeleotris lineolata</i>	210									
	<i>Cherax quadricarinatus</i>	155									

Table C.2 cont.

		1	2	3	4	5	6	7	8	9	10
Site	Species	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
L5	<i>Glossignius giurus</i>	69	70	72	66	58					
	<i>Glossamia aprion</i>	25	48	40							
	<i>Toxotes chatareus</i>	52	54								
	<i>Craterocephalus stercusmuscarum</i>	38	40	15	18	20	46				
	<i>Oxyeleotris selheimi</i>	285									
	<i>Nematalosa eribi</i>	52									
	<i>Melanotaenia splendida</i>	31	46	42	42	43	34				
	<i>Hephaestus fuliginosus</i>	260	70								
	<i>Amniataba percoides</i>	61									
	<i>Oxyeleotris lineolata</i>	85									

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Table C.3 Fish Weight Measurements from Lawn Hill Creek within the vicinity of the Century-MMG Mine, March - April 2015

		1	2	3	4	5	6	7	8	9	10
Site	Species	g	g	g	g	g	g	g	g	g	g
RL3	<i>Melanotaenia splendida</i>	4	3	2	<1	<1	<1	<1	<1	<1	
	<i>Amniataba percoides</i>	18	11	22	16	8	5				
	<i>Glossamia aprion</i>	3	1								
	<i>Oxyeleotris selheimi</i>	40									
	<i>Craterocephalus stercusmuscarum</i>	1									
	<i>Hephaestus fuliginosus</i>	21									
	<i>Glossigmius giurus</i>	8									
RL2	<i>Melanotaenia splendida</i>	11	1	1	1	1	2	3			
	<i>Amniataba percoides</i>	3	18	3	3	6					
	<i>Glossamia aprion</i>	5	16	4	12						
	<i>Hephaestus carbo</i>	132	23								
	<i>Oxyeleotris lineolata</i>	45	26								
	<i>Hephaestus fuliginosus</i>	83	2								
	<i>Glossigmius giurus</i>	18									
	<i>Strongylura krefftii</i>	170									
	<i>Leiopotherapon unicolor</i>	12									
RL1	<i>Melanotaenia splendida</i>	<1	1	3	<1	3	4	4	2	2	
	<i>Glossamia aprion</i>	<1	40	<1							
	<i>Craterocephalus stercusmuscarum</i>	1	<1								
	<i>Oxyeleotris lineolata</i>	39	49								
	<i>Amniataba percoides</i>	15									
	<i>Toxotes chatareus</i>	6									
	<i>Neosilurus ater</i>	96									
	<i>Hephaestus carbo</i>	18									
RL0	<i>Oxyeleotris lineolata</i>	8	8	15	8	6					
	<i>Melanotaenia splendida</i>	<1	<1								
	<i>Glossamia aprion</i>	10									
	<i>Hephaestus carbo</i>	15	27								
	<i>Craterocephalus stercusmuscarum</i>	<1	<1	<1	<1	<1					

Table C.3 cont.

		1	2	3	4	5	6	7	8	9	10
Site	Species	g	g	g	g	g	g	g	g	g	g
L1A	<i>Glossamia aprion</i>	5	70	38	11	7	3				
	<i>Oxyeleotris lineolata</i>	62	18								
	<i>Amniataba percoides</i>	21	18								
	<i>Hephaestus carbo</i>	27									
	<i>Melanotaenia splendida</i>	2	2								
	<i>Glossigmius giurus</i>	4									
L1B	<i>Amniataba percoides</i>	22									
	<i>Oxyeleotris lineolata</i>	75									
	<i>Ambassis spp.</i>	3									
	<i>Glossigmius giurus</i>	3									
	<i>Melanotaenia splendida</i>	2	3	3	2	3	2				
	<i>Hephaestus fuliginosus</i>	6									
L1C	<i>Ambassis spp.</i>	1	2	2	2	2					
	<i>Glossamia aprion</i>	4	23	9	4	2					
	<i>Leiopotherapon unicolor</i>	27	19	19							
	<i>Amniataba percoides</i>	15	9	4	5	8	12				
	<i>Melanotaenia splendida</i>	3	4	3	2	2	2	3			
L2	<i>Oxyeleotris lineolata</i>	123	8	124	525	308	478	33	92	106	26
	<i>Glossigmius giurus</i>	14	18	18	11	18					
	<i>Amniataba percoides</i>	9	7	8	6	2	1	29	27	5	
	<i>Leiopotherapon unicolor</i>	20	11	5	7	110					
	<i>Glossamia aprion</i>	20	6	13	31	5	5	4	30	1	
	<i>Hephaestus carbo</i>	22	41	31							
	<i>Melanotaenia splendida</i>	4	<1	2	<1	1	<1				
	<i>Hephaestus fuliginosus</i>	13	12	19							
	<i>Scortum ogilbyi</i>	12									
L2A	<i>Glossamia aprion</i>	20	10	34							
	<i>Amniataba percoides</i>	17	5								
	<i>Glossigmius giurus</i>	4	1								
	<i>Oxyeleotris lineolata</i>	22	60	2							
	<i>Melanotaenia splendida</i>	2	3								
	<i>Craterocephalus stercusmuscarum</i>	4	4	4	3	4					
	<i>Hephaestus carbo</i>	15									
L3	<i>Oxyeleotris lineolata</i>	128	57	74	165	258	120	692			
	<i>Melanotaenia splendida</i>	2	1	2	1	14					
	<i>Craterocephalus stercusmuscarum</i>	1	<1	<1							
	<i>Ambassis spp.</i>	<1	1	<1	<1						
	<i>Glossamia aprion</i>	31	9	<1	2	8					
	<i>Amniataba percoides</i>	10	6	6	5	3					
	<i>Hephaestus carbo</i>	102									
	<i>Glossigmius giurus</i>	19	17								
	<i>Hephaestus fuliginosus</i>	10									
	<i>Toxotes chatareus</i>	5	7								

Table C.3 cont.

		1	2	3	4	5	6	7	8	9	10
Site	Species	g	g	g	g	g	g	g	g	g	g
L3A	<i>Hephaestus carbo</i>	80	52	75	81						
	<i>Strongylura krefftii</i>	5	64	2							
	<i>Leiopotherapon unicolor</i>	16	5	35	3	6	11	13	5	8	9
	<i>Melanotaenia splendida</i>	9	2	6	2	7					
	<i>Amniataba percoides</i>	1	11	2	4	2	2	1			
	<i>Hephaestus fuliginosus</i>	4									
	<i>Glossamia aprion</i>	27	25	1	15	18					
	<i>Oxyeleotris selheimi</i>	51	417								
	<i>Oxyeleotris lineolata</i>	200	177	186	203	1					
	<i>Craterocephalus stercusmuscarum</i>	1									
	<i>Glossigmius giurus</i>	15	13								
L4	<i>Neosilurus hyrtlii</i>	24	35								
	<i>Leiopotherapon unicolor</i>	12	13	42	20	10					
	<i>Melanotaenia splendida</i>	1	2	3	5	2	2	2	13	10	3
	<i>Craterocephalus stercusmuscarum</i>	3	5	3							
	<i>Glossamia aprion</i>	1	5								
	<i>Glossigmius giurus</i>	<1	33								
	<i>Oxyeleotris lineolata</i>	212									
L5	<i>Cherax quadricarinatus</i>	124									
	<i>Glossigmius giurus</i>	5	6	6	5	3					
	<i>Glossamia aprion</i>	11	3	2							
	<i>Toxotes chatareus</i>	6	5								
	<i>Craterocephalus stercusmuscarum</i>	1	<1	<1	<1	<1	2				
	<i>Oxyeleotris selheimi</i>	519									
	<i>Nematalosa eribi</i>	3									
	<i>Melanotaenia splendida</i>	<1	2	1	1	1	<1				
	<i>Hephaestus fuliginosus</i>	494	11								
	<i>Amniataba percoides</i>	8									
	<i>Oxyeleotris lineolata</i>	14									